Biodiversity of the high seas
Final Report Lot 1

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Contents

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Abstract

Human activities in the areas outside national jurisdiction (High Seas and the Area) are increasing and may threaten marine biodiversity. This report presents a review of human activities and their potential impact on biodiversity of the high seas. For each activity, the technical details, the extent and spatial distribution of the activity and their socio-economic importance is described and the potential impact on marine biodiversity is analysed. The human activities considered are: (i) fisheries; (ii) mining; (iii) shipping; (iv) iron fertilization; (v) CO2 storage; (vi) tourism; (vii) infrastructure; (viii) bioprospecting and marine scientific research and (ix) diffuse sources (anthropogenic impacts that can not be linked directly to activities at sea). The ecosystem components considered represent different biota (fish, birds, marine mammals, benthos, sea turtles) or ecosystem properties (benthic habitats, food chain) which are expected to be affected to a different degree by the various anthropogenic activities.

The effect of anthropogenic activities was assessed by expert judgement distinguishing between the (i) severity, (ii) recoverability, and (iii) extent of the impact. The product of Severity*Recoverability* Extent gives an indication of the absolute impact of an activity in a certain sea area, such as an ocean basin (North Atlantic, Indian Ocean, etc). Severity and Recoverability are assessed from a population dynamic point of view by attempting to estimate the impact on mortality and reproductive rates of the population.

Threats to the biodiversity of the high seas are manifold and of a diverse nature. Some can be linked to anthropogenic activities (such as fisheries, mining, shipping). These threats primarily occur locally (i.e., in the impacted sites), although indirect effects may occur via the influence on the mobile components of the ecosystem. Other threats are due to activities that cannot be defined or localised easily (such as air based pollution, littering, acidification). Even more complex is the accumulation of effects due to multiple activities in the same area. Methods for such assessment are currently under development. The diverse nature of the threats implies that management of biodiversity in the high seas needs to be tackled from several angles.

The quantification of the impact of anthropogenic activities on marine biodiversity proved to be a major challenge, due to the lack of quantitative information on both the activities as well as the biodiversity. Quantitative data on the nature of the activities, the scale of operation and the impact on specific ecosystem components is largely lacking. For activities for which information is available, such as fishing, no distinction is made between the high seas and the areas within the EEZ. In addition, our knowledge of biodiversity of the high seas is limited and many areas are still unexplored.

Comparison of the current activities suggests that the impact is largest from fishing. The analysis also showed that the anthropogenic activities should not be pooled in too broad categories, as the impact may differ between different types of fisheries. For instance, birds are impacted by longline fishing, but not by demersal trawling, while marine mammals will be mainly affected by pelagic purse seine. Further, garbage from shipping may have a substantial impact on benthos and benthic habitats. In Antarctica, tourism is a threat to marine mammals and birds due to disturbance and the risk of species introductions. In the future, bioprospecting and CO2 storage could have major impacts. Bioprospecting could potentially lead to the exploitation of a variety of other organisms for bio-technological use, although at present this does not occur. A comparison of the impact of various activities within an ecosystem component again shows the dominant impact of fishing for all ecosystem components considered. It is noted that fishing, bioprospecting and Antarctic tourism are activities that will be concentrated in areas of high biomass or high biodiversity. This is in contrast to other activities such as shipping or infrastructure that will be unrelated to biodiversity hotspots.

The review of the high seas biodiversity threats of human activities will form the basis to evaluate management options for high seas marine biodiversity conservation. In a parallel report, the legal dimension of the management of the diverse set of human activities is explored.

1. Introduction[1]

General

Human activities in the areas outside national jurisdiction are increasing and may threaten biodiversity of the marine ecosystem of the high seas. Generally, fisheries are considered as most threatening, but also other activities such as mining, shipping, tourism, bio-prospecting, scientific research, pollution, and military activities play a more or less important role. Threats of the biodiversity concern different components of the marine ecosystem (e.g. fish, seabirds, marine mammals and benthos), the ocean floor as a habitat, the food chain (functioning of the ecosystem) and ecosystem services.

The legal framework for the management and protection of marine biodiversity mainly consists of the United Nations Convention of the Law of the Sea (UNCLOS) and the Convention on Biological Diversity (CBD), but there are several ongoing developments. General agreement exists that for the protection of marine biodiversity a shift is needed from a sectoral approach to a more integrated ecosystems approach. In this respect the focus is especially on sustainable use of natural resources and the implementation of marine protected areas. In order to create marine protected areas the question arises whether an effective system to decide on which areas to protect and how to properly manage such areas in areas outside national jurisdiction will only be possible through a new specific legal instrument, such as an Implementation Agreement under the UN Convention of the Law of the Sea, or that it would be sufficient to protect areas under existing agreements regulating specific user functions. Since international rules are agreed for most user functions and management organisations have been formed, one can question (i) how effective cooperation between different organizations and agreements can be reached, and (ii) what role these organisations can play in the further development of the international framework concerning the protection of biodiversity. For an optimally functioning international legal order overlapping competences should be avoided and attuned as far as possible.

From the discussions in the General Assembly of the United Nations it can be concluded that important questions still remain concerning the interpretation of the general legal framework for the use of the oceans as contained in UNCLOS. Especially the question about the relation between the high seas regime and the regime as contained in Section XI of UNCLOS is a sensitive one and could easily lead to a reopening of the discussion about other aspects of the Convention. Also the elaboration of a specific regime for the subjects discussed here (protected areas, sustainable use) could result in questions about the competence of different institutions under the Convention, such as the “International Seabed Authority” or the “Conference of the Parties”.

The complexity of these questions and the fact that so many States and other actors are involved in the negotiations results in a rather slow progress in the development of international law when compared with the growth in economical activities. Alarming news about the decreasing biodiversity regularly hits the headlines of newspapers and leads to an increasing pressure on the international community to reach an effective protection. There is, for example, at present a lobby to implement a moratorium on bottom trawling on the high seas. The Netherlands have committed themselves for the protection of the biodiversity under the Biodiversity Treaty and during the World Summit on Sustainable Development in 2002. Within the Netherlands several ministries are involved in international negotiations (Foreign Affairs, Transport, Public Works and Watermanagement, Agriculture, Nature and Food Quality). To support the process of positioning within the international discussions a critical overview is needed of different economical activities in the area, their size and development and their impact on biodiversity. Besides, a review is needed of the existing international legal framework and rules to decide on which measures could be taken to protect biodiversity in areas outside national jurisdiction. The wide context and complex relations between user functions, existing legal framework and international parties involved means that this report aims to answer the specific questions posed while acknowledging the fundamental implications for the Law of the Sea in its totality.

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Approach

The contract consists of two parts: Lot 1 has focused on user functions and different aspects of the ecosystem, Lot 2 on the legal framework. The study was carried out by a consortium of Dutch research institutions (Wageningen IMARES, NILOS - Netherlands Institute for the Law of the Sea; LEI – Institute for Agricultural Economy en Grontmij). The Royal Netherlands Institute for Sea Research (NIOZ) and Framian were subcontracted. Wageningen IMARES coordinated the study. This report presents the results of Lot 1.

The main aim of Lot 1 was to get a good picture of (i) the socio-economic importance (countries, trends), (ii) type and size, and (iii) ecological impact of different user functions on the marine biodiversity in areas outside national jurisdiction.

The "High Seas" are the open ocean lying beyond the 200 nautical mile Exclusive Economic Zones (EEZ) of coastal States. The Area is the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction, whereas "high seas" with lower case 'h' and 's' covers both the High Seas and the Area. In this report we will mainly use the term "high seas" (Figure 1.1).

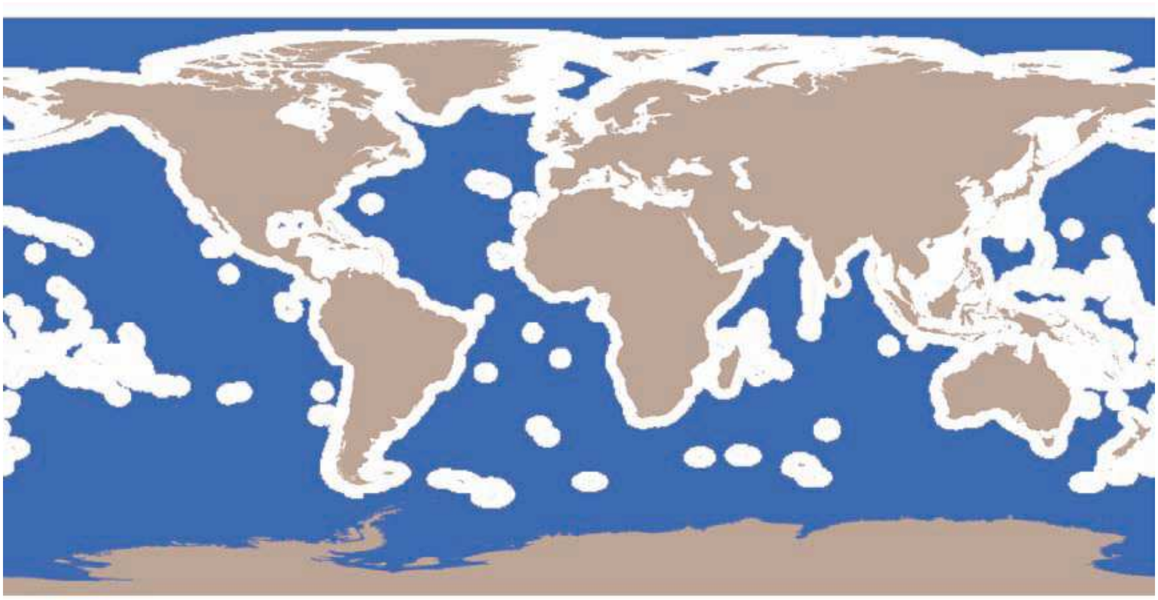

Figure 1.1 The high seas as defined in this analysis (i.e., dark blue marine areas outside of national EEZs). This covers approximately 202 million km2, as opposed to 363 million km2 for the World Ocean.

The matrix below roughly indicates the importance of different combinations of user functions and ecosystem aspects. The + and 0 codes suggest an estimate of the relative importance for high seas biodiversity, with 0 suggesting no or very minor impact.

Aspect	User functions Fisheries	Mining	Shipping	Tourism	Rest[1]
Socio-economy	+++	++	++	++	+
Fish	+++				0
Benthos & habitat	+++	++	0	0	+
Birds	+++		+	++	+
Sea mammals	+++		+	++	+
Rest (a.o. sea turtles)	+++	0	0	0	0
Food chain	++	+	+	0	+

[1]Scientific research, Bio-prospecting, Infrastructure, Military activities

In order to assess the effects of various anthropogenic activities on the biodiversity of the High Seas, a transparent and consistent methodology is needed. In this report, the anthropogenic activities considered will differ in their impact on the ecosystem components. The marine ecosystem components considered represent species groups (fish, birds, benthos, sea turtles) or ecosystem properties (benthic habitats, food chain) which are expected to be affected to a different degree by the various anthropogenic activities. The effect of anthropogenic activities will be assessed using three aspects: (i) severity; (ii) recoverability; (iii) extent.

Severity is the product of the intensity of the activity and the direct effect on the population dynamic response (change in intrinsic population growth rate due to a change in mortality or in the reproductive rate of a population). The effect on the mortality and reproduction induced by an activity is compared to the background level of natural mortality and reproductive rate, assuming no synergistic effects. Ideally, the intensity can be quantified in terms of the dose (for instance: trawling frequency, release of a chemical substance, noise, etc) that can then be linked to the immediate population dynamic effect. In practice, however, this is impossible for most of the ecosystem components and anthropogenic activities. Hence, we have estimated the severity by expert judgment. The effect of an impact on ecosystem components such as benthic habitats and food chain, has been interpreted in terms of the probability that benthic habitat is damaged (benthic habitats) or has reduced the food availability for higher trophic levels (food chain).

Recoverability is evaluated as the time period (years) needed to recover after the activity considered has been stopped. The time scale adopted matches the recovery time scale of 2-20 years mentioned by the FAO to assess the impact of deep sea fisheries (draft FAO document: FAO TC DSF WD.doc). The product of Severity*Recoverability gives the local ecosystem impact of an activity. The absolute effect will further depend on the *extent* of the activity. If spatially explicit data on human activities and ecosystem components are available, the local impact can be mapped. The *extent* of the impact is evaluated against the proportion of the distribution area of the ecosystem component affected. The product of Severity*Recoverability* Extent gives an estimate of the absolute impact of an activity in a certain sea area, such as an ocean basin (North Atlantic, Indian Ocean, etc).

Table 1.1 Criteria used to score the three effects of anthropogenic impacts on ecosystem components

Effect of an impact	0	1	2	3
Severity (S)	Effect negligible	<1%	1-50%	>50%
Extent (E)	No interaction	present but small	significant regional	substantial global
Recovery (R) (time period in years)	<1 year	1-5	5-20	>20

The approach adopted is quite similar to that of the integrated framework for ecosystem advice in European seas developed by ICES (ICES, 2007), although we did not include the impact on the water column and bio-chemical habitat. The impact on phyto and zooplankton was included in the entry 'food web'.

Also, the approach is close to Halpern et al. (2008) who recently presented a first integrated map on human impacts on the worlds oceans. The main difference was that their goal was to estimate the total impact of anthropogenic drivers and not to compare the impact of various drivers. Also, they used a different classification of human activities and ecosystem components. Anthropogenic drivers included a.o. fishing, ocean and land based pollution, oil rigs, climate change and atmospheric pollution. Ecosystem components included surface water, deep water, coral reefs, see grass beds, mangroves, sea mounts. The impact of the various anthropogenic drivers was estimated by expert judgement.

In the report Chapter 2 to 11 provide details on each of the different kinds of human use of the high seas: fisheries (2), economic aspects if high sea fisheries (3), mining (4), shipping (5), iron fertilisation (6), CO2 storage (7), tourism (8), Infrastructure (9), bioprospecting and marine scientific research (10) and diffuse sources (11). In Chapters 12 to 17 different ecosystem aspects are dealt with: fish (12), benthos and benthic habitats (13), seabirds (14), marine mammals (15), turtles (16) and the food web (17). Based on the information presented in Chapters 2 to 17 the impact of the different forms of use of the high seas will be discussed in Chapter 18. Here also the current and possible future threats of marine biodiversity in areas outside national jurisdiction will be discussed, based on expected developments in different user functions.

Finally the strengths and weaknesses of the current management regime will be analysed and, in dialogue with Lot 2, and within the appropriate legal context, management policy will be developed for an improved management system to protect the biodiversity of the high seas.

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ICES 2007 ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO) 11–18 April, 2007. ICES CM 2007/ACE:04

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2. Fisheries[2]

2.1 Introduction

Fishing on the high seas continues to attract the attention of international organisations, non-governmental organisations (NGOs) and the general public. They all have a growing interest in management of high seas resources and a general concern for overfishing and impacts on non-target species. High seas resources are defined as those occurring outside exclusive economic zones (EEZs), which extend maximum 200 nautical miles into the sea (FAO, 2007), an area that covers approximately 202 million km^2, or 64% of the worlds oceans. The most important and well known high seas fisheries target epipelagic fish (tuna and tuna-like species) and deepwater fish. There are also fisheries for krill, squid, and marine mammals.

Several types of (fish) stocks can be distinguished: highly migratory stocks (such as some tunas, that occur part of their life in different EEZ's and in the high seas), straddling stocks (of species with a very wide distribution, partly in EEZ's, partly in the high seas) and there are typical high seas stocks. Of the species that spend part of their life in EEZ's, some occur predominantly in EEZ's others predominantly in the high seas). Furthermore there are transboundary species that occur in the EEZ's of different countries, as well as in the high seas. Especially when it comes to the reporting of catches all these options tend to work out in a very confusing way. The "easiest" stocks are those that occur solely within the EEZ's or within the high seas. It is often impossible to collect precise information from where (inside or outside EEZ's) catches originate. It is therefore often problematic to extract information that refers to "strictly high seas" fisheries.

In this chapter some background information on the main high seas fisheries will be given. For marine mammals and whaling the reader is referred to Chapter 15. Although also fisheries for sea cucumbers and sea urchins exist, they are believed to be mainly artisanal fisheries that are carried out inside the EEZ's and will not be discussed here.

Furthermore, this chapter contains sections on the fleets and IUU fisheries. Not exclusively relevant for fisheries, but included in this chapter, is a section on the CBD Working Group on Protected Areas.

The socio-economic aspects of high seas fisheries are dealt with in Chapter 3.

2.2 Fishing methods

The main gears used for fishing for a wide variety of species in the high seas are longline, gill-net, purse-seine, trawl and jigs.

Longlining is a type of fishery that uses long lines to which many branch lines are attached. Each branch line has a baited hook at its end. Longlines can be used near the surface or at the bottom.

Gill-nets hang vertically in the water and fish get entangled in the netting. Gill-nets can also be deployed at the surface or at the bottom.

Purse-seines are used to encircle schooling fish. As soon as a shoal is encircled the net is closed from below. Purse-seines can only be used at the surface. Tunas are caught by purse-seine vessels in three types of schools, those associated with dolphins, those associated with floating objects, such as flotsam or FADs, and those associated only with other fish (unassociated schools). A fish aggregating (or aggregation) device (FAD) is a man-made object used to attract ocean going pelagic fish such as marlin, tuna and mahi-mahi (dolphin fish). They usually consist of buoys or floats tethered to the ocean floor with concrete blocks.

Trawls are cone-shaped nets towed by one or more fishing vessels, with mesh sizes that decrease from the front part of the net towards the closed cod-end in which the catch accumulates. They can either be

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deployed at the bottom and have a heavy bottom-gear roling over the sea-floor, or be equipped with doors that can be used to fish the net at different depths in the water column. Trawls used to fish for krill are very fine-meshed.

Since the ban on large scale driftnets in 1992 jigging is used to fish for squid. Squid jigging (Figure 2.1) can be carried out using either mechanically powered or hand operated jigs. Overhead lights illuminate the water and attract the squid which gather in the shaded area under the boat. Squid are caught using barbless lures on fishing lines which are jigged up and down in the water. Using barbless lures means that as the lures are recovered over the end rollers, the squid fall off into the boat (Wikipedia).

Some other methods that are mentioned in some of the tables include dredges, pots, baitboats and trolling.

Dredges are gears which are dragged along the bottom to catch shellfish. They consist of a mouth frame to which a holding bag constructed of metal rings or meshes is attached. Target species are scallops and other shellfish and therefore dredges are usually confined to rather shallow coastal areas.

Pots are constructed either of wooden slats or, more commonly, coated wire mesh. They are set on the bottom individually or in strings. They may be used to trap crustaceans (lobsters and crabs), gastropods (such as whelks) or fish. Pot fishing can be done in shallow estuaries, but also in deeper water offshore. The traps range in size from smaller crab pots to very large (3x3 m) deep water traps used in the Bering Sea crab fisheries.

In pole and line (baitboat) fishing a school of tuna is attracted to the side of a "bait-boat" by throwing live fish overboard. This creates a tuna feeding frenzy and fish are hauled out of the water, one-by-one, using pole and line. The size of the tuna caught this way is small, mostly consisting of skipjack, but also some yellowfin and bigeye. Many countries use this technology but the most important fleet of industrialised baitboats is based in Ghana.

Trolling is a method of fishing used from a moving boat. One or more fishing lines, baited with lures or bait fish, are drawn through the water.

The oceanic fish species targeted by these methods can be grouped by epipelagic and deep-water species. Purse seines, surface longlines and surface gill-nets typically target epipelagic (tuna and tuna-like) species. Bottom longlines, bottom gill-nets and (semipelagic) trawls are deployed to target a wide variety of deepwater species living on or near the bottom of the sea floor. This is summarised in the Table 2.1.

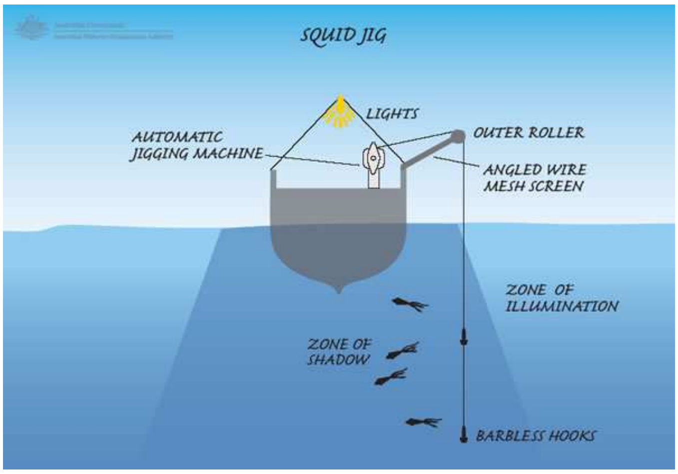


Figure 2.1 Jig used in fisheries for squid (Australian Fisheries Management Authority).

Table 2.1 Most common fishing methods and their target species.

	Target species			
	epipelagic fish	deepwater fish	krill	squid
longline surface	X			
longline bottom		X		
gill-net surface	X			
gill-net bottom		X		
purse-seine	X			
bottom trawl		X		
midwater trawl	X			
finemeshed trawl			X	
jig				X

2.3 High Seas fisheries

2.3.1 Epipelagic and demersal fish

FAO fisheries statistics are essential for estimates of the world's fisheries catches. Unfortunately, it is not possible to extract from these statistics a precise estimate of capture production from the high seas, as catch statistics are reported by broad fishing areas whose boundaries are not directly comparable with those of the EEZs. Thus, the available data do not reveal whether or not the fish were caught within or outside EEZs. However, as catch statistics for oceanic species are available in the FAO capture database, these can be used to analyse the catch trends and fishery development phases of this group of species, which are fished mostly seaward of the continental shelves (FAO, 2007).

In Maguire *et al.* (2006), a method to identify and study phases of fishery development was applied to the 1950–2004 catch data series of oceanic species. In their study they have distinguish epipelagic and deep-water species. The total catch trends (Figure 2.2) show that oceanic epipelagic catches increased fairly steadily during the whole period, whereas fisheries for deepwater resources only started developing significantly in the late 1970s. This was made possible by technological developments applicable to fishing in deeper waters, but was also prompted by the need to exploit new fishing grounds following reduced opportunities owing to extended jurisdictions and declining resources in coastal areas.

In Figures 2.3 and 2.4, different stages of fisheries development have been used to analyse the development in oceanic epipelagic fisheries (Figure 2.3) and in deepwater fisheries (Figure 2.4). This analysis shows in greater detail that by the late 1960s the oceanic epipelagic resources classified as "undeveloped" had fallen to zero. This did not happen until the late 1970s for the oceanic deep-water resources. During the same 20-year period, the percentage of deep-water species classified as "senescent" exceeded that of epipelagic species and has continued to remain higher ever since. This result may be considered as further evidence that deep-water species are generally very vulnerable to overexploitation, mainly on account of their slow growth rates and late age at first maturity.

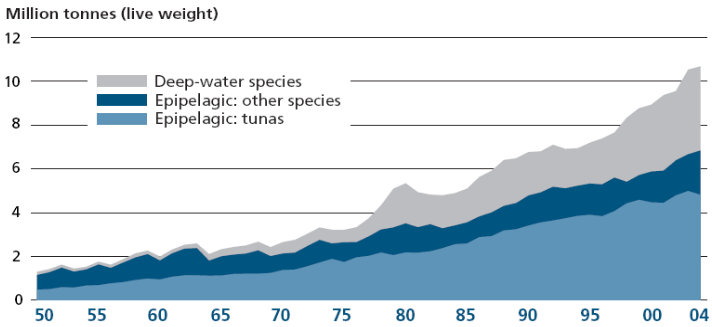


Figure 2.2 World catches of oceanic species (epipelagic and deep-water) occurring principally in high seas areas

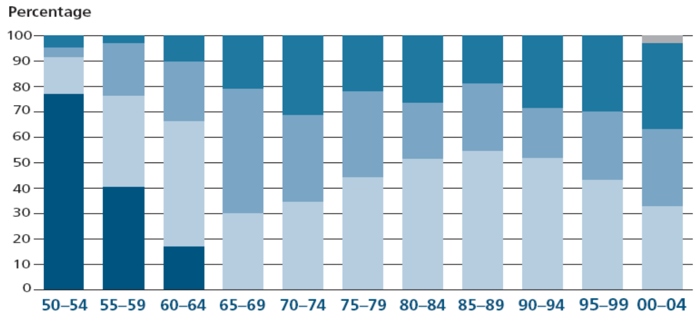


Figure 2.3 Percentage of oceanic epipelagic resources in various phases of fishery development, 1950-2004.

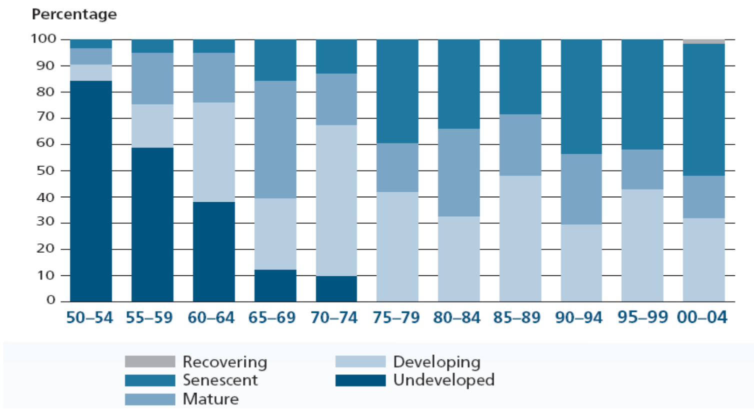


Figure 2.4 Percentage of oceanic deep-water resources in various phases of fishery development, 1950-2004.

An overview of the most important fish species targeted by high seas fisheries is given in Maguire *et al.* (2006). Their paper is based on the *Review of the state of world marine fishery resources* (FAO, 2005). In the overview below, the landings indicated for each species refer to the average landings as reported to the FAO for the years 2000 to 2004.

Epipelagic species

The group of epipelagic species consists of tunas, tuna-like species and oceanic sharks. These are also the highly migratory species as listed in Annex 1 of the LOS Convention. Other epipelagic species are the pomfrets, sauries and dolphinfish.

Tunas

albacore (*Thunnus alalunga*)	214,800 t
bluefin tuna (*T. thynnus*)	34,400 t
bigeye tuna (*T. obesus*)	196,800 t
yellowfin tuna (*T. albacares*)	1,311,800 t
blackfin tuna (*T. atlanticus*) more continental	
southern bluefin tuna (*T. maccoyii*)	15,000 t
skipjack tuna (*Katsuwonus pelamis*)	2,036,200 t
little tuna (*Euthynnus alleteratus* and *E. affinis*) more continental	
frigate mackerel (*Auxis thazard* and *A. rochei*) more continental	

Tuna-like species (this group is often referred to as billfish)

marlin (*Tetrapturus* sp. (6x) and *Makaira* sp.(2x))	43,800 t
sailfish (*Istiophorus platypterus* and *I. albicans*)	2,600 t
swordfish (*Xiphias gladius*)	59,200 t

> Of the highly migratory tuna and tuna-like species 21% are moderately exploited, 50% fully exploited, 21% overexploited and 8% depleted. The skipjack, the tuna that yields the largest catch, is considered to be in a healthy state and on a global scale only moderately exploited, but in the Atlantic its status is uncertain. Yellowfin tuna is considered fully exploited, with the possible exception of the western and central Pacific. The Atlantic bluefin tuna is overexploited (Majkowski, 2007).

Oceanic sharks

bluntnose sixgill shark (*Hexanchus griseus*)		8 t
basking shark (*Cetorhinus maximus*)		320 t
thresher sharks (*Alopias pelagicus*, *A. superciliosus* and *A. vulpinus*)		1,087 t
whale shark (*Rhincodon typus*)		
silky shark (*Carcharhinus falciformis*)	]	7,811 t
oceanic whitetip shark (*C. longimanus*)	] requiem sharks	181 t
blue shark (*Prionace glauca*)	]	26,096 t
winghead shark (*Eusphyra blochii*)	]	
scalloped bonnethead (*Sphyrna corona*)	]	
whitefin hammerhead (*S. couardi*)	]	
scalloped hammerhead (*S. lewini*)	] Sphyrnidae	2,013 t
scoophead (*S. media*)	]	
great hammerhead (*S. mokarran*)	]	
bonnethead (*S. tiburo*)	]	
smalleye hammerhead (*S. tudes*)	]	
smooth hammerhead (*S. zygaena*)	]	
great white shark (*Carcharodon carcharias*)	]	
shortfin mako (*Isurus oxyrhinchus*)	]	4,539 t
longfin mako (*I. paucus*)	] mackerel sharks	2 t
salmon shark (*Lamna ditropis*)	]	
porbeagle (*L. nasus*)	]	1,684 t

10% of the highly migratory oceanic sharks are moderately exploited, 35% fully exploited, 40% overexploited and 15% depleted

Other highly migratory species

pomfrets (Bramidae, several species a.o. Atlantic pomfret (*Brama brama*))	9,169 t
sauries (Scomberesocidae, several species)	368,016 t
dolphinfish (*Coryphaena* spp., 2 species)	49,047 t

Maguire *et al.* (2006) also discuss a selection of straddling fish stocks, but these are believed to be mainly linked to the continental shelves, and fished there, and therefore not further considered here.

Deepwater (demersal) species

High seas fisheries resources that can be considered as demersal deep sea species, and which are not highly migratory, consist of:

orange roughy (*Hoplostethus atlanticus*)	90,000 t in early 1990s, 26,000 t in 2004
oreo dories (*Allocyttus* spp., *Neocyttus* spp., and *Pseudocyttus* spp.)	± 20,000 t
alfonsino (*Beryx splendens*)	15,000 in 2003, 7,000 t in 2004
toothfish (*Dissostichus* sp.)	40,000 t in 1992, 27,000 t in 2004
armourhead (*Pseudopentaceros* sp.)	>133,000 t in 1969-77, almost nothing now
hoki (*Macruronus novaezelandiae*)	> 300,000 t in late 1990s, 160,000 t in 2004

Although Maguire *et al.* (2006) provide the above data for catches presumed to have been taken from the high seas, i.e. outside the 200 nm EEZ's, there are some doubts as far as the reliability of these data is concerned. For the toothfish for example, around 50% of the catch is believed to originate from within the EEZ's (see also Chapter 3).

Many deep water fisheries may be characterized by a “boom and bust” pattern: landings of newly discovered fisheries are initially high, and then rapidly decline to very low levels. The fleet then starts looking for alternative areas (seamounts) or species and the pattern is repeated. Also the development of new technologies or new markets may further strengthen this phenomenon. Although the overall landings of deepwater species steadily increase (Figure 2.2), certain target species (such as orange roughy) have meanwhile become (locally) depleted.

The number of species classified as deep-water species continues to increase, reaching 115 in 2004, while the number of epipelagic species remains stable at 60. Lack of detail in catch statistics causes management problems. For example shark species are often not distinguished at species or even genus-level in catch statistics, but are just mentioned under the generic category “sharks nei”, meaning sharks that are not elsewhere identified. The improved breakdown of deep-water species reported at species level in national catch statistics parallels the increase that occurred for shark species in recent years. Possible reasons may include a growing global awareness that vulnerable species need to be protected by effective conservation and management measures and these cannot be formulated and agreed unless basic information such as catch statistics is systematically collected.

Other species

In some of the tables throughout this report, other species may be mentioned, most of which are fished inside the EEZ's but where no distinction of catches inside and outside EEZ's could be made in the catch statistics. The species meant here include:

northern prawn (*Pandalus borealis*)
queen crab (*Chionoecetes opilio*)
ocean quahog (*Arctica islandica*) (a bivalve)
American sea scallop (*Placopecten magellanicus*) (a bivalve)
Atlantic herring (*Clupea harengus*)
Atlantic redfish (*Sebastes* spp.)
Greenland halibut (*Rheinhardtius hippoglossoides*)
cod (*Gadus morhua*)
haddock (*Melanogrammus aeglefinus*)

Stock status of some important species

As can be seen in Figure 2.4 oceanic deep-water fish stocks that are considered undeveloped do no longer occur and at the same time, the number of overexploited stocks has increased in the course of the past 50 years. In all, 23 stocks of principal market tunas can be distinguished. Four of these are considered moderately exploited, 8-10 are about fully exploited, and 5 or 6 are overexploited or depleted. The status of three stocks is uncertain (Majkowski, 2007).

Swordfish is moderately exploited in the NE Pacific, fully exploited in the North Atlantic and SE Pacific. In the Indian Ocean swordfish catches are not sustainable in the long term, in the South Atlantic the stock seems to be in a healthy state. Significant uncertainties exist about the status of many billfishes. Only swordfish is a targeted species, the others are by-catches. Atlantic blue and white marlin are over-exploited, in the Pacific blue marlin is fully exploited. Striped marlin is moderately exploited in the eastern Pacific, and about fully exploited in the western and central Pacific.

Regional Fisheries Management Organisations (RFMOs, see also 3.1) are responsible for the long-term conservation and sustainable use of the fish stocks under their jurisdiction.

Conclusions

- Fisheries statistics do not distinguish between catches from within 200 nm (EEZs) and outside the EEZ's. It is therefore difficult to correctly determine what percentage of landings are from high seas fisheries.
- In high seas fisheries for fish a distinction must be made between epipelagic fisheries (for tuna and tuna-like species) and deepwater fisheries (for a variety of deepwater species).'
- Catches of oceanic (high seas) species have steadily increased since the 1950s.
- Since the mid 1960s there are no "undeveloped" fisheries for epi-pelagic resources, and since the mid 1970s the same holds for deepwater resources.
- Some important high seas fish species are:
    - yellowfin tuna (*Thunnus albacares*)
    - skipjack tuna (*Katsuwonus pelamis*)
    - swordfish (*Xiphias gladius*)
    - sauries (different sp. of Scomberesocidae)

- orange roughy (*Hoplostethus atlanticus*)
- toothfish (*Dissostichus* sp.)
- hoki (*Macruronus novaezelandiae*)
- blue shark (*Prionace glauca*) part by-catch, part target

2.3.2 Krill

Probably most krill is being fished within the 200 nm zones. The total size of the stocks is huge and recent exploitation levels are rather low. Information is from Wikipedia (January 2008) and from Nicol & Endo (1999).

Krill are small shrimp-like crustaceans, part of the zooplankton community, that live in the oceans world-wide. Estimates for how much krill there is in the oceans vary wildly, depending on the methodology used. They range from 125 – 725 million t of biomass globally. The total global harvest of krill from all fisheries amounts to 150 – 200,000 t per annum, but few fisheries are being exploited to their maximum theoretical potential. Currently at least six krill fisheries can be distinguished harvesting six different species of Euphausiids, the first two are by far the most important ones:

Euphausia suprba in the Antarctic
E. pacifica off Japan and off western Canada
E. nana off Japan
Thysanoessa inermis off Japan and off eastern Canada
T. raschii and *Meganyctiphanes norvegica* off eastern Canada (experimental fishery)

Krill are rich in protein (40% or more of dry weight) and lipids (about 20% in *E. superba*). Most krill is used as aquaculture feed and fish bait. About 34% of the Japanese catch of *E. superba* and 50% of *E. pacifica* is used for fish food and the Canadian catch is used almost exclusively for this purpose as well. Other uses include food for livestock or pet foods. Only a small percentage is prepared for human consumption but considerable effort has been put into its development, particularly from Antarctic krill. Medical applications of krill enzymes include products for treating necrotic tissue and as chemonucleolytic agents.

Krill are fished with very fine-meshed plankton nets. Even though large krill aggregations tend to be monospecific a by-catch of e.g. juvenile fish can not be avoided. Krill must be processed within one to three hours after capture due to the rapid enzymatic breakdown and the tainting of the meat by the intestines. They must be peeled because their exoskeleton contains fluorides, which are toxic in high concentrations. Because krill needs to be processed as quickly as possible after it has been caught a method to continuously pump the catch from the trawl has been introduced recently. This method means that vessels no longer have to stop fishing to take the catch on board.

Most krill is processed to produce fish food. The krill is sold freeze-dried, either whole or pulverized. Krill as a food source is known to have positive effects on some fish, such as stimulating appetite or resulting in an increased disease resistance. Furthermore, krill contains carotenoids and is thus used sometimes as a pigmentizing agent to color the skin and meat of some fish.

Antarctic
The krill fishery in the Southern Ocean, with large stern trawlers using midwater trawls and a continuous pumping method, targets *E. superba*, which can grow to about 6 cm. The USSR launched its first experimental operations in the early 1960s and began a permanent fishery in 1972, landing 7,500 t in

1973 and then expanding quickly. The Japanese began experimental fishing operations in the area in 1972 and started full-scale commercial operations in 1975. The krill catch increased rapidly.

In the 1980s Poland, Chile, and South Korea also started fishing in the area. Their catches amounted to a few thousand tonnes annually; the lion's share went to the USSR, followed by Japan. A peak in krill harvest was reached in 1982 (Figure 2.5) with a total production of over 528,000 t, of which the USSR produced 93%. In the following two years, production declined. It is unclear whether this was due to the discovery of fluorides in the krill's exoskeleton or to marketing problems. The trade recovered quickly, and catches reached more than 400,000 t again in 1987.

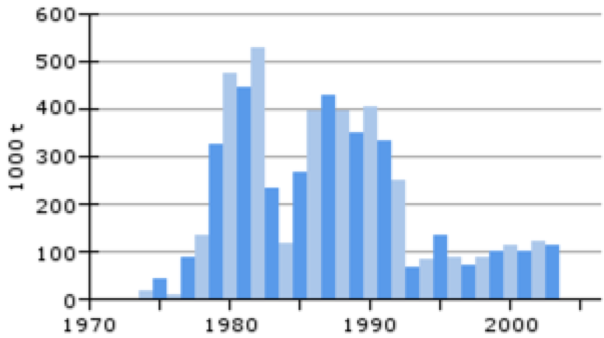


Figure 2.5 Catch of *Euphausia superba* in the Southern Ocean from 1974 until 2003 (FAO data)

With the demise of the Soviet Union, two of its successor nations, Russia and Ukraine, took over the operations. Russian operations and catches dwindled, and were abandoned altogether in 1993. Since then, Japan, Poland and Ukraine are the largest krill-fishing nations. Since 2000, the small South Korean Antarctic krill fishery has also expanded considerably.

Table 2.2 Annual catch of *E. superba* by the major fishing nations. Data from the FAO databases. A dash means "no catch", a zero indicates a small catch < 500 t.

Country	**Annual Catch (in 1000 tonnes, rounded)**																							
	80	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**
Japan	36	28	35	43	47	40	60	78	73	79	69	69	78	57	61	63	59	60	67	66	81	67	51	60
S. Korea	-	-	1	2	3	-	-	2	2	2	4	1	1	-	-	-	-	-	3	0	7	8	14	20
Poland	0	-	0	0	-	0	2	3	5	8	3	10	15	7	8	13	22	14	20	20	20	14	16	9
Ukraine	-	-	-	-	-	-	-	-	-	-	-	-	55	-	13	59	10	-	-	7	-	14	32	18
USSR/Russia	441	420	492	186	69	228	333	344	310	258	326	249	103	2	-	-	-	-	-	-	-	-	-	-
U.S.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	12	10

In 1982, the CCAMLR Convention (Convention on the Conservation of Antarctic Marine Living Resources) came into force, as part of the Antarctic Treaty System. Its purpose is to regulate the fishery in the Southern Ocean to ensure a long-term sustainable development and to prevent overfishing. In 1993, the CCAMLR Commission started to set catch quotas for krill, which amounted to nearly five million tonnes per year. The annual catch of *E. superba* since the mid-1990s is about 100,000 t annually, i.e., only about one fiftieth of the CCAMLR catch quota. Still, the CCAMLR is criticized for having defined its catch limits too generously, as there are no precise estimates of the total biomass of Antarctic krill available and there have been reports indicating that it is declining since the 1990s. Plans to take up to 746,000 t a year were disclosed at the 2007 annual meeting of the CCAMLR Commission (see also Chapter 3.9).

Other areas
Fisheries for krill also exist in other areas, e.g. in Canadian and Japanese waters but these do not extend into the high seas.

Management
Because of the central ecological role of krill in many marine ecosystems, including that as prey for many other species which are commercially fished, krill fisheries require careful management. The size of the world harvest of krill may currently be limited by lack of demand, but some fisheries are deliberately being managed at low levels because of ecological concerns.

Conclusions

- Recent exploitation levels of krill are believed to be low compared to current estimates of total stock size.
- Most krill is fished within 200 nm. What proportion of the stocks is distributed outside 200 nm limit is not clear.
- Krill is mainly being used for animal feed, but has potential for pharmaceutical use.
- Krill has a central role in marine ecosystems and fisheries require careful management .

Further reading:
Everson, I. (ed.) 2000. Krill: biology, ecology and fisheries. Oxford, Blackwell Science. ISBN 0-632-05565-0.

2.3.3 Squids

Three main types of cephalopods can be distinguished: cuttlefish (Dutch “zeekat”), octopuses and squid (Dutch “pijlinktvis”). Cuttlefish and octopuses are mainly associated with the continental shelf (usually within 200 nm) and for most squid species this will be the same. Part of the squid, however, is distributed on the high seas. Most cephalopods, worldwide, are probably caught as by-catch in demersal fisheries, and within EEZ’s. A number of targeted fisheries, however, do exist and partly these are high seas fisheries.

Due to declining catches in traditional fisheries the interest for cephalopods has increased. The total biomass of squid may be huge. Taking the consumption of especially sperm whales into account, some authors estimate that these whales consume a greater mass of squid than the total world catch of all marine species combined (Vos (1973) and Clarke (1983) in FAO 2005). The commercial potential of squid fisheries may thus be enormous. Also there is some evidence that squid populations increase in regions where overfishing of groundfish stocks occurs (Caddy & Rodhouse, 1998). Total international catches of squid, slightly over 1 million tonnes in 1982, increased to between 2 and 2.6 million tonnes in the years 1995 – 2002. Catches are dominated by *Illex argentinus* (southern Atlantic, off Argentina) and *Todarodes pacificus* (northern Pacific, off Japan). In 2002 these two squid species comprised 46 percent of the world catch. Between 1991 and 2002 *Dosidicus gigas* (eastern Pacific) also made a substantial contribution to world catches.

Catches of squid fisheries are quite variable due to high variations in stock sizes. This may be due to the biological characteristics of squid which are short-lived and semelparous: they die after reproduction. Most commercially exploited squid have a life span of approximately one year, at the end of which they spawn once and die.

Some squids are almost exclusively caught using jigs armed with barbless hooks, fished in series of lines using automatic machines. The vessels use lamps to attract the fish (NB.: the lamps used in this fishery are visible for certain satellites which facilitates the study of the distribution of these fisheries). Fisheries for loliginids use trawls, either conventional otter trawls with a high vertical net-opening, or pelagic trawls in case of rough grounds.

Table 2.3 Summary of the world squid catch in 2002 (from FAO, 2005 (NEI: not elsewhere identified = species not known)

Species	Family	Common name	Nominal catch tonnes	Percent of world cephalopod catch
Loligo gahi	Loliginidae	Patagonian squid	240,976	0.8
Loligo pealei	Loliginidae	Longfin squid	16,684	0.5
Loligo reynaudi	Loliginidae	Cape Hope squid	7,406	0.2
Common squid nei	Loliginidae		225,958	7.5
Omnastrephes bartrami	Omnastrephidae	Neon flying squid	22,483	0.7
Illex illecebrosus	Omnastrephidae	Northern shortfin squid	5,525	0.2
Illex argentinus	Omnastrephidae	Argentine shortfin squid	511,087	16.1
Illex coindetii	Omnastrephidae	Broadtail shortfin squid	527	<0.1
Dosidicus gigas	Omnastrephidae	Jumbo flying squid	406,356	12.8
Todarodes sagittatus	Omnastrephidae	European flying squid	5,197	0.2
Todarodes pacificus	Omnastrephidae	Japanes flying squid	504,438	15.9
Nototodarus sloani	Omnastrephidae	Wellington flying squid	62,234	1.9
Martialia hyadesi	Omnastrephidae	Sevenstar flying squid	-	-
Squids nei	Various		311,450	9.8
Total squids			2,189,206	75.8
Total cephalopods			3,173,272	100.0

A Japanese fishery for different species of squid started in the 1970s in the north Pacific using jigs and drift-nets. Korea and Taiwan joined the drift-net fishery in the early 1980ies. Due to concerns about the incidental catches of sea turtles and dolphins the United Nations General Assembly adopted a global (although non-legally binding) moratorium on all large-scale pelagic driftnet fishing on the high seas at the end of 1992 (Ichii *et al.* 2006).

From the distribution of different squid species (Figure 2.6) it can be seen that certain species have distributions extending into the high seas. Especially *Omnastrephes bartrami* (Figure 2.6B) is an epipelagic species which occurs in the deep ocean in the Atlantic, Pacific and Indian Oceans. The species is only commercially exploited, however, in the northwest Pacific, off northeast Japan. Also *Dosidicus gigas* (Figure 2.6A) is largely an off-shelf species.

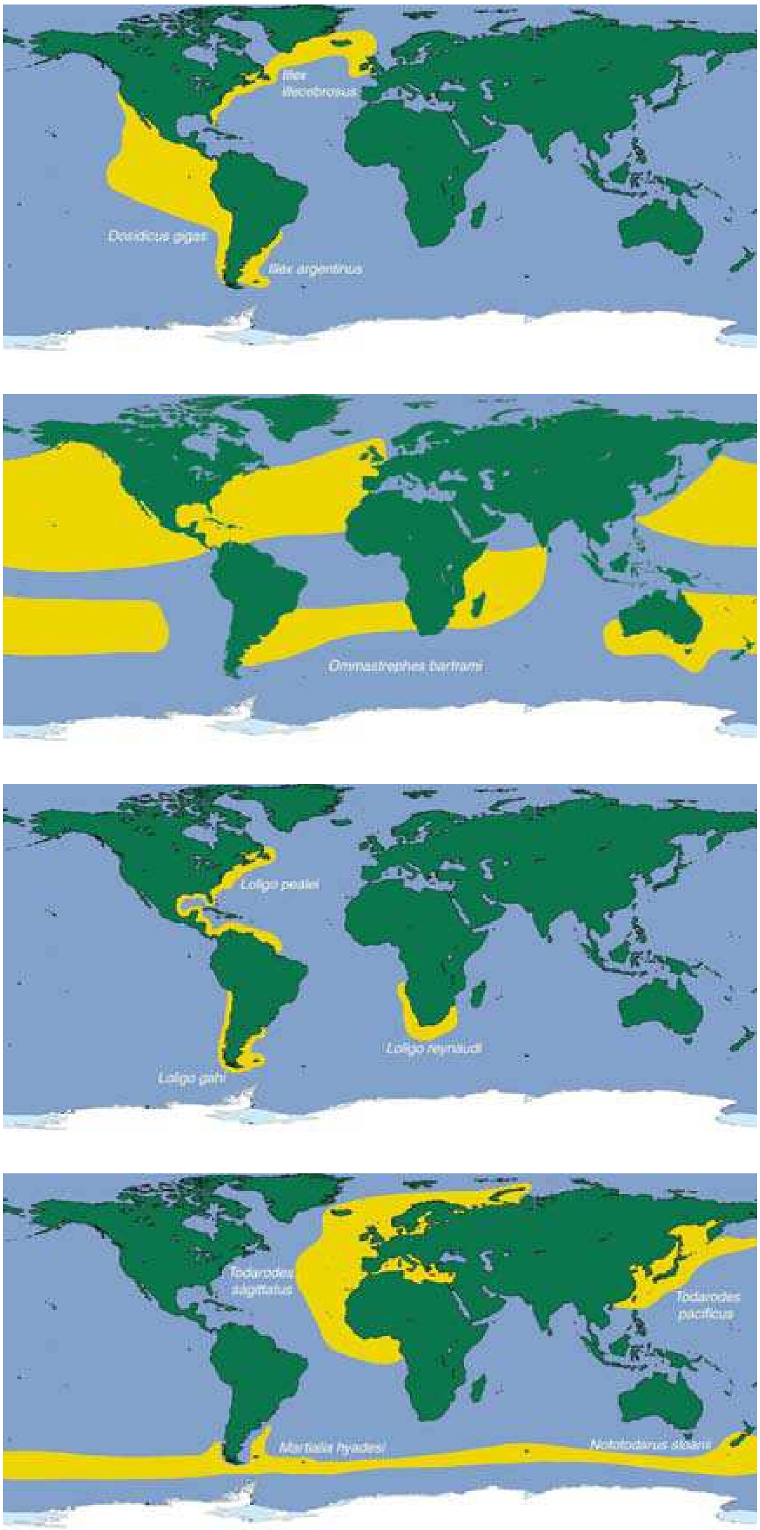
The typical short life span of squids presents particular problems for the management of the fisheries. There are no methods to assess the potential recruitment and stock size can only be determined once the new generation recruits to the fishery. In the 1980s it was, therefore, recommended that cephalopod fisheries should be managed by effort limitation and assessed in real-time (Caddy (1983) and Csirke (1986) in FAO, 2005). This system has been adopted in squid fisheries around the Falkland Islands (Islas Malvinas).

Cephalopod fisheries have potential to increase, not only in some of the species mentioned above. There are other species that are so far only lightly exploited, e.g. *Thysanoteuthis rhombus* that occurs in tropical/subtropical waters of all oceans and *Berryteuthis magister* from the north Pacific.

Finally, Figure 2.7 provides a map indicating cephalopod species richness in the high seas.

Conclusions

- Total stock size of squids worldwide is probably huge
- Part of squid (pelagic) fisheries is in the high seas
- Squid biomass is very variable due to short lifespan and therefore difficult to assess
- Squid stocks are probably not fully exploited



A: Omnastrephidae

B: *Omnastrephes bartrami*

C: Loliginidae

D: flying squids

Figure 2.6 Distribution of the world's major squid stocks exploited by commercial fisheries and reported at species level by FAO (from FAO, 2005)

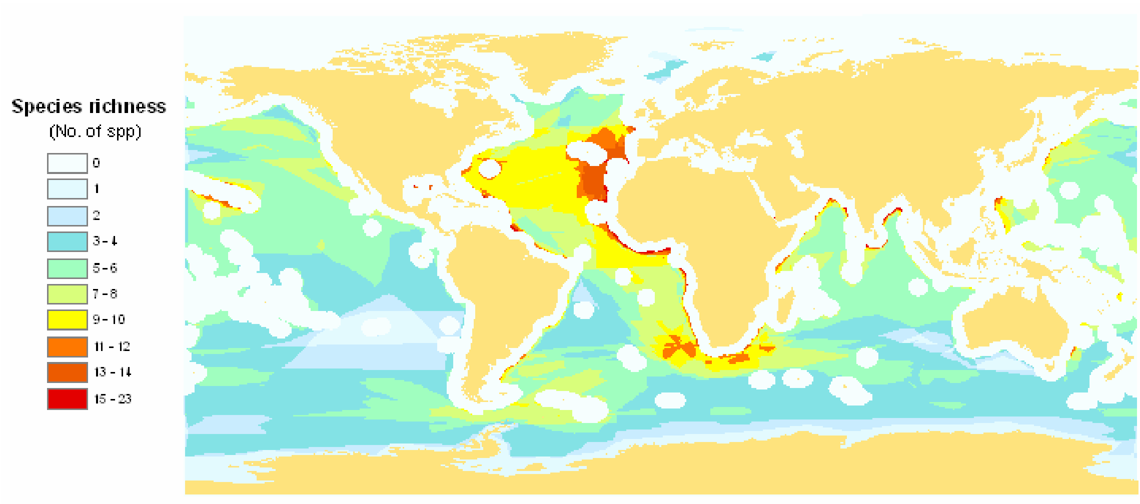


Figure 2.7 Map of species richness of commercial cephalopods (largely squid and cuttlefish) in the high seas, based on 119 distribution ranges in Roper *et al.* (1984). The total number of cephalopods (both high seas and coastal) is 786 (www.cephbase.org). Copied from UNEP (2005).

2.4 The fleets

There is no single and complete database or register of high seas fishing vessels in the world (High Seas Task Force, 2005). However, there have been attempts at global (FAO) and regional (by regional fisheries management organisations, RFMOs) levels to establish registers of fishing vessels that operate on the high seas.

The only truly global attempt to establish a high seas vessel register is the FAO High Seas Vessels Authorization Record (HSVAR) database, which contains distinctive and descriptive elements of high seas fishing vessels as well as information on registration and authorization status, infringements etc. The database has been duly established and is functioning, although it does not appear to be regularly updated (FAO-website). Other impediments are that it is entirely dependent upon the quality of information provided by flag states, that it has restricted access, and that not all flag states contribute to the database.

Furthermore, as may be concluded from Table 2.4, the overview of all data stored does not distinguish between vessels used for high seas fisheries and other fisheries. According to this list, the Netherlands for example, would have 301 vessels operating in high seas fisheries.

On a regional scale, several RFMOs such as the International Commission for the Conservation of Atlantic Tunas (ICCAT) or the North-East Atlantic Fisheries Commission (NEAFC), maintain registers of high seas fishing vessels. Most of the RFMOs with high seas coverage have established regional registers of fishing vessels authorized to fish in their respective area of competence, all of different formats. These lists highly depend on the authenticity of the information provided by the flag state, and are not independently verified. Furthermore, many of these registers are not broadly accessible. Where possible the fleets have been identified in Chapter 3.

Conclusion

- Only phragmented data for the high seas component of national fleets available

Table 2.4 Overview of data stored in the FAO HSVAR database. The database presently comprises 5943 records (http://www.fao.org/fi/hsvar/index.jsp).

Party	No. of vessels	Last update		Party	No. of vessels	Last update
Belgium	64	Feb 2004		Belize	151	Jan 2006
Cyprus	54	May 2004		Benin	12	Nov 2003
Denmark	160	Feb 2004		Canada	6	1995
Finland	24	Feb 2004		Ghana	110	Jun 2004
France	167	Feb 2004		Japan	1890	Dec 2001
Germany	51	Feb 2004		Madagascar	0	Feb 2004
Greece	133	Feb 2004		Morocco	0	Oct 2003
Ireland	96	Feb 2004		Namibia	6	Feb 2004
Italy	337	Feb 2004		New Zealand	51	Aug 2005
Netherlands	301	Feb 2004		Norway	125	Jan 2001
Portugal	185	Feb 2004		Syrian Arab Republic	22	Apr 2004
Spain	855	Feb 2004		United St. of America	847	Sep 2004
Sweden	67	Feb 2004				
United Kingdom	229	Feb 2004				

2.5 IUU fisheries

In recent years much attention is given to Illegal, Unreported and Unregulated (IUU) fisheries. It occurs increasingly in virtually all fisheries, makes proper management of the stocks extremely difficult, and thereby contributes to the collapse of entire fisheries. In 2001 the FAO developed an International Plan of Action to Prevent, Deter and Eliminate IUU Fishing (IPOA-IUU), which identifies tools for countries to combat IUU fishing, individually and in collaboration with other countries (FAO, 2001).

The High Seas Task Force estimates that the worldwide catch of IUU in the high seas is worth USD 1.25 billion a year (HSTF, 2006). Table 2.5 gives an overview of the estimates of the annual value of high seas IUU catches, as compared to the value of legitimate catches if possible. See also Chapter 3 for more details and estimates by species(groups).

IUU fisheries are described by HSTF (2006) as follows:

Illegal fishing is

- Operations by vessels flagged to members of an RFMO (including cooperating nonparties) but which operate in violation of the rules established by the RFMO
- Unauthorised foreign fishing within EEZs

Unreported fishing is

- Catch not reported or misreported by foreign vessels within EEZs
- High seas catches not reported or misreported to national authorities or RFMOs

Unregulated fishing is

- Fishing on the high seas by stateless vessels or vessels flagged to non-members of RFMOs outside the rules of the RFMO

Whatever definitions are decided, there is always going to be considerable overlap between the categories.

Conclusion

- In 2006 the High Seas Task Force estimated that the value of IUU groundfish landings was 10.6% of the value of the legal landings. The value of IUU landings of all species is estimated at 1244 million US$

Table 2.5 Estimates of annual value of high seas IUU catches (HSTF, 2006).

	Species group	**IUU annual value ($m estimated)**	**Legitimate fishery annual value ($m estimated)**	**Gears used**	**Areas**
Tunas and tuna-like fish	bluefin	33		pelagic longline, seines	Southern Pacific and Indian Ocean
	skipjack, yellowfin, albacore, bigeye	548		pelagic longline	worldwide
Sharks	sharks	192		pelagic longline	worldwide
Groundfish	toothfish	36	427	demersal longline	Southern Ocean
	cod high seas	220	1872	bottom trawl	North Atlantic
	redfish	30	274	bottom/semi-pelagic trawl	North Atlantic
	orange roughy / alfonsino	32	453	bottom/semi-pelagic trawl	Southern Pacific and Indian Ocean
Other pelagic species	jack mackerel	45		seines and pelagic trawls	Southeast Pacific
	squid	108		jig	South Atlantic and Pacific
total		1244			

2.6 Assessment of ecological effects

The ecological effects of fishing depend on the fishing method and the targeted species or species groups. The main fishing methods applied in the high seas are presented in Chapter 2.2. Gear types such as pots and dredges are not considered here as these are being used to catch crustaceans and molluscs in shallower areas within the EEZs.

High seas fisheries have a variety of ecological effects.

- bycatch of undersized fish (mainly in mixed trawl fisheries)
- bycacth of unwanted species (fish, sea mammals, birds, benthos),
- damage to benthic habitats (sea bed disturbance, damage to biogenic structures, damage to physical structures)
- changes in species and size structure of the fish community
- reduction of fish biomass (overfishing)
- noise and pollution as in all shipping

In fisheries for epi-pelagic species the main concern is for overfishing of the target species and for the undesired by-catch such as pelagic sharks, birds (albatrosses, see Chapter 14), turtles (Chapter 16) and marine mammals (Chapter 15).

Bottom trawls are presumed to be rather destructive when biodiversity of the high seas is concerned. A major problem is that they are not selective and have a considerable by-catch of unwanted fish and benthos species. Furthermore they can be very damaging to vulnerable habitats such as cold water corals.

Deepwater fishes in general are very sensitive to fishing since they often get very old and have a high age of first maturity. In addition they can be extra vulnerable when they aggregate for spawning.

Seamounts are also very sensitive habitats with many endemic species. A fishery can target specific seamounts for a short time until the local fish populations are depleted (Gianni, 2004).

In addition to the target species mentioned in Chapter 2.2 there are several species that are impacted by high seas fisheries, but are not part of the landed catch. The most important discarded species from pelagic longlines, fishing for highly migratory tuna and tuna-like species, are sharks among which the blue shark (*Prionace glauca*) is most common. Depredation by sharks and bycatch of sharks in longline fisheries in several countries (Australia, Chile, Fiji, Italy, Japan, Peru, South Africa, U.S.A.) is described in Gilman *et al.* 2007. Apart from sharks, several other species are discarded, not only fish but also seabirds such as albatrosses and petrels (see FAO, 2003a and 2003b) and turtles (see FAO 2004a and 2004b). Purse seines used in tuna fishing also discard several fish species but are well known to have a by-catch of dolphins.

Significant segments of society want a number of these species protected, regardless their abundance. Marine mammals, sea turtles and sea birds have long standing status as species at risk of extinction and/or may be concerned as charismatic species. More recently, cold-water corals (*Lophelia* sp.) have widely gained public attention. Some species of these corals might have extremely small geographic ranges (e.g. on top of a single seamount), which means they may be vulnerable to localized depletion and possibly extinction, as well as being charismatic. However, apparent localized geographic distributions might also reflect under-sampling in other areas where the species might be present.

Krill are fished with very fine-meshed plankton nets. Even though large krill aggregations tend to be monospecific a by-catch of e.g. juvenile fish can not be avoided. The method of continuous pumping used in krill fisheries is also raising concerns for possible ecological effects of this fishery. Because of the central ecological role of krill in many marine ecosystems, including that as prey for many other species which are commercially fished, krill fisheries require careful management. The size of the world harvest of krill may currently be limited by lack of demand, but some fisheries are deliberately being managed at low levels because of ecological concerns.

Due to concerns about the incidental catches of sea turtles and dolphins the United Nations General Assembly adopted a global (although non-legally binding) moratorium on all large-scale pelagic driftnet fishing on the high seas at the end of 1992 (Ichii *et al.* 2006). The use of driftnets longer than 1.5 miles is prohibited on the high seas.

The ecological impact of high seas fisheries are summarised in Table 18.1. Of all forms of human use of the high seas fisheries undoubtedly have the largest impact.

Conclusions

- Deepwater trawling can be very damaging to vulnerable deepwater habitats such as cold water corals.
- Deepwater species are vulnerable to overexploitation due to slow growth and late maturity.
- Fisheries in the high seas can have significant by-catches of other fish species (sharks), birds, turtles and marine mammals.

2.7 Future developments

Many of the target species in high seas fisheries are fully or even over exploited, and possibilities for a further increase of these fisheries are therefore limited. It has however been suggested (see 2.3.3) that, for example in cephalopods, certain high seas fisheries may have the potential to be further developed. If the need for, and prices of animal proteins further increase, then it may become profitable to develop fisheries for species such as mesopelagic fish species (see Chapter 12). These species occur at greater depths and are fairly small but are believed to occur in great quantities that may be interesting for reduction purposes (fish meal and fish oil).

On the other hand, fuel prices have steeply increased over recent years. Visiting fishing areas at the high seas, at great distances from the home ports, might soon no longer be profitable.

2.8 CBD WG on Protected Areas in Areas beyond National Jurisdiction

In 2004 the "Conference of the Parties" of the Convention on Biological Diversity (CBD) decided to establish an *Ad Hoc Open-ended Working Group on Protected Areas* in marine areas beyond the limits of national jurisdiction. The WG had its first meeting in 2005. A second meeting of the WG was held before the ninth meeting of the Conference of Parties, in February 2008. Meanwhile several publications have been written with background information and reviews of biodiversity in the high seas and the legal regime.

One of the factors that is crucial for the success of marine protected areas (MPAs) in areas beyond national jurisdiction is sufficient scientific information on where such areas are to be created.

As areas with a special high biodiversity UNEP (2005a) mentions seamounts, cold water coral reefs and hydrothermal vents. The biodiversity in these areas is often seriously and increasingly threatened by human activities. Rapid action to address these threats on the basis of the precautionary and the ecosystem approach needs to be undertaken.

More than 30,000 seamounts over 1000 m high are estimated to exist, less than 200 of these have been comprehensively sampled. Seamounts are considered hot spots for the evolution of new species, refuges for ancient species, and stepping-stones for species to spread across ocean basins. Endemism rates are high. Many species occurring on seamounts have biological characteristics that make them particularly vulnerable to human impact, especially for destructive fishing activities.

Cold-water corals grow in dark deep waters and do not have light-dependent symbiotic algae in their tissues. Cold-water corals can occur as small, scattered colonies of no more than a few meters in diameter to vast reefs measuring tens of kilometers across. Some reefs may be up to 8000 years old. They occur in fjords, along the edge of the continental shelf, and around offshore submarine banks and seamounts. The greatest of the cold water coral reefs known to date is on the Sula Ridge on the mid-Norwegian shelf. This structure is more than 13 km long and up to 450-500 m wide. Average height is about 15 m, but some individual sub-structures are 35 m high (Dons, 1944 and Freiwald et al. 1999 in ICES 2002). Cold water coral reefs support rich and diverse assemblages of marine life, and are home to thousands of other species such as sponges, polychaetes, crustaceans, echinoderms, bryozoans and fish. *Lophelia pertusa* is probably the best known (studied) coral species so far. Damage from bottom trawling has been reported as the main threat to cold-water coral reefs.

Hydrothermal vents are typically found along mid-ocean ridges, at an average depth of 2100 m. Hydrothermal vents are characterized by extremely high temperatures (up to 400 ºC), high pH values, and extreme salinity and toxicity. They are only found in areas with volcanic activity. A Hydrothermal Vent Database currently lists 212 vent sites. Such vents were discovered in the latter quarter of the twentieth century. More than 500 new animal species, often endemic to vents, have been described. The only current threat may stem from marine scientific research. Potential future threats may be bioprospecting, mining of polymetallic sulphide deposits, and high-end tourism.

The main conclusion of UNEP (2005a) concerning species richness for different groups are as follows:

- In invertebrates overexploitation of cephalopods, crustaceans, and non-cephalopod molluscs is considered the biggest threat, especially in relation to seamounts and cold-water corals.
- In fish higher species richness is observed in the tropics, in particular in southeast Asia. In temperate areas species richness is related, again, to seamounts and cold-water corals. By the 1990s, with fleets fishing much deeper and further offshore, the risk of extinction has increased dramatically as stocks are being overfished, and in some areas locally extirpated.
- As far as reptiles are concerned, turtles are widely dispersed and no particular areas with high or endangered biodiversity can be distinguished.

When all data are combined the tropical Indo-Pacific emerges as an important area to be considered for protection as well as seamount areas in the Pacific, Indian and Atlantic Oceans. Seamounts are often associated with cold-water corals, plus a high species richness of fish and invertebrates.

Potential areas for targeted conservation action are:

- areas in the Indo-Pacific, specifically centred on South-East Asia, northern Australia and the Tasman Sea
- seamounts in North and South Atlantic, and the Southern Ocean Convergence Zone (will also protect cold-water coral areas)
- adjacent to islands in the Southern Ocean
- small shelf areas in the northeast and Northwest Atlantic.

Conclusions

- CBD WG on protected areas: first meeting in 2005
- Focus on seamounts, cold-water corals and hydrothermal vents
- Potential areas for conservation action:
    - areas in the Indo-Pacific
    - seamounts in North and South Atlantic, and the Southern Ocean Convergence Zone

- adjacent to islands in the Southern Ocean
- small shelf areas in the NE and NW Atlantic.

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3 Economic Aspects of High Seas Fisheries[3]

3.1 Introduction

At present about 40 RFMOs exist, with varying tasks. Table 3.1.1 presents a complete overview by region and main task. In principle a distinction can be made between RFMOs with management tasks and those with scientific and advisory tasks. From the perspective of the present project, focus was put on a selection of RFMOs within the first group based on the following criteria:

- Focus on management of high seas
- Coverage of economically important fisheries in international waters (outside EEZs).

On the basis of these criteria the following RFMOs have be discussed:

- NAFO – North Atlantic Fisheries Commission
- NEAFC – North-East Atlantic Fisheries Commission
- ICCAT – International Commission for the Conservation of Atlantic Tunas
- WCPFC - Western and Central Pacific Fisheries Commission
- IATTC – Inter-American Tropical Tuna Commission (covers Eastern Pacific Ocean)
- CCSBT – Commission of Conservation of Southern Bluefin Tuna
- CCAMLR – Commission for Conservation of Antarctic Living Marine Resources
- IOTC - Indian Ocean Tuna Commission

These RFMOs cover all major high seas fisheries.

Several RFMOs having management tasks specified in Table 3.1.1 have not been addressed for the following reasons:

CCBSP - The Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea. Signatory Parties: People's Republic of China, Japan, Republic of Korea, Republic of Poland, the Russian Federation, and the United States of America

GFCM – General fisheries Council for the Mediterranean. GFCM does not provide any statistics on fleet and/or catch. Distinction between catches within and outside EEZ would be extremely difficult.

IPHC - International Pacific Halibut Commission. Deals mainly with EEZ of Canada and the USA, who are the only members of IPHC.

IWC – International Whaling Commission. Is concerned with protection of whales, which are not exploited commercially.

NASCO – North Atlantic Salmon Commission. NASCO Convention prohibits fishing of salmon in high seas.

NPAFC - North Pacific Anadromous Fish Commission. Members are Canada, Japan, Republic of Korea, Russian Federation, United States of America. NPAFC protects salmon and steelhead trout and prohibits its catch in the high seas.

PSC - Pacific Salmon Commission. Implements management of salmon stocks in the trans-boundary rivers between USA and Canada.

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[3] Authors: J.A.E. van Oostenbrugge and P. Salz

SEAFO - Southeast Atlantic Fisheries Organization. Members: Angola, Namibia, EU, Norway. Economic size of the fishery seems limited and particularly statistics are not available.

SIOFA - South Indian Ocean Fisheries Agreement. Exists since 2006, no further information is available. FAO does not even provide a fact sheet, which seems to imply that SIOFA is not active.

SPRFMO - South Pacific RFMO. Is in the process of being established. Fifth meeting on the establishment was held in March 2008.

Table 3.1.1 Overview of all RFMO's by task (management or advice). Source: FAO

Management bodies with management mandate		**Advisory bodies** with advisory mandate (scientific and/or management)	
CCAMLR	NPAFC	APFIC	ICES
CCBSP	PSC	BOBP-IGO	LVFO
CCSBT	SEAFO	CARPAS	MRC
GFCM	SIOFA	CECAF	NAMMCO
IATTC	SPRFMO	CIFA	OLDEPESCA
ICCAT	WCPFC	COMHAFAT	PICES
IOTC		COPESCAL	RECOFI
IPHC		COFREMAR	SEAFDEC
IWC		COREP	SPC
NAFO		CPPS	SRCF
NASCO		EIFAC	SWIOFC
NEAFC		FFA	WECAFC

The following chapters present a general overview of the structure and trends in high seas fisheries in the areas under the different RFMOs. Estimations are presented of the economic scale of these fisheries in terms of volume and value of catch, income[4] (gross value added) and employment. The following qualifications must be made:

- In most cases it is not possible to determine whether catches have been realized within or outside national EEZs.
- Catches and fleets are declared according to their country of registration (vessel flag). This does not necessarily mean that the owner of the vessel is also located in that country. This applies in particular to smaller producers (which are usually not specifically mentioned in the report).
- Only rough estimates of employment can be made, based on limited indications of the average size of the crew per type of vessel. A significant part of the crew often does not have the nationality of the flag of the vessel.

[4] Income is defined according to the definition of gross national product (gross value added) containing labour income, profit, depreciation and interest.

Summary

Region / RFMO	Catch (1000 t)	Value (million Euro)	Employment Min - max (1000 persons)
NAFO*	270	250	2.5
NEAFC	4,850	1,790	8-
ICCAT	570	630	50-100
WCPFC	2,150	1,500	105-175
IATTC EPO	740	726	
CCSBT	16	80	
CCALRM*	130	180	1.5
IOFC	1,700	1,500	40-66

* only in international waters

Valuation of a fishery depends evidently on prices used. National price statistics have been used as much as possible. However, for some species like tuna a number of significantly different markets exists, ranging from relatively low priced skipjack for canning, with prices around US$ 800 /tonne to high price sashimi market with prices in excess of US$ 7-10,000 / tonne. In between there is a wide variety of specific markets, where the price depends on the use, size of the fish, fishing technique and of course quality. In 2007 prices of skipjack increased sharply due to poor supply. For tuna, the valuation presented in this report is based on a snap-shot of 2004/5 coupled with the long term trend analysis by FAO[5].

Although high seas fisheries represent considerable economic value, their relative importance to the total world fishery and national fisheries is mostly limited. To put the results in a national perspective Appendix 3.1 gives an overview of the landings value per country in the different area's and the total value of the national fisheries from FAO statistics.

3.2 Methods

Tuna prices

Despite the fact that tuna is a globally traded commodity, the prices are largely different, depending on species (skipjack, yellowfin, etc.), product form (fresh, frozen, whole, gilled and gutted, headless and gutted, size of the fish, etc.) and market (Japan pays more for a given quality).

Furthermore data obtained from various sources need to be adjusted to account for trade margins, transport costs, etc. The following sources were identified for 2004:

- Landings prices, France, average fresh and frozen product
- Infofish price quotations for wholesale Japan and c&f imports Thailand
- UN: world export, value and volume per product type (HS2002 classification – 6 digits).
- FAO, *Developments of tuna prices and future trends*, by Helga Josupeit, April 2007 (conference paper)

The findings are summarized below:

5 H. Josupeit, Fishery Market Officer, FAO, Developments of tuna prices and future trends, April 2007

Tuna prices, 2004, Euro/ton (rounded to 10)

	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin	Other
France	560	820	680	1060		
World exports[6]	420	1000	1830	1100	7000	1240
FAO, long term price level	620	1150				
Infofish, Japan, wholesale		970-1700				
Infofish, Thailand, c&f	640-890					
Assumed price	**600**	**1100**	**1200**	**1100**	**7000**	**1200**

Value of landings and income

Total value of landings per country is estimated using the above prices and the catches, obtained from the yearbooks of the various RFMOs. In view of the global nature of the tuna industry (catching, processing, trade and consumption), and the relatively low costs of transportation, it is rather likely that ex-vessel prices are quite similar independently of the fishing area. Furthermore, most tuna is caught in the Western Pacific, with Bangkok being the leading market for raw material for canning and Japan determining the price of tuna for fresh consumption.

Estimation of gross income (value added, i.e. revenues minus operational costs) is based on several international studies of costs and earnings of fishing fleets (FAO, EU). These studies indicate that for many fleets, gross value added amount to about 40-60% of the value of production. As a significant number of the studied fleet segments shows rates of 55-60%, the present study assumes that gross value added amounts to 55% of the value of production.

Estimation of employment

There does not seem to be any source of statistical information on employment in high seas fisheries. Neither any of the FRMOs nor the contacted states involved in this activity could provide any measurement. The estimation therefore relies on indications of average crew per type of vessel, which were obtained in personal communications from various experts. Crew size differ according to the type of the fishery and the size of the vessel. However, information could be only found on numbers of vessels by gear, but not by size[7]. Therefore a 'High' and a 'Low' estimate of employment by fleet and country was determined using the following average crew sizes:

	Longline (LL)	Pole&line (PL)	Purse seine (PS)
Crew indication	15-25	6-25	18-25
- maximum	25	25	25
- minimum	15	6	18

In this way a range of employment figures per country and fishing area has been calculated.

Comment

Comparison of average gross value added per crewman with the GNP / capita in the different countries gives very significant differences. These differences can be explained by two effects:

[6] File: Export tuna 2004, all to world, using € = 1.24 US$ and assuming 35% margin between vessel and export price.

[7] Some size data is available, but it could not be used for the present estimation.

1. Most vessels operate with crews from low income countries. Consequently, average value added / man is relatively low for vessels flying a flag of a high income country.
2. It is not possible to distinguish catches from within and outside the EEZs. Consequently, countries where foreign fleets exploit tuna within their EEZ declare relatively high catches. Our estimate produces a high total value, leading to a gross value per man significantly above the GNP/capita.

3.3 NAFO

The NAFO Convention Area encompasses a large portion of the Atlantic Ocean and includes the 200-mile zones of Coastal States jurisdiction (USA, Canada, St. Pierre et Miquelon and Greenland).

Summary for 2005 (data from Canada and USA for 2004):

• Total landings in NAFO area:	2,100,000 t
• Catches in international waters:	270,000 t
• Countries fishing in the area:	USA, Canada, Spain, Russia, Portugal, Portugal, Estonia, Iceland, Lithuania, Norway, Faroe Islands, France, Latvia, Japan, Germany, Poland, Cuba and Ukraine
• Total value of production:	250 Million Euro
• Total income generated:	140 Million Euro
• Total employment:	2.500 (excluding Canada and the US)
• IUU	5%

The focus for this chapter is high sea fisheries outside the national zones. This area is, however, not specified in the NAFO statistics. In this chapter data and effort is used from fisheries in NAFO area 1F, 2J, 3K, 3L, 3M, 3N, 3O, 6E, 6F, 6G in combination with detailed data on landings outside the EEZ's from the Sea Around Us project[8]. The dataset from the Sea Around Us project contained catch data up to 2004 and was used to deduct which part of the total catch was taken outside the EEZ. Most of the countries active in this fishery are not allowed inside the EEZs, but Canada, the US, Portugal and Spain are allowed to fish both inside and outside. Catches outside EEZ for Portugal and Spain were estimated for 2005. For Canada and the US, catches from 2004 from Sea Around Us are presented. Greenland had no fishery in this area in 2005 but some fisheries mainly in 1 F in 2004 and 2006.

Fleet and effort

According to NAFO statistics, the registered fleet consisted of around 120 trawlers. The following comments can be made:

- Vessel and effort information from Canada and the US is not publically available.
- Effort information is not available for all fishing trips (around 75% coverage). Thus effort numbers are estimated based on catch proportions and the assumption of constant CPUE.
- Besides Canada and the US, Spain, Russia, Estonia and Portugal have the largest fleets operating in the Area. As Spain and Portugal are also allowed to fish within the EEZ and take a large part of

[8] Sea Around Us, 2008. A global database on marine fisheries and ecosystems. World Wide Web site www.seaaroundus.org. Fisheries Centre, University British Columbia, Vancouver (British Columbia, Canada).

their catch there, the number of vessels operating in international waters is most probably an overestimate.

- The Spanish fleet also takes some catches using lines and pots, but for these gears no information on vessels and effort is available.

Table 3.3.1 Active fleet (number of vessels) in NAFO, 2005*

Country	Trawl
Spain[1)]	25
Russia	23
Estonia	21
Portugal	14
Iceland	5
Lithuania	3
Norway	2
Poland	1
Faeroe Islands	3
Other	20-30
Total	**117-130**

Source: www.nafo.int. *Fleet information from Canada and US is not publically available. Portugal AER 2005. [1)] Values for Spain are own estimates, the Spanish fleet probably also include some liners

Table 3.3.2 Fishing effort in NAFO* (seadays)

Country	Bottom trawl	Midwater trawl	Shrimp trawl	other	**Total**
Estonia	1,566				**1,566**
Russia	882	841			**1,723**
Faroe Islands	347	96		7	**443**
Spain	1193				**1,193**
Lithuania	514	65			**579**
Japan	489				**489**
Portugal	634				**634**
Other	316	103	119	0	**537**
Total	**5,940**	**1,105**	**119**	**7**	**7,164**

Source: www.nafo.int. * Effort information from Canada and US is not publically available.

The total fishing effort in the area is around seven thousands days a year for the countries other than US and Canada for which no effort data are available More than 95% of this effort is carried out by trawlers.

Catches

In total around 280.000 ton of fish are caught in the NAFO area. The majority of the catch is taken by the US and Canada. Other important countries are Russia and Estonia. Spain and Portugal have also considerable fishing fleets in the area, but attain around 75% of the total catch within the EEZ. Most important species (in terms of value) are the northern prawn, Atlantic redfishes, ocean quahog (clam), Greenland halibut and queen crab. In terms of volume, however, the pelagic species mostly caught by the US are more important: Atlantic herring (48.000 t) and Atlantic mackerel (21,000 t). Other important species caught by US vessels are American sea scallop (16,000 t) and northern shortfin squid (11,000 t).

Table 3.3.3 Catches by country and species in NAFO, 2005 (1000 t)

Country	northern prawn	Atlantic redfishes	ocean quahog	Greenland halibut	queen crab	other	**Total**
USA	0.2	0.0	31.5	0.0	0.0	127.5	**159.2**
Canada	0.8	0.0	0.0	0.0	6.2	50.1	**57.1**
Russia	0.4	13.6	0.0	3.3	0.0	0.2	**17.5**
Estonia	12.3	1.1	0.0	0.4	0.0	0.9	**14.7**
Spain	0.1	0.9	0.0	1.6	0.1	3.5	**6.2**
Faroe Islands	3.5	2.2	0.0	0.3	0.0	0.0	**6.0**
Lithuania	3.9	1.3	0.0	0.1	0.0	0.1	**5.5**
Portugal	0.0	3.3	0.0	0.9	0.0	0.7	**4.9**
Japan	0.0	0.8	0.0	2.1	0.0	0.2	**3.1**
other	4.0	2.0	0.0	0.0	0.0	0.7	**6.8**
Total	**25.2**	**25.2**	**31.5**	**8.6**	**6.3**	**184.1**	**280.9**

Sources: USA and Canada:Sea around us detailed statistics for 2004, Other fishing fleets: Nafo 21B catch statistics (www.nafo.int).

The most important gears used are trawls. Together, bottom and midwater trawls account for over 30% of the total catch. Other important gears are dredges for clams and scallops, lines for herring and pots for crabs. Atlantic herring, which is the most important species under other gears, is mostly caught by purse seine.

Table 3.3.4 Catches by gear and species in NAFO, 2005 (1000 t)

	bottom trawl	dredge	lines	midwater trawl	pots	other	**Total**
American sea scallop	0.0	16.7	0.0	0.0	0.0	1.8	**18.4**
Atlantic herring	0.0	0.0	13.1	0.0	0.0	65.7	**78.9**
Atlantic redfishes	8.4	0.0	0.0	16.9	0.0	0.0	**25.2**
Greenland halibut	8.6	0.0	0.0	0.0	0.0	0.0	**8.6**
northern prawn	23.5	0.0	0.0	0.0	0.0	1.7	**25.2**
ocean quahog	0.0	31.5	0.0	0.0	0.0	0.0	**31.5**
queen crab	0.0	0.0	0.0	0.0	6.3	0.0	**6.3**
swordfish	0.0	0.0	1.0	0.0	0.0	0.4	**1.4**
other	29.2	3.5	11.1	4.9	8.4	28.3	**85.4**
Total	**69.7**	**51.6**	**25.3**	**21.8**	**14.7**	**97.9**	**280.9**

Sources: USA and Canada:Sea around us detailed statistics for 2004, Other fishing fleets: Nafo 21B catch statistics (www.nafo.int).

Value, income and employment

The total value of the fish production in the high seas NAFO area is estimated at 247 million Euro in 2005. More than 50% is generated by fisheries from the US and Canada, mainly from ocean quahog, and queen crab but also from American sea scallop (16 million Euro) Atlantic herring (6 million Euro) and northern shortfin squid (5 million Euro). For the other fishing fleets northern prawn, Atlantic redfishes and Greenland halibut are the main species.

Table 3.3.5 Value by country and species in NAFO, 2005 (million Euro)

Country	northern prawn	Atlantic redfishes	ocean quahog	Greenland halibut	queen crab	other	**Total**
USA	0.4	0.0	26.2	0.0	0.0	63.3	**89.9**
Canada	1.6	0.0	0.0	0.0	24.4	21.6	**47.5**
Estonia	24.7	1.3	0.0	1.1	0.0	0.5	**27.5**
Russia	0.8	15.4	0.0	9.8	0.0	0.1	**26.2**
Faroe Islands	7.1	2.4	0.0	0.9	0.0	0.0	**10.4**
Spain	0.2	1.0	0.0	4.9	0.3	4.0	**10.4**
Lithuania	7.9	1.5	0.0	0.2	0.0	0.1	**9.7**
Japan	0.0	0.9	0.0	6.1	0.0	0.2	**7.3**
Portugal	0.0	3.8	0.0	2.5	0.0	0.6	**6.9**
other	8.1	2.3	0.0	0.1	0.0	0.8	**11.2**
Total	**50.7**	**28.7**	**26.2**	**25.7**	**24.7**	**91.2**	**247.1**

Sources: own estimate

More than 50% of the total value of the fisheries is generated through trawling. For most countries only trawls contribute significantly to the total value of the catch, but for the US and Canada other gears such as dredges, lines and pots are also important.

Table 3.3.6 Value by country and gear in NAFO, 2005 (million Euro)

Country	bottom trawl	dredge	lines	midwater trawl	pots	other	**Total**
USA	13.5	44.7	11.4	2.3	2.2	15.9	**89.9**
Canada	5.3	0.8	5.9	0.4	24.9	10.3	**47.5**
Estonia	27.5	0.0	0.0	0.0	0.0	0.0	**27.5**
Russia	12.1	0.0	0.0	14.0	0.0	0.0	**26.2**
Faroe Islands	8.0	0.0	0.0	2.4	0.0	0.0	**10.4**
Spain	8.1	0.0	1.9	0.0	0.3	0.0	**10.4**
Lithuania	8.8	0.0	0.0	0.9	0.0	0.0	**9.7**
Japan	7.3	0.0	0.0	0.0	0.0	0.0	**7.3**
Portugal	6.9	0.0	0.0	0.0	0.0	0.0	**6.9**
other	5.7	0.0	0.3	1.8	0.0	3.5	**11.2**
Total	**103.2**	**45.5**	**19.4**	**21.8**	**27.5**	**29.7**	**247.1**

Sources: own estimate

The fisheries generate an income of approximately 135 million Euro. Moreover, the fishery provides employment to at least 2,500 people, but probably many more. Based on the proportion in the total income between the US and Canada and the other fishing nations from the area, the total number of fishermen is most probably between 5,000 and 6,000.

Table 3.3.7 Income and employment by country in NAFO, 2005

Country	Incomes (Million Euro)[1]	Employment (persons)[2]
USA[3]	49.5	n.a.
Canada[3]	26.2	n.a.
Estonia	15.1	420
Russia	14.4	460
Faroe Islands	5.7	60
Spain	5.7	500
Lithuania	5.3	60
Iceland	4.0	100
Portugal	3.8	340
Others	6.2	500-700
Total[3]	135.9	2380-2580

Sources: own estimate (see appendix 3.1)
1) Based on 55% of estimated value of landings.
2) Employment data indicate the approximate crew on board the given fleet. This does not mean that the crew has a corresponding nationality.
3) Total employment is excluding employment in Canada and the USA

IUU

Current NAFO IUU List includes 15 vessels. Of the 334 at-sea inspections carried out in 2006, 18 (e.g. 5%), indicated that the vessel inspected might have violated NAFO regulations.

EEZ and international waters

In 2005, the catch estimates for the NAFO Convention Area (FAO statistical area 21) amounted to just under 2.1 million tons. Of this total approximately 280,000 tons, i.e. about 13% of the total catches, in the NAFO Regulatory Area.

3.4 NEAFC

NEAFC covers all stocks outside the 200-mile zone in the North-East Atlantic, except tuna. These stocks include a variety of both pelagic and demersal fish spieces that are occurring both inside and outside the EEZ. Presented data is from the ICES catch database (catches), from national landings statistics (prices) and from the Annual Economic Report (economic data)(AER,2005). As no distinction is made in the ICES database between high seas and the EEZ, total landings from the species managed by NEAFC area are presented here including those from inside EEZs.

Summary for 2005:

• Total landings:	4,850,000 t
• Catches in international waters:	1,040,000 t
• Countries involved:	Norway, UK, Iceland, Russian Fed.
• Total value of production:	1,790 million Euro
• Total income generated:	1,110 million Euro
• Total employment:	8,300, excluding France and Spain
• IUU	only for redfish, estimated at 25% of the legal fishery

Fleet and effort

According to NEAFC statistics, the registered fleet consisted of around 540 fishing vessels. The following comments can be made:

- Other are mostly combined trawlers/purse seiners.
- Data from Spain and France were missing in the AER for 2005 and are thus missing here.

Table 3.4.1 Active fleet (number of vessels), 2005

Country	Trawl	Longline	Other	Total
Norway	72		46	118
UK	71			71
Iceland	78		31	109
France[1)]				
Spain[1)]				
Portugal	14			14
Germany	11			11
Faeroe Islands	52	19	8	79
Other	16		125	141
Total	314	19	210	543

Sources: AER 2005. [1)] no data available in AER 2005

Effort information is only available for a small part of the fleets. Thus, it is impossible to make reliable estimates of total effort.

Catches

The pelagic species are most important in terms of catch. These species are mainly used as fishmeal and frozen fish, and thus have low values per kg. On the estimates of the catches of individual species the following comments can be made:

- Reported catches of most species in Fishstat are higher than reported in NEAFC statistics. This is because of area restrictions or because of specific fish stocks that are not distinguished in the ICES statistics.
- Only Norwegian spring spawning herring is managed under NEAFC, but this is not distinguished in the statistics of Fishstat. Thus, the estimates for total herring catches are 800,000 t too high.
- Also, all catches of haddock are included in the ICES catches (232,000 t). In this calculation however only catches of Rockall haddock (catch 5,000 t) which is managed under NEAFC are taken into account.

Less than 60% of the total catches can be linked back to gears, thus this information cannot be provided on a country by county bases.

Table 3.4.2 Catches by country and species in NEAFC, 2005 (1000 t)

Species	Herring	Atlantic Mackerel	Blue whiting	Greenland halibut	Redfish	Other	Total
Norway	748.2	119.7	738.6	32.6	5.3	44.6	1,670.6
UK	130.8	126.6	126.1	4.2	1.8	17.2	403.2
Iceland	261.5	0.4	265.9	38.8	30.4	9.5	580.6
Russian Fed.	140.1	40.5	332.2	14.2	24.7	6.9	549.9
Faeroe Islands	71.9	10.3	267.5	3.9	7.4	17.7	376.3
Denmark	167.5	23.2	39.1	0.0	0.0	15.4	245.2
Netherlands	128.0	23.5	128.4	0.0	0.1	2.3	282.2
France	41.0	18.3	7.2	0.3	0.5	19.7	86.7
Other	362.5	85.0	154.6	25.8	12.1	30.0	651.0
Total	2,051.4	447.4	2,059.6	119.8	82.2	163.2	4,845.7

Sources: ICES catch data. For haddock only catches of Rockall haddock are taken into account.

Value, income and employment

Norway, Iceland and the UK are the most important countries utilizing the stocks under NEAFC. Together they contribute to around 70% of the total income from these fisheries. The most important species blue whiting, herring Atlantic mackerel and Greenland halibut contribute to more than 80% of the catch value.

Table 3.4.3 Value by country and species in NEAFC, 2005 (million Euro)

Species	Herring	Atlantic Mackerel	Blue whiting	Greenland halibut	Redfish	Other	Total
Norway	332.3	126.2	73.4	32.6	4.6	39.1	608.1
UK	39.9	120.3	8.8	4.2	2.8	23.7	199.6
Iceland	90.3	0.4	19.0	38.8	35.7	6.7	190.9
Russian Fed.	57.3	42.7	31.0	14.2	27.6	5.8	178.7
Faeroe Islands	29.4	10.9	25.0	3.9	8.3	14.9	92.3
Denmark	36.0	40.0	3.3	0.0	0.1	2.7	82.0
Netherlands	27.6	12.5	29.1	0.0	0.1	1.6	70.7
France	16.4	6.9	3.1	0.3	0.5	37.7	64.9
Other	115.7	41.8	39.9	25.8	18.6	57.4	299.1
Total	744.8	401.4	232.6	119.8	98.3	189.6	1,786.4

Sources: own estimation based on ICES catch data and National price statistics. For haddock only catches of Rockall haddock are taken into account.

Total income generated by the fisheries is estimated at around 1.0 billion Euro. Moreover, the fishery provides employment to at least 8,300 people, but probably many more. Based on the proportion in the total income between the UK and the Russian Federation and the other fishing nations from the area, the total number of fishermen is most probably around 10,000.

Table 3.4.4 Income and employment by country in NEAFC, 2005

Country	Income (million Euro)	Employment (1000 persons)
Norway	334.5	2
Iceland	109.8	-[1)]
UK	105.0	2
Russian Fed.	98.3	-[1)]
Faeroe Islands	50.8	0.4
Denmark	45.1	0.5
Netherlands	38.9	0.4
France	35.7	1.4
Other	164.5	1.6
Total	982.5	8.3[2)]

Sources: *Employment data from AER 2005. [1)] no data available in AER 2005 [2)]Excluding Spain

IUU

IUU catches of redfish have occurred over the last year and seem to be most important in the NEAFC area. MRAG reports that: *Two recent studies conducted by the EC Joint Research Centre using satellite imagery vessel detection system (VDS) and compared to VMS position reports indicated that not all fishing vessels could be accounted for. The discrepancy between the two sources of information indicates that the unreported effort might be a significant amount and could be more than 25% higher than that reported to NEAFC (NEAFC, 2004). This could put the level of IUU fishing within NEAFC waters as high as about 15,000t, equivalent to $30million.*
This total catch is only a small fraction of the total catch in the area, but important for this species.

EEZ and international waters

Around 25% of the total catches in the NEAFC area are realised in international waters. For deep sea species, this proportion is higher (around 35%).

Table 3.4.5 Total catch and catch in international waters in NEAFC area, 2005

Species	Total (*1000 t)	International waters (*1000 t)
Redfish	69.0	32.0
Bleu Whiting	1,973.0	695.0
Norwegian Spring spawning herring	1,254.0	195.0
Atlantic Mackerel	356.0	35.0
Haddock	5.0	5.0
Deep sea species	199.7	73.4
Total	3,856.7	1,035.4

Sources: NEAFC statistics

3.5 Atlantic tuna - ICCAT

ICCAT covers the tuna fishery in both the Atlantic and the Mediterranean. Data presented originate form the ICCAT database. In this database information on fishing fleets, effort and landings is available at different levels of coverage for both the Atlantic and the Mediterranean. As there is no high sea area in the Mediterranean, the fishing activities in this area are not taken into account in this chapter as far as possible (catches and value).

Summary for 2005:

- Total landings: 570,000 t
- Catches in international waters: data available but no distinction between high seas and EEZs
- Countries involved: Spain, Ghana, France and many others
- Total value of production: 630 million Euro
- Total income generated: 350 million Euro
- Total employment: 50,000-100,000 persons
- IUU estimated at 1-5% of the legal fishery

Fleet and effort

According to ICCAT statistical Bulletin, the registered tuna fleet consisted of some 6,000 vessels, of which 2,500 longliners, 125 purse seiners and over 500 pole & line vessels in 2005. The following comments can be made:

- Information on the fleet and effort is problematic for the ICCAT area. In February 2008 an ICCAT meeting on this subject is scheduled, but as this information was not yet available, information available from the Statistical Bulletin (1950 – 2005) and from the electronic vessel register available at the ICCAT website is used (Table 4.1). The total number of large scale (>24m) vessels registered in 2005 was 5921 and around 2000 in the period 2006-2008. The total of 2005 includes many vessels operating under flags of convenience: Granada and Trinidat and Tobago, approx 2000 vessels.
- The 2005 list also includes 700 Cuban vessel (recreational and trammel net vessels), which are most probably only fishing in the Cuban EEZ.
- In the fleet register no distinction is made between vessels operating in the Atlantic and the Mediterranean. It can be assumed however that the Greek (472) and Maltese vessels (435) operate predominantly in the Mediterranean.

Table 3.5.1 Active fleet (number of vessels), 2005 and range of vessels in register in period 2006-2008*

Country	Longline	Purse seine	Pole&line	Other	Total	Total 2006-2008
Spain			207		207	432-444
Ghana		9	26		35	0-32
France						45-45
Brasil	63	7	35		105	3-36
Chinese Taipei	139				139	0-38
Japan	248				248	97-456
EC.Portugal	69		224		293	55-57
U.S.A.	112	5		29	146	0-155
Other	2072	109	137	2576	4894	
Total	2591	125	629	2576	5921	2012-2094

Sources: Data from vessel register at ICCAT website (http://www.iccat.int/vessels.asp), total number of vessels per Country.

Information on effort is only available for part of the fishing fleets and information is scattered, so that extrapolation to total fishing effort is impossible.

Catches

The total catch in the ICCAT region is estimated at around 570,000 t. The four main tuna species attribute more than two thirds of the total catch. Spain, Ghana and France are the most important fishing nations in this area, but their total catch only contributes 40% to the total catch. A large number of other countries is taking relatively small part of the total catch. Appendix 3.1 lists all reported catches in the region. Figure 3.5.1 to 3.5.9 provide information on the distribution of the catches for 9 different species.

Table 3.5.2 Catches by country and species in ICCAT, 2005 (1000 t)

	Skipjack	Yellowfin	Bigeye	Albacore	Other	**Total**
Spain	28,1	11,8	7,6	20,7	39,7	**107,9**
Ghana	44,7	17,5	13,9	0,0	7,1	**83,2**
France	14,8	22,7	2,8	8,6	13,2	**62,2**
Brazil	26,4	7,2	1,1	0,6	10,7	**46,0**
Chinese Taipei	0,0	3,6	12,0	13,3	2,5	**31,4**
Japan	0,0	4,5	14,8	1,7	7,5	**28,4**
Portugal	4,7	0,2	4,1	0,6	14,7	**24,2**
U.S.A.	0,0	5,6	0,5	0,5	16,8	**23,4**
Other	37,8	33,3	16,0	8,7	112,6	**208,4**
Total	**156,7**	**106,3**	**72,7**	**54,7**	**177,0**	**567,4**

Source: ICCAT database

Most of the tuna catches are realized by longliners and purse seiners. Baitboats target predominantly skipjack and trolling vessels target albacore.

Table 3.5.3 Catches by gear and species in ICCAT, 2005 (1000 t)

	longline	purse seine	baitboat	trolling	Other	**Total**
Skipjack	0,7	84,4	69,1	0,3	2,2	**156,7**
Yellowfin	22,1	60,2	15,9	0,3	7,3	**105,8**
Bigeye	38,9	18,2	15,1	0,0	0,5	**72,7**
Albacore	19,2	0,6	15,5	10,2	9,1	**54,7**
Other	98,8	6,2	6,6	3,9	59,5	**174,9**
Total	**179,6**	**169,7**	**122,3**	**14,7**	**78,6**	**564,8**

Source: ICCAT database

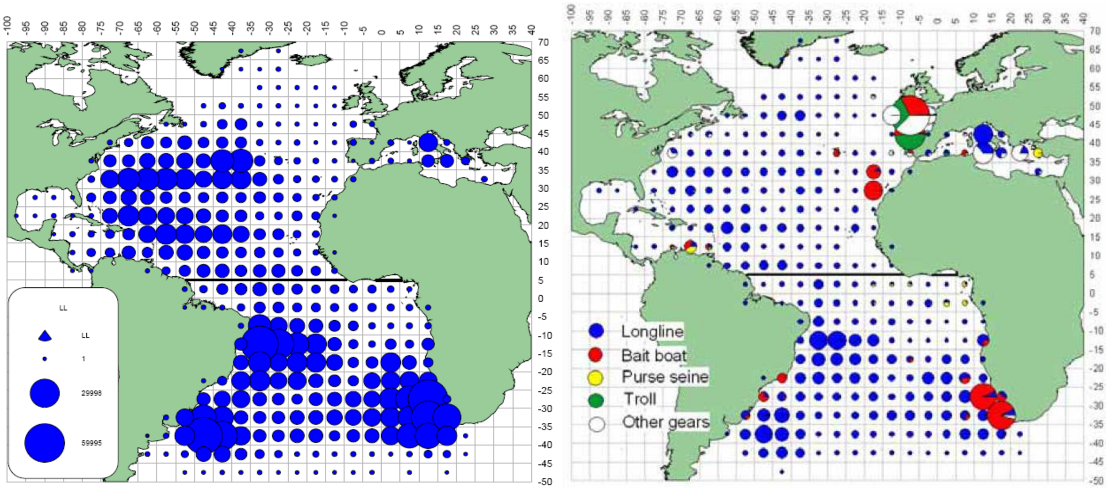

Figure 3.5.1 Geographical distribution of albacore catches (*Thunnus alalunga*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

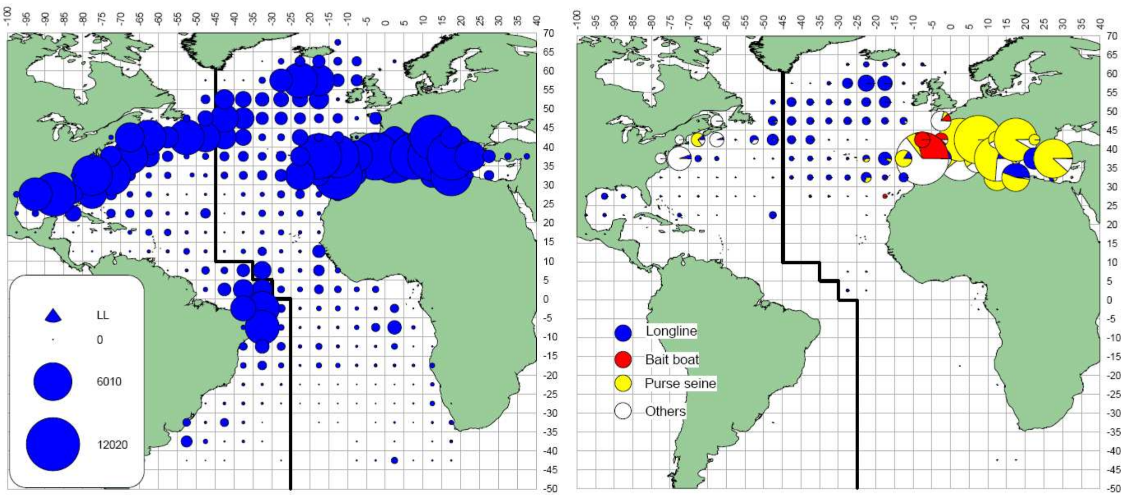

Figure 3.5.2 Geographical distribution of bluefin catches (*Thunnus thynnus*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

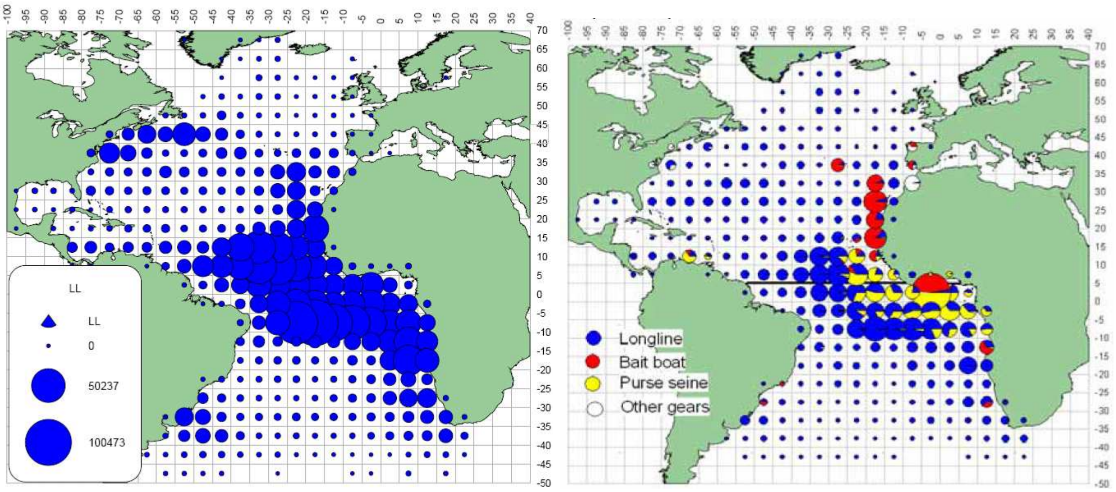

Figure 3.5.3 Geographical distribution of bigeye tuna catches (*Thunnus obesus*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

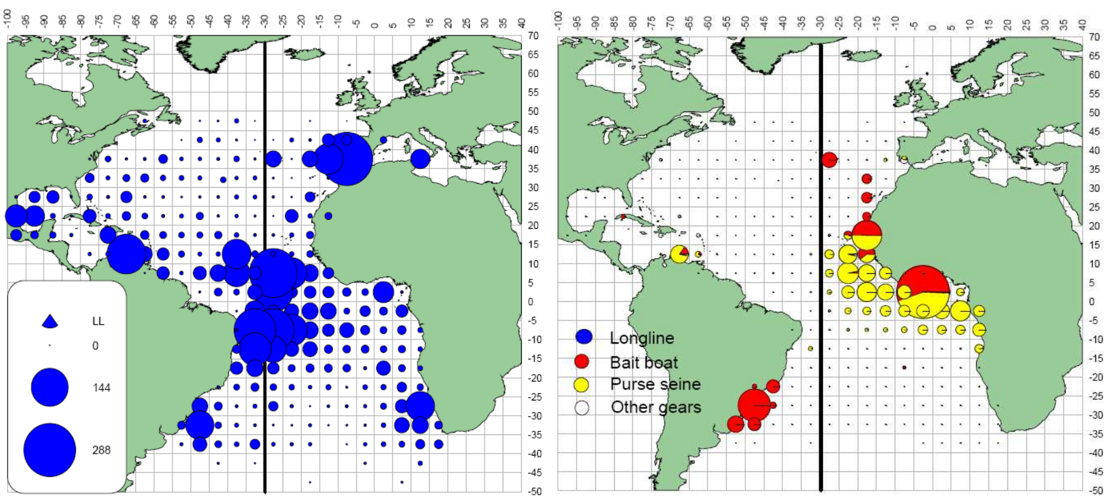

Figure 3.5.4 Geographical distribution of skipjack catches (*Katsuwonus pelamis*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

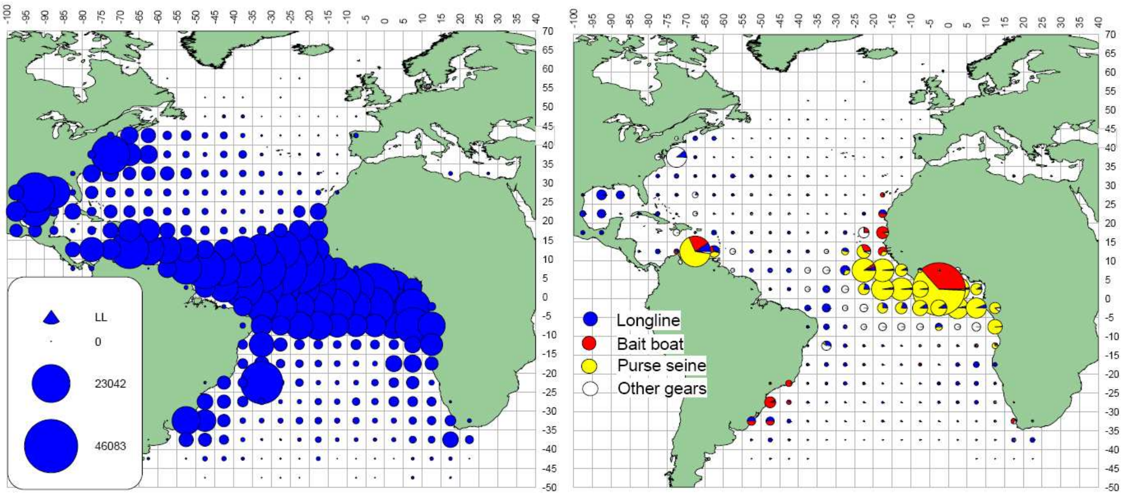

Figure 3.5.5 Geographical distribution of yellowfin catches (*Thunnus albacares*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

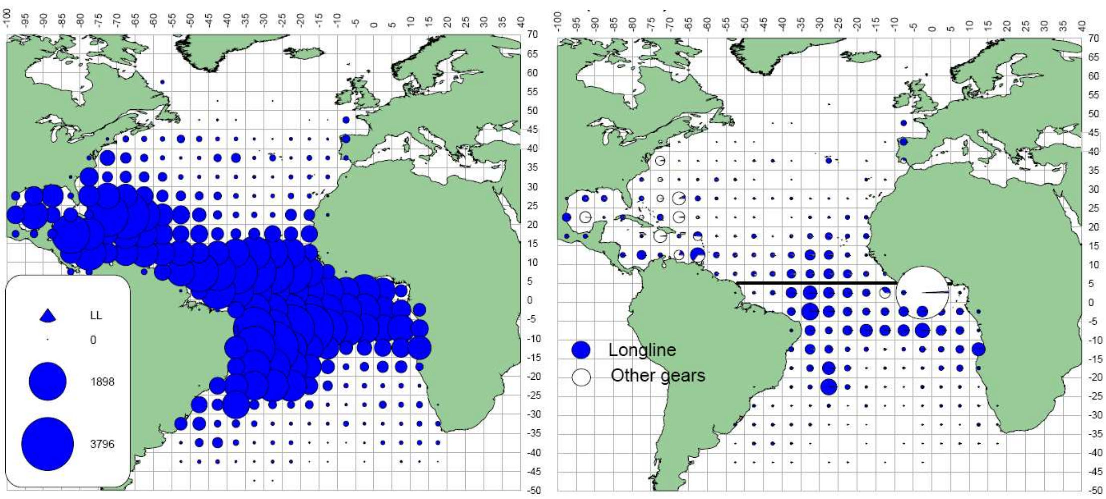

Figure 3.5.6 Geographical distribution of blue marlin catches (*Makaira nigricans*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

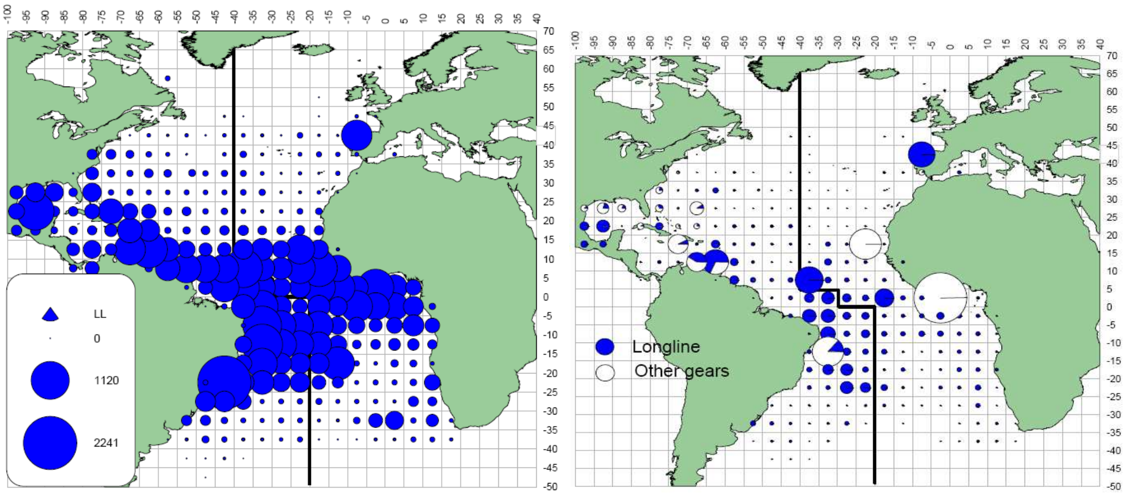

Figure 3.5.7 Geographical distribution of sailfish catches (*Istiophorus albicans*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

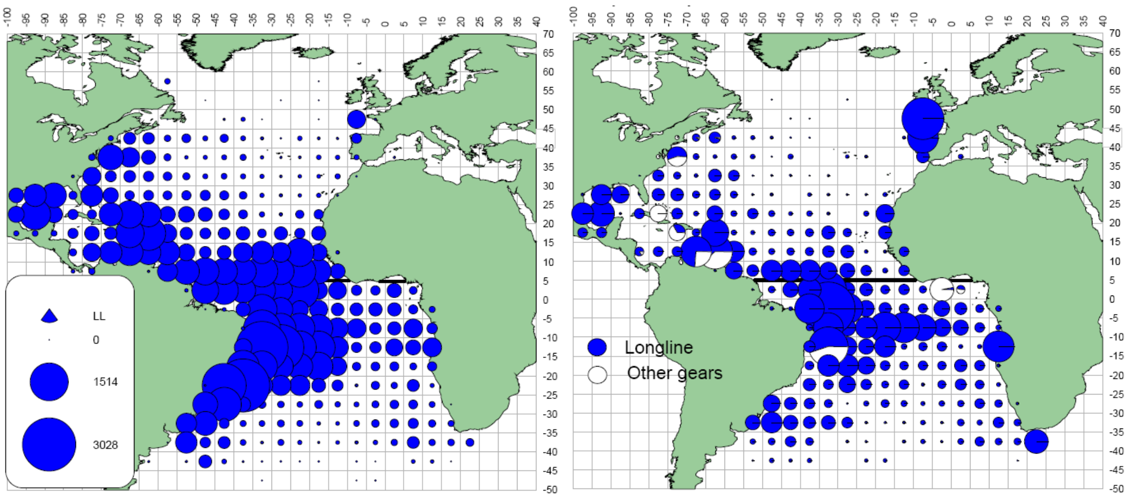

Figure 3.5.8 Geographical distribution of white marlin catches (*Tetrapturus albidus*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

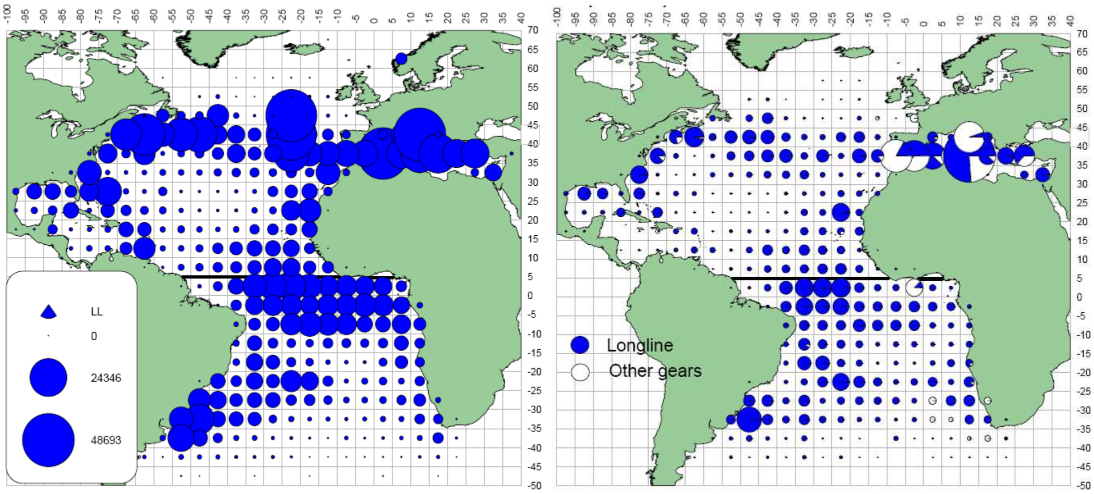

Figure 3.5.9 Geographical distribution of swordfish catches (*Xiphias gladius*) by all gears for the period 1950-2004 (left panel), and by gear for 2000-2004 (right panel). From ICCAT 2007, Statistical Bulletin Vol. 36.

Value, income and employment

The total value of the catch is estimated at 630,000 Euro. Yellowfin is the most important species in terms of value, because of its relative high price. Because of its' low price, skipjack is second most important. The main producers of tuna in this area are Spain, Ghana, France and Japan. These countries contribute around 50% to the total value of the catch. Because of its' high price bluefin tuna is the third most important species. The most important gears are longline and purse seine.

Table 3.5.4 Value by country and species in ICCAT, 2005 (million Euro)

	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin	Other	**Total**
Spain	16,9	13,0	9,1	22,8	21,7	43,9	**127,4**
Ghana	26,8	19,2	16,7	0,0	0,0	8,5	**71,3**
France	8,9	24,9	3,4	9,5	5,7	14,8	**67,3**
Japan	0,0	4,9	17,7	1,9	20,8	5,4	**50,8**
Brazil	15,8	7,9	1,3	0,6	0,0	12,9	**38,5**
Chinese Taipei	0,0	4,0	14,4	14,6	0,1	3,0	**36,0**
U.S.A.	0,0	6,1	0,6	0,5	5,9	19,2	**32,4**
Portugal	2,8	0,2	4,9	0,7	0,5	17,5	**26,6**
Other	22,7	36,6	19,2	9,5	21,3	74,2	**183,6**
Total	**94,0**	**116,9**	**87,3**	**60,1**	**76,1**	**199,4**	**633,9**

Source: Own estimation

Table 3.5.5 Value by country and gear in ICCAT, 2005 (million Euro)

	longline	purse seine	baitboat	trolling	Other	**Total**
Spain	44,0	26,7	37,8	12,5	6,3	**127,4**
Ghana	0,0	36,4	33,3	0,0	1,6	**71,3**
France	0,0	34,7	2,7	0,0	29,8	**67,3**
Japan	50,8	0,0	0,0	0,0	0,0	**50,8**
Brazil	17,6	1,3	18,4	0,0	1,3	**38,5**
Chinese Taipei	36,0	0,0	0,0	0,0	0,0	**36,0**
U.S.A.	7,2	1,4	0,0	2,8	21,0	**32,4**
Portugal	18,0	0,0	7,8	0,0	0,8	**26,6**
Other	57,0	52,6	13,8	31,6	28,6	**183,6**
Total	**230,7**	**153,0**	**113,8**	**47,0**	**89,5**	**633,9**

Source: Own estimation

The total income generated by the fisheries in ICCAT is estimated at 350 million Euro. Based on the number of vessels registered in 2005 the total employment is somewhere between 50,000 en 100,000 persons.

Table 3.5.6 Income and employment by country in ICCAT, 2005

Country	Income (million Euro)	Employment (1000 persons) [1)]	
		Minimum	Maximum
Spain	70	1.2	5.2
Ghana	39	0.3	0.9
France	37	0.0	0.0
Japan	21	1.3	2.6
Brazil	20	2.1	3.5
Chinese Taipei	28	3.7	6.2
U.S.A.	15	2.4	7.3
Portugal	18	1.8	3.2
Other	101	39.0	78.6
Total	**349**	51.9	107.4

Source: Own estimation [1)] Employment data indicate the approximate crew on board the given fleet. This does not mean that the crew has a corresponding nationality.

IUU

According to MRAG (2005,p.)[9] the IUU in the ICCAT region can be assumed at 5-15%. It states:

IUU on bluefin tuna has dropped to relatively low levels of about 1% of the reported catch (Restrepo, 2004). These estimates were made using reconciliation of Trade Statistics and the document system statistics. The IUU catch of bigeye tuna has also dropped since the introduction of the document scheme, although it is still estimated at about 5% of reported catches. If we assume the same for yellowfin tuna, we can estimate that there may be between 5000 and 10000 t of these tunas being taken by IUU vessels in the Atlantic. There are currently no estimates for skipjack tuna IUU in the Atlantic.

Based on this information and the total value of landing made here, the total value of tuna caught by IUU fisheries is around 10-15 million €.

EEZ and international waters

Although it does say at the statistics webpage (http://www.iccat.int/accesingdb.htm), ICCAT statistics do not explicitly distinguish between high seas catches and catches within EEZ. Spatial information on catches can be found in the ICCAT database, but a detailed analysis to estimate the catches in the high seas was outside the scope of this study.

3.6 Western and central pacific - WCPFC

Tuna fisheries in the Western and Central Pacific (WCPO) are managed by WCPFC. Presented data on catches and landings originates from the WCPFC database. The database provides information only for the four main tuna species. Data on accompanying catches (mainly billfish and seerfish) is not available / accessible.

Summary for 2005:

- Total landings of 4 main tuna species: 2.2 million t
- Catches in international waters: 500,000 t

9 MRAG, Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries, Final Report to DFID, July 2005.

- Countries involved in international waters: Japan, Korea, Taiwan
- Total value of tuna production: 1.5 billion Euro
- Total income generated: 0.8 billion Euro
- Total employment: 105,000 - 175,000 people
- IUU estimated at 5-15% of the legal fishery

Fleet and effort

According to WCPFC[10] the tuna fleet allowed to operate in the WCPO was composed of some 7,000 vessels, of which 5,000 longliners, 1,400 purse seiners and over 500 pole & line vessels. The following comments can be made:

- The fleets of Philippines and Indonesia operate mostly within the national EEZ and may be composed of relatively smaller vessels.
- Most of the catch is in international water is realized by longliners and purse seiners from Japan, Taiwan and Korea. However, how many of these vessels are really active (full or part time) in the region is not known.

Table 3.6.1 Active fleet in WCPO (number of vessels), 2005

Country	Longline	Pole&line	Purse seine	**Total**
Japan	1,470	390	53	**1,913**
Philippines [1) 2)]	14		175	**189**
Indonesia [1)]	894	84	1,035	**2,013**
Taiwan	1,554		34	**1,588**
Korea	153		28	**181**
Papua New G.	51		41	**92**
Vanuatu	55		8	**63**
USA	165	6	15	**186**
Other	659	64	41	**764**
Total	**5,015**	**544**	**1,430**	**6,989**

Source: WCPFC Yearbook 2005

1) Probably mostly fishing within the national EEZ.

2) The fleet of the Philippines seems too small in relation to its catch

Table 3.6.2 Fishing effort in WCPO, 2005

Country	Longline (million hooks)	Pole&line (days)	Purse seine (days)
Japan	104.4	19,709	8,603
Philippines			
Indonesia			
Taiwan	78.8		8,205
Korea	112.5		7,174
Papua New G.	7.6		9,886
Vanuatu *			1,850
USA			3,184
Other [1)]	42.0	1,098	2,454
Total	345.3	20,807	41,356

Source: WCPFC, Tuna bulletin 2007/7, * Yearbook 2005.

1) Probably incomplete

10 Annual Report 2005

Catches

The total catches of tuna amounted in 2005 to 2.2 million t, of which about 70% skipjack (mostly destined for canning) and 30% the more valuable tuna species. There is no consistent data on catches of the highly prized bluefin tuna. About 90% of the tuna fishery in the WCPO is carried out by 8 countries. Three countries dominate the high seas fishing, namely Japan, Taiwan and Korea.

Long term trends show that the tuna fishery in the WCPO developed quite gradually till approximately 1978/80. Till those years Japanese longline fleet played a very dominant role. The purse seine was introduced into the fishery at the end of the seventies, targeting in particular skipjack. Although Japan still remains the most important fishing nation in the area, other countries have started exploiting tuna resources as well. The distribution of the catches by different gears is shown in Figures 3.6.1 to 3.6.3.

Table 3.6.3 Catches by country and species in WCPO, 2005 (1000 t)

	Albacore	Bigeye	Skipjack	Yellowfin	**Total**
Japan	57.6	38.6	343.2	47.6	**486.9**
Philippines	0.0	22.9	170.4	119.4	**312.6**
Indonesia	0.0	27.3	182.5	52.0	**261.8**
Taiwan	13.5	17.4	170.1	47.9	**249.0**
Korea	3.9	18.2	171.6	49.0	**242.7**
Papua New G.	2.1	9.8	166.3	44.9	**223.2**
Vanuatu	9.3	2.6	62.1	11.1	**85.1**
USA	1.0	9.4	53.0	17.8	**81.2**
Other	28.3	17.4	149.2	39.7	**234.5**
Total	**115.7**	**163.5**	**1,468.3**	**429.3**	**2,176.9**

Source: WCPFC Yearbook 2005

Purse seine is by far the most productive gear, accounting for almost 70% of the catch of the four registered tuna species. Some 80% of purse seine catch is composed of skipjack. Yellowfin tuna is the second most important species, accounting for 20% in volume. About half of yellowfin catches is realized with purse seine.

Table 3.6.4 Catches by gear and species in WCPO, 2005 (1000 t)

	Longline	Pole&line	Purse seine	Other	**Total**
Skipjack	5.1	147.0	1,234.6	81.6	**1,468.3**
Yellowfin	74.5	14.9	231.8	108.1	**429.3**
Bigeye	84.9	8.6	42.3	27.8	**163.5**
Albacore	74.0	35.0	0.9	5.8	**115.7**
Total	**238.4**	**205.5**	**1,509.7**	**223.3**	**2,176.9**

Source: WCPFC Yearbook 2005

Value, income and employment

The value of the tuna production in WCPO is estimated at about 1.7 billion Euro in 2005. Our estimate is supported by an estimate by FFA[11].

[11] http://www.ffa.int/node/862. FFA puts the landings value in 2005 at 3.1 billion US$, i.e. 2.5 billion Euro. However, the FFA estimate is based on wholesale prices on the markets of destination and consequently includes trade margins and costs of insurance and freight. We have assumed these costs at about 35% of the wholesale price, in which case the FFA equivalent would amount to about 1.8 billion Euro in terms of ex-vessel prices.

Skipjack is the most important species in terms of value, despite its lower price, accounting for about 50% of the total fishery. Five countries have major commercial interests in WCPO tuna fishery. Japan, Taiwan and Korea have interests in international fishing. Philippines and Indonesia rely primarily domestic fleets.

Table 3.6.5 Value by country and species in WCPO, 2005 (million Euro)

	Albacore	Bigeye	Skipjack	Yellowfin	**Total**
Japan	63.4	46.3	205.9	52.4	**368.0**
Philippines	0.0	27.5	102.2	131.3	**261.1**
Indonesia	0.0	32.8	109.5	57.2	**199.5**
Taiwan	14.9	20.9	102.1	52.7	**190.5**
Korea	4.3	21.8	103.0	53.9	**183.0**
Papua New G.	2.3	11.8	99.8	49.4	**163.2**
Vanuatu	10.2	3.1	37.3	12.2	**62.8**
USA	1.1	11.3	31.8	19.6	**63.8**
Other	31.1	20.9	89.5	43.7	**185.2**
Total	**127.3**	**196.3**	**881.0**	**472.3**	**1,677.0**

Sources: own estimate (see appendix 3.1)

Table 3.6.6 Value by country and gear in WCPO, 2005 (million Euro)

	Longline	Other	Pole&line	Purse seine	**Total**
Japan	75.3	14.9	110.6	167.1	**367.8**
Philippines	3.9	148.4		108.7	**261.0**
Indonesia	20.9	35.6	37.6	105.4	**199.4**
Taiwan	57.5	1.0		132.1	**190.6**
Korea	37.7			145.2	**182.9**
Papua New G.	3.7			159.6	**163.3**
Vanuatu	13.2			49.6	**62.8**
USA	6.4	1.0	0.3	56.0	**63.7**
Other	49.6	6.7	4.9	123.9	**185.2**
Total	**268.2**	**207.6**	**153.4**	**1,047.6**	**1,676.8**

Sources: own estimate (see appendix 3.1)

The fishery generates an income of approximately 1 billion Euro, assuming that in addition to the four mentioned species some 20-25% is further generated by accompanying catches. The fishery provides employment to 100-175,000 people, most of whom on board Indonesian, Japanese and Taiwanese vessels.

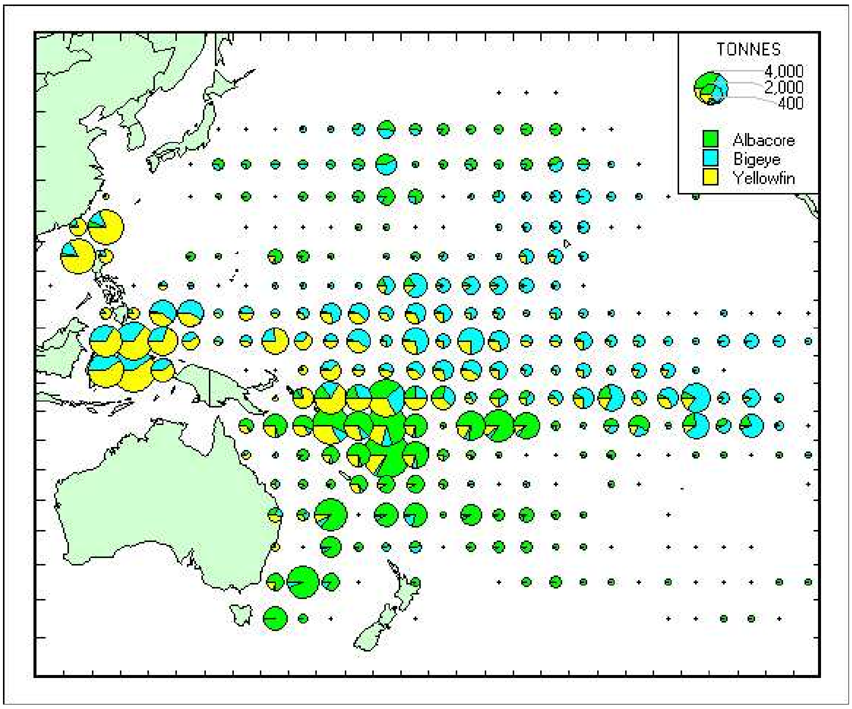

Figure 3.6.1 Longline catches of albacore, bigeye and yellowfin tuna in 2005 (from: WCPFC, Western and Central Pacific Tuna Bulletin, July 2007).

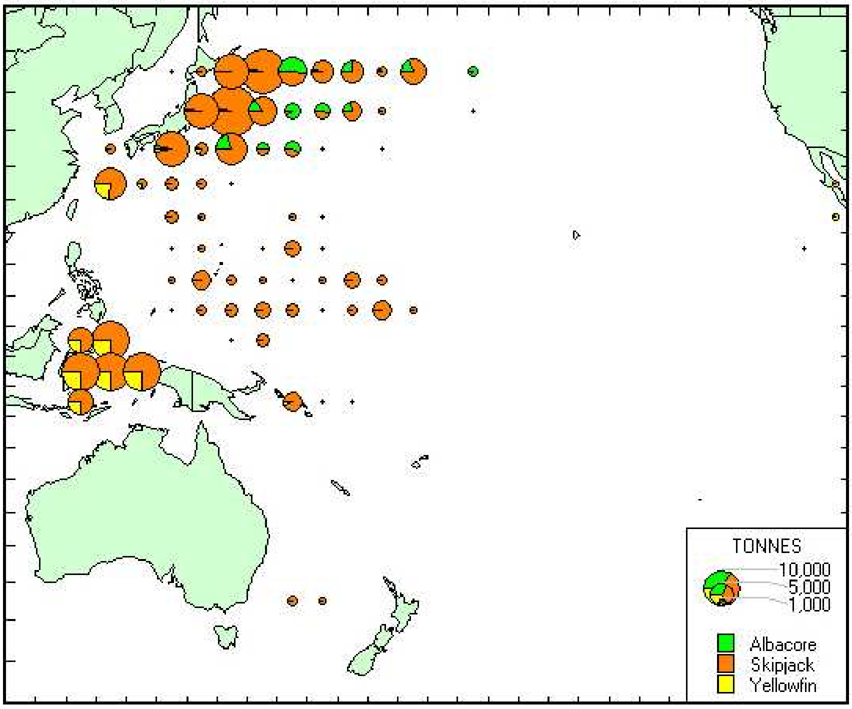

Figure 3.6.2 Pole-and-line catches of albacore, bigeye and yellowfin tuna in 2005 (from: WCPFC, Western and Central Pacific Tuna Bulletin, July 2007).

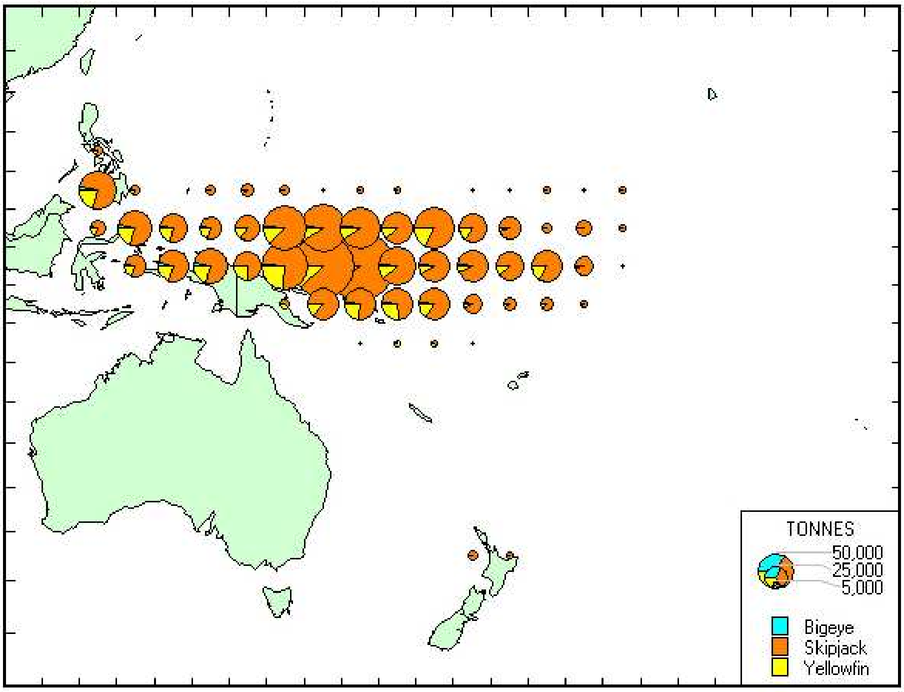

Figure 3.6.3 Purse seine catches of bigeye, skipjack and yellowfin tuna in 2005 (from: WCPFC, Western and Central Pacific Tuna Bulletin, July 2007).

Table 3.6.7 Income and employment by country in WCPO, 2005

Country	Income (million Euro) [2]	Employment (1000 persons) [3]	
		Minimum	Maximum
Japan	184.8	25.3	47.8
Philippines [1) 4)]	153.2	3.4	4.7
Indonesia [1)]	109.7	32.5	50.3
Taiwan	86.9	23.9	39.7
Korea	79.1	2.8	4.5
Papua New G.	63.3	1.5	2.3
Vanuatu	28.4	1.0	1.6
USA	26.9	2.8	4.7
Other	81.3	11.0	19.1
Total	**813.5**	**104.2**	**174.7**

Sources: own estimate (see appendix 3.1)
1) Domestic fishery, probably within EEZ
2) Based on 55% of estimated value of landings.
3) Employment data indicate the approximate crew on board the given fleet. This does not mean that the crew has a corresponding nationality.
4) Estimate of the employment in the Philippines is low due to the low number of registered vessels.

IUU

According to MRAG (2005,p.)[12] the IUU in the WCPO can be assumed at 5-15%. It states:

"In the Western Pacific, the bulk of IUU fishing probably occurs within EEZs and in particular within the waters of FFA members. This is mostly conducted by the vessels of distant water fishing nations, and there is likely to be some fishing by open register vessels in high seas waters (Richards 2004). FFA has not yet made an assessment of IUU fishing in its region, because of problems of standardising methodologies, but intends to initiate such a study in 2005 (A. Richards, pers. comm.). Greenpeace[13] has estimated the IUU catch in the Pacific to be between 100,000 and 300,000 t with an estimated value of $134 - 400M, although this is a general estimate "assuming a conservative 5-15% IUU."

On the basis of our estimate of the total value of the WCPO tuna fishery, value of IUU would be estimated at about 50-150 mln Euro (or 27-82 million Euro in terms of income), which includes fishing within as well as outside the EEZs.

EEZ and international waters

Tuna

FFA has published an overview presenting catch data by country and EEZ. According to FFA 1.65 million t of tuna is caught within the EEZ of WCPO countries, while only 510,000 t is caught in international waters. This would imply that only about 25% of the total value, income and employment generated by the tuna fishery depends on international waters.

12 MRAG, *Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries*, Final Report to DFID, July 2005.

13 http://weblog.greenpeace.org/pacific/background/pirate_threat.html. Greenpeace estimate is based on CIF prices in Bangkok and Japan and does not seem to consider transport and insurance costs and trade margins.

The interpretation of the table below is not entirely straightforward as the columns contain information which could be theoretically overlapping. However, assuming that most catches of the national fleet are realized, as far as possible, within the national EEZ we can draw the following conclusions:

- Indonesia, Philippines and PNG exploit largely their own resources and their fleets depend only marginally on EEZs of other countries in the region.
- Significant quantities of tuna are caught by foreign fleets in the EEZs of FSM, Kiribati, Solomon Islands and PNG.
- Fleets of Korea and Taiwan depend entirely on foreign waters. Approximately 75% of their catches is realized within the EEZs of FFA and 25% (about 120,000 t) in international waters. These two countries account for about 25% of the catches in international waters.
- Japan catches about 470,000 t, of which 130,000 in its own EEZ, 72,000 in FFA waters and 268,000 in international waters. This means that Japan alone accounts for more than 50% of the catches in international waters.

Table 3.6.8 Catches in WCPO by country and area (1000 t)

	National waters	National fleet	National fleet in FFA waters	FFA members in own waters
FFA				
FSM	187.7	27.8	22.6	6.9
Kiribati	209.1	9.2	7.7	2.1
Marshall Islands	25.0	56.2	38.3	4.1
Nauru	49.5	0	0	0
New Zealand	12.5	20.2	19.1	12.4
PNG	310.2	223.3	191.9	115.4
Solomon Islands	108.4	24.2	23.9	22
Vanuatu	9.2	85.2	61.9	1.3
Other	37.1	20.3	17.7	13.1
Sub-total FFA	***948.7***	***466.4***	***383***	***177.2***
Non-FFA				
Indonesia	263.3	261.8	0	
Japan	131.1	471.2	72.7	
Philippines	281.3	312.6	29.8	
Taiwan	6.0	246.0	184.0	
China	0	61.5	45.7	
Korea	0	243.0	178.2	
USA	0	81.2	53.8	
Other	17.7	15.3	1.4	
Sub-total non-FFA	***699.3***	***1,692.60***	***565.7***	
Total	**1,648.00**	**2,158.90**	**948.7**	**177.2**

Source: http://www.ffa.int/node/862

Catches of other species in international seas of WCPO region

Other species caught in international waters, either as by-catch of tuna (mainly longlining) or in directed fishery are sharks. According to FAO shark catches in the Western Pacific amounted to 92,000 t. However, a recent study[14] concludes that world wide catches may be 3-5 times higher than those reported to FAO. MRAG puts shark price at about 260 US$ / tonne (210 Euro). Value of shark landings ranges than between 20 mln Euro (FAO Fishstat) and about 100 mln Euro (5 times higher). It is not clear how much of the catch is realized within the EEZ and how much outside. The relative shares could be expected to be comparable to the tuna catches, which would put 25% in international waters. These figures show that the value of shark fishing (along with possible other species, mainly billfish and seerfish) is much lower than tuna, but still may contribute substantially (by an assumed 20-30%) to the total value of the WCPO fishery.

3.7 Eastern Pacific - IATTC

Tuna fisheries in the Eastern Pacific (EPO) are managed by IATTC. Presented data on catches and landings originates from the IATTC database. The database provides information not only for the main tuna species, but also for several other large pelagics like marlin, swordfish, sailfish, etc. However, in terms of volumes these 'Other' species are relatively unimportant individually and therefore have been grouped together.

Summary for 2005:

- Total landings: 740,000 t
- Catches in international waters: data available but no distinction between high seas and EEZs
- Countries involved: Ecuador, Mexico, Panama
- Total value of tuna production: 724 million Euro
- Total income generated: 400 mln Euro
- Total employment: 9,500 – 12,600
- IUU ???

Fleet and effort

The IATTC fleet register contains 3,742 vessels. However, the active fleet was composed in 2005 of 220 purse seiners, 4 pole&line vessels and an unpublished number of longliners and trollers.

Table 3.7.1 Active fleet in EPO (number of vessels), 2005

Country	Purse seine	Pole&line	**Total**
Ecuador	81		**81**
Mexico	59	4	**63**
Panama	25		**25**
Venezuela	26		**26**
Japan		na	
USA	2		**2**
Korea		na	
El Salvador	4		**4**

[14]Clarke, S.C, M.K. McAllister, E.J. Milner-Gulland, G. P. Kirkwood, C.G.J. Michielsens, D.J. Agnew, E.K. Pikitch, H. Nakano and M. S. Shivji (submitted) *Global Estimates of Shark Catches using Trade Records from Commercial Markets*. Proceedings of the National Academy of Sciences (submitted) (reference based on MRAG)

Other	28		**28**
Total	**220**	**4**	**224**

Source: IATTC, Document IATTC-75-06

Table 3.7.2 Fishing effort in EPO, 2005

Country	Purse seine (1000 m^3 well volume)	Longline and pole&line (mln hooks)
Ecuador	55.0	
Mexico	56.6	
Panama	32.3	
Venezuela	33.8	
Japan		71.7
USA	1.3	2.6
Korea		16.8
El Salvador	6.3	
Other	28.2	68.6
Total	**213.5**	**159.7**

Source: IATTC, DOCUMENT IATTC-75-06

Catches

Yellowfin, skipjack and bigeye tuna are by far most important and represent about 95% of the total tonnage.

Total catches of the large pelagic species in the EPO in 2006 amounted to some 740,000 t, of which 285,000 t was yellowfin caught by the purse seine fleet. In 2006 the catches dropped to 636,000 t. The purse seine fleet accounted for over 80% of all catches in that year. It must be stressed that it is not possible to distinguish between catches within and outside the national EEZs. The 2005 production was well above the long term average of 430,000 t, but a substantial decrease from the peak year 2003 when catches reached very exceptional levels of 850,000 t.

The long term trends show that historically yellowfin tuna was the most important species, but its catches decreased rapidly since 2002, while the catch of skipjack started increasing in 1994. Purse seining is by far the most important technology, while the role of longlining has be marginalized especially in the recent years. There has been a major shift in the role of the various flag states. USA was dominant until approximately 1980, when the ‘dolphin free’ regulations started gaining on importance. These regulations were strictly national, and a result of pressure from environmental groups. The vessels were gradually sold by the owners (usually big canneries), the canneries themselves moved to Asia in order to be closer to the fisheries, and because of cheaper labour costs[15]. USA was replaced by Ecuador, Mexico and a group of other countries. Japan, Korea and Taiwan play only a minor role in the EPO tuna fishery, contrary to many other regions.

Table 3.7.3 Catches by country and species in EPO, 2005 (1000 t)

	Yellowfin	Skipjack	Bigeye	Albacore	Other	**Total**
Ecuador	40.2	137.1	30.6	0.0	0.5	**208.4**
Mexico	113.4	32.9	0.0	0.0	6.2	**152.4**
Panama	32.1	28.6	13.4	0.1	1.2	**75.4**
Venezuela	42.2	14.3	0.1	0.0	0.0	**56.6**
Japan	4.3	0.1	21.1	2.8	4.4	**32.7**

15 See also Schoell, M. 1999. The Marine Mammal Protection Act and its role in the decline of San Diego’s tuna fishing industry. The Journal of San Diego History. Volume 45, nr 1.

USA	0.9	0.0	0.5	10.9	0.9	**13.3**
Korea	0.5	0.0	11.6	0.2	0.8	**13.1**
El Salvador	7.0	5.3	1.0	0.0	0.1	**13.5**
Other	44.2	46.6	33.8	10.9	39.4	**174.8**
Total	**284.8**	**264.9**	**112.2**	**24.8**	**53.5**	**740.3**

Source: IATTC database

Purse seine is by far the most important fishing gear accounting for almost 80% of the catches in the years 1997-2006. The distribution of the catches in the IATTC area is shown in Figure 3.7.1 to 3.7.7.

Table 3.7.4 Catches by gear and species in EPO, 2005 (1000 t)

	Longline	Pole&line	Purse seine	Troll	Unkn. / Oth.	**Total**
Yellowfin	10.4	1.8	268.6	0.0	4.0	**284.8**
Skipjack	0.2	1.3	261.6	0.0	1.8	**264.9**
Bigeye	43.4	0.0	68.7	0.0	0.0	**112.2**
Albacore	9.1	0.1	0.0	13.9	1.8	**24.8**
Other	24.9	0.0	7.1	0.0	21.6	**53.5**
Total	**88.1**	**3.2**	**606.0**	**13.9**	**29.2**	**740.3**

Source: IATTC database

Value, income and employment

The total value of the EPO fishery in 2005 is estimated at over 700 million Euro, with Ecuador and Mexico representing more than 50% of the total. Yellowfin tuna is economically the most important species. About 95% of the production is realized with purse seines.

Table 3.7.5 Value by country and species in EPO, 2005 (million Euro)

	Yellowfin	Skipjack	Bigeye	Albacore	Other	**Total**
Ecuador	44.2	82.3	36.7		0.6	**163.8**
Mexico	124.7	19.7			33.7	**178.2**
Panama	35.3	17.2	16.1	0.1	1.5	**70.1**
Venezuela	46.4	8.6	0.1		0.1	**55.1**
Japan	4.7		25.4	3.1	5.3	**38.5**
USA	1.0		0.6	12.0	1.6	**15.2**
Korea	0.6		13.9	0.2	1.0	**15.6**
El Salvador	7.7	3.2	1.2		0.2	**12.3**
Other	48.6	28.0	40.5	11.9	48.4	**177.5**
Total	**313.3**	**158.9**	**134.6**	**27.3**	**92.2**	**726.4**

Source: own estimation

Table 3.7.6 Value by country and gear in EPO, 2006 (million Euro)

	Longline	Pole&line	Purse seine	Troll	Unknown / Other	**Total**
Ecuador	0.0		163.8			**163.8**
Mexico		2.8	175.4			**178.2**
Panama	3.6		66.5			**70.1**
Venezuela			55.1			**55.1**
Japan	38.5					**38.5**
USA	1.0	0.1		10.0	4.1	**15.2**
Korea	15.6					**15.6**
El Salvador	0.0		12.3			**12.3**
Other	44.8		97.7	5.3	29.7	**177.5**
Total	**103.6**	**2.9**	**570.9**	**15.3**	**33.8**	**726.4**

Source: own estimation

Table 3.7.7 Income and employment by country in EPO (purse seine and pole&line), 2005

Country	Income (million Euro)	Employment (1000 persons)	
		Minimum	Maximum
Ecuador	90.1	1.5	2.1
Mexico	98.0	1.1	1.5
Panama	38.6	0.5	0.7
Venezuela	30.3	0.4	0.6
Japan	21.2		
USA	8.4		
Korea	8.6		
El Salvador	6.8		
Other	97.6	2.0	2.7
Total	**399.5**	**5.5**	**7.6**

Source: own estimation

The above estimation of employment excludes three fleet segments (longline, troll and other), which have caught about 130.000 t worth an estimated 150 million Euro. These fisheries have generated value added (income) of about 82 million Euro. A significant part of the fleets concerned originates in Japan, Korea, Taiwan and to lesser extent various Central and South American countries. This implies that artisanal fishing for tuna in the EPO area is probably not very significant. Therefore we propose to assume that these fleets employ about 4-5,000 persons, which implies a productivity of about 30 t/man or annual value of production of 25-30,000 Euro / man.

IUU

IATTC maintains list of vessels over 24 meter which were active in the EPO areas, without authorization (or which were involved in other illegal activities. At present this list contains 26 vessels, of which 2 purse seiners and 22 long liners. It is not clear whether it could be assumed that these vessel were all operating during 2005 (or any other recent year at the same time). Even if this fleet would be able to carry out a year round operation, the total catches would probably not exceed 10,000 t[16], i.e. 1.5-2% of the total catch in EPO region.

EEZ and international waters

Data on catches within and outside EEZ are not publicly available, although distribution maps of catches are published by IATTC. While such maps are difficult to interpret quantitatively, they provide a clear indication that a significant part of the catch (possibly 20-40% of skipjack and yellowfin) is realized within the EEZ.

16 Catch per purse seiner can be assumed at 1,500-2,000 t / year and for a 30 m longliner around 300 t.

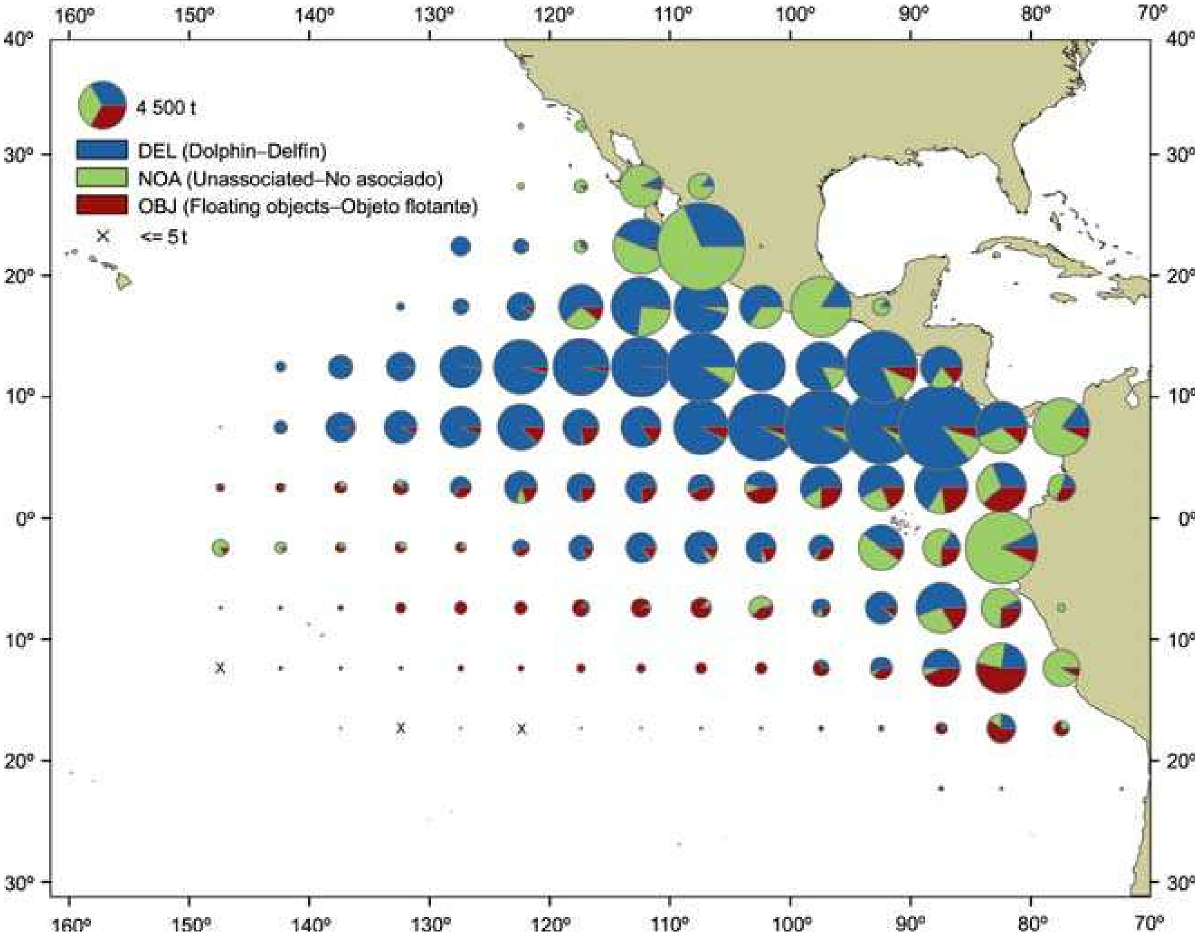

Figure 3.7.1 Average annual distributions of the purse-seine catches of yellowfin, by set type, 1990-2004. The sizes of the circles are proportional to the amounts of yellowfin caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006). Tunas are caught by purse-seine vessels in three types of schools, those associated with dolphins, those associated with floating objects, such as flotsam or FADs, and those associated only with other fish (unassociated schools) (see also Chapter 2.2).

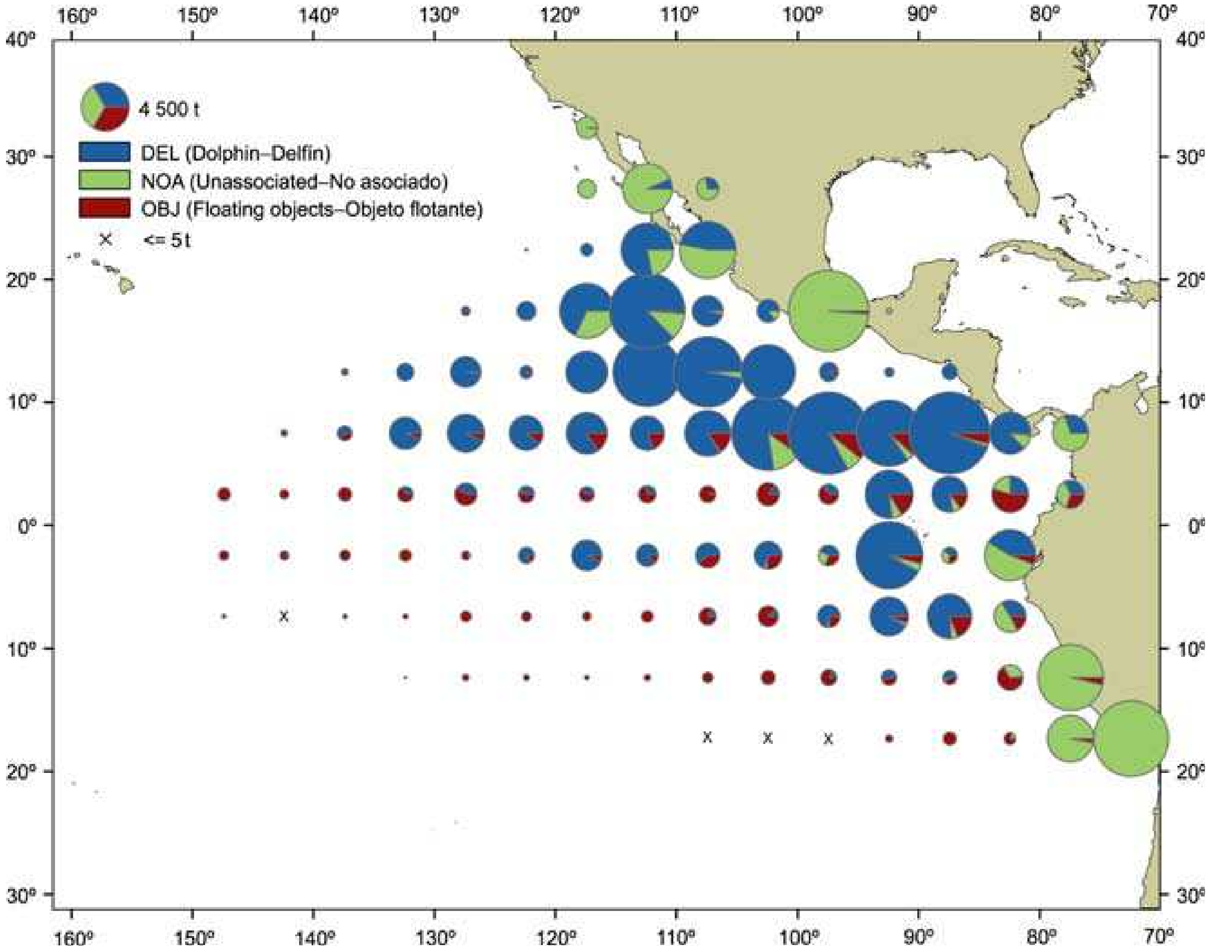

Figure 3.7.2 Average annual distributions of the purse-seine catches of yellowfin, by set type, 2005. The sizes of the circles are proportional to the amounts of yellowfin caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

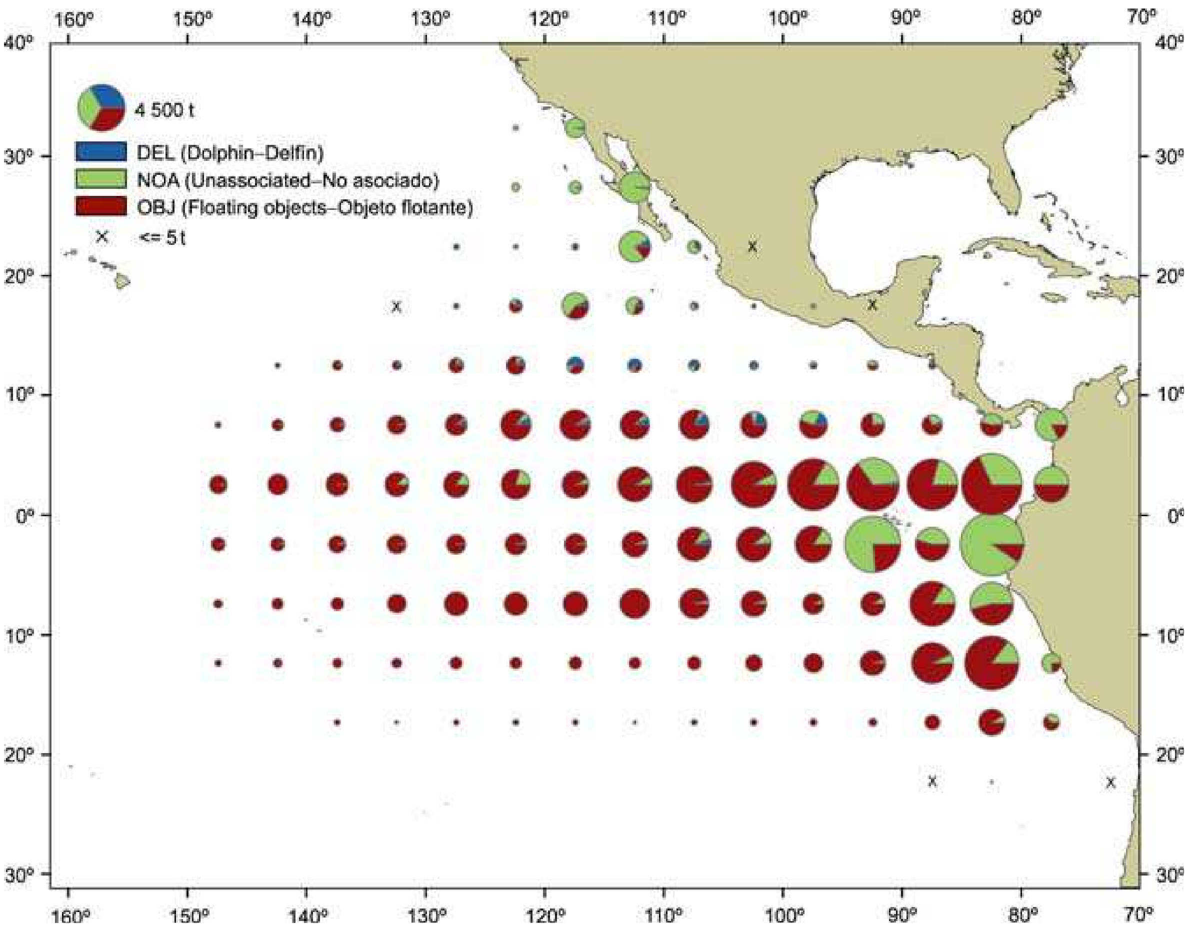

Figure 3.7.3 Average annual distributions of the purse-seine catches of skipjack, by set type, 1990 - 2004. The sizes of the circles are proportional to the amounts of skipjack caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

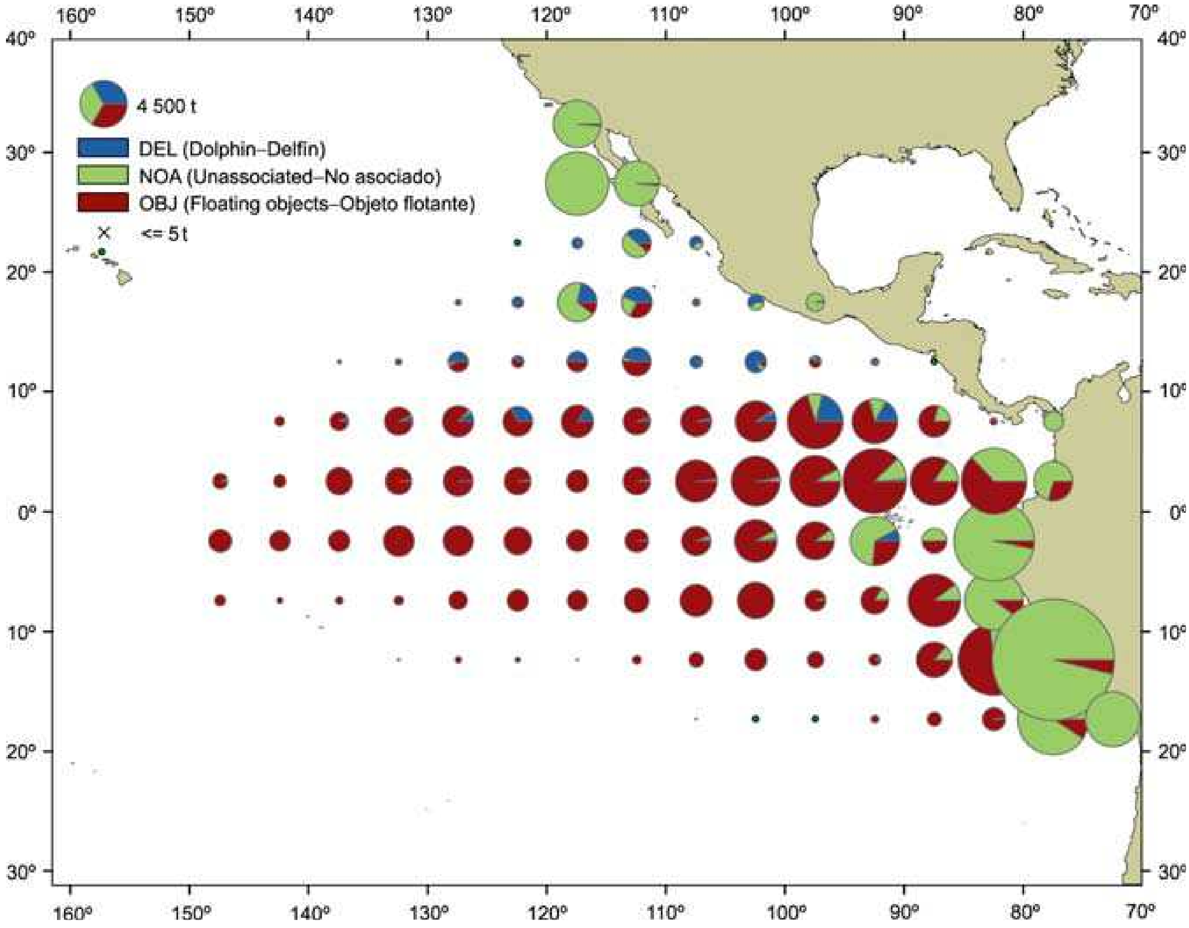

Figure 3.7.4 Average annual distributions of the purse-seine catches of skipjack, by set type, 2005. The sizes of the circles are proportional to the amounts of skipjack caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

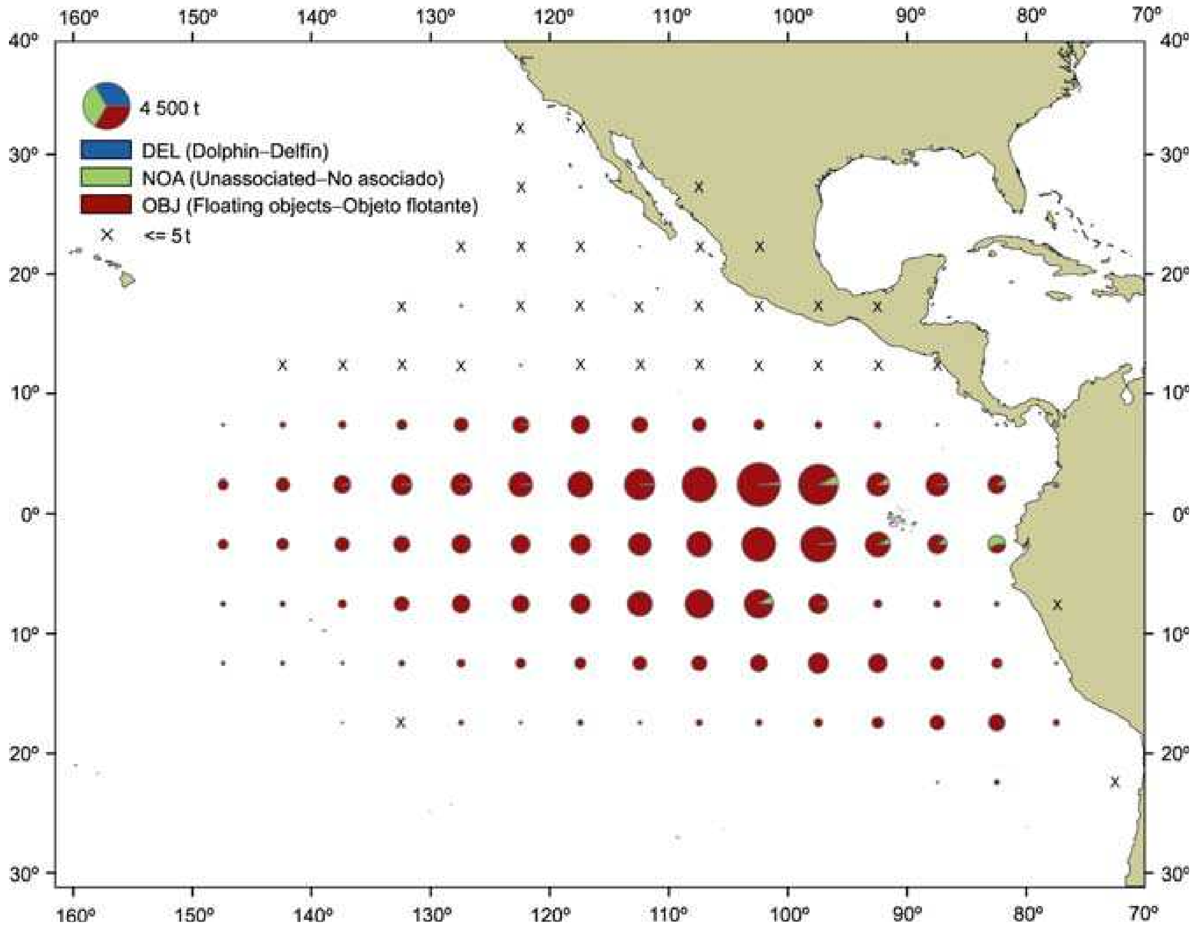

Figure 3.7.5 Average annual distributions of the purse-seine catches of bigeye, by set type, 1994 - 2004. The sizes of the circles are proportional to the amounts of bigeye caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

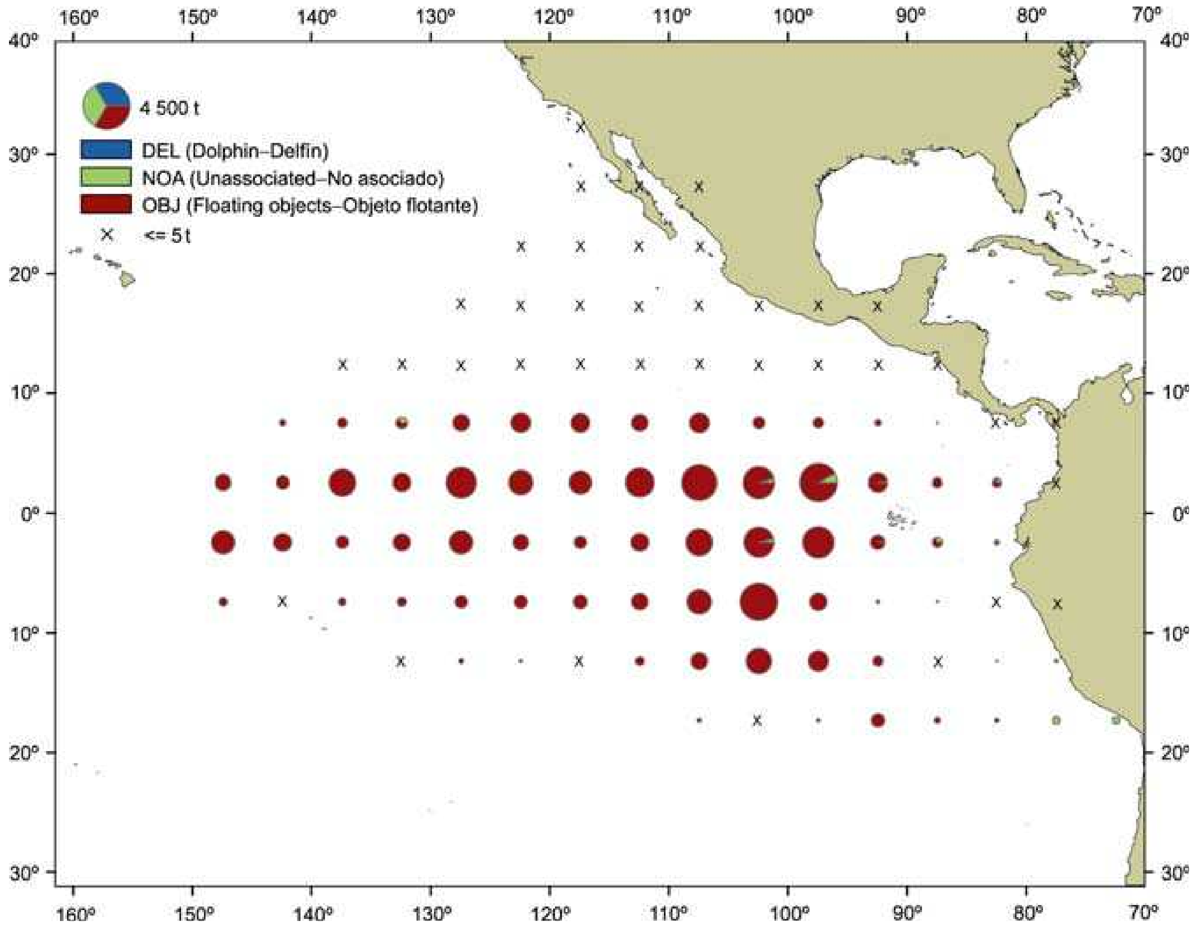

Figure 3.7.6 Average annual distributions of the purse-seine catches of bigeye, by set type, 2005. The sizes of the circles are proportional to the amounts of bigeye caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

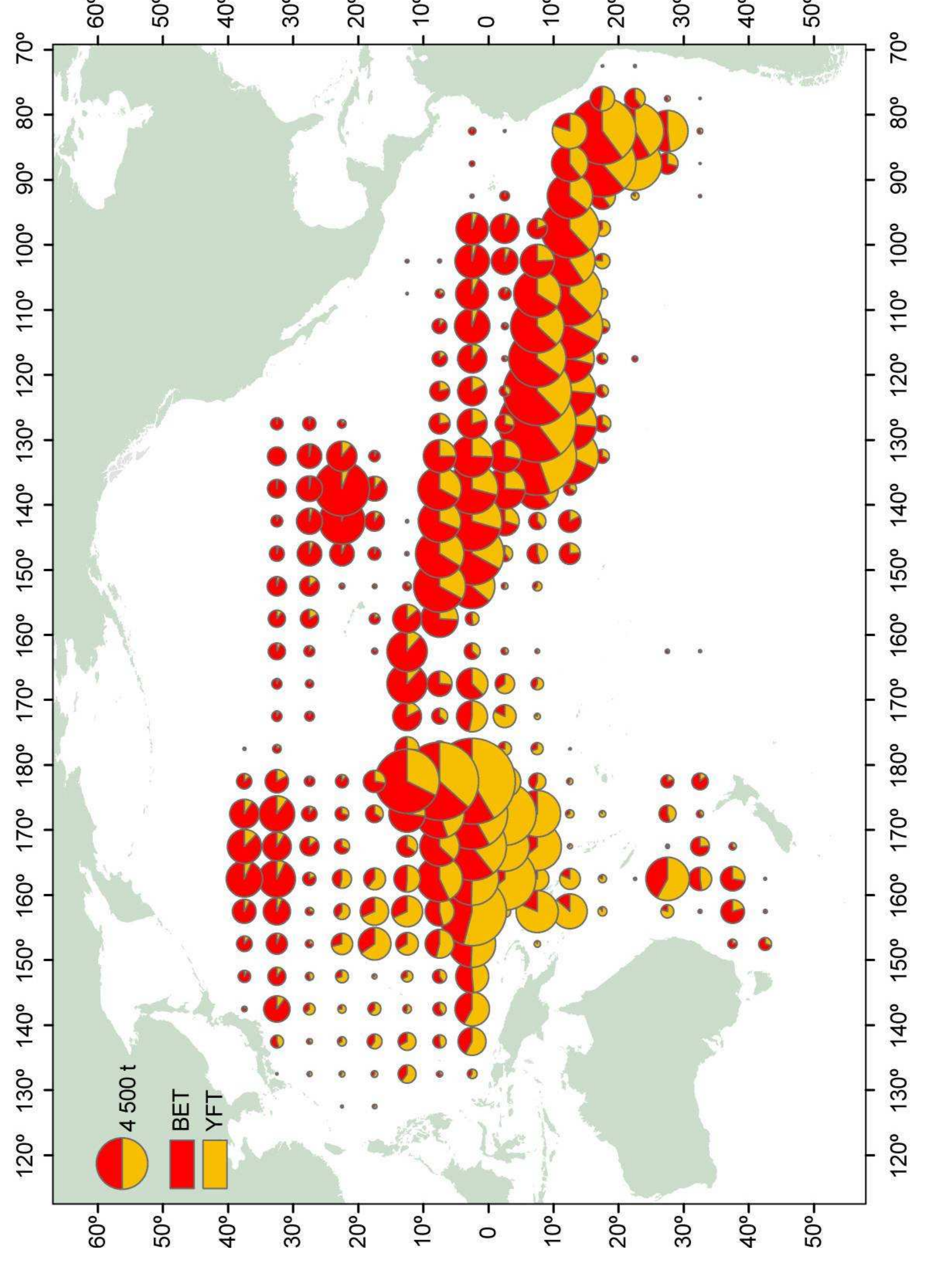

Figure 3.7.7 Distributions of the catches of bigeye and yellowfin tunas in the Pacific Ocean, in metric tons, by the Japanese longline fleet, 2000- 2004. The sizes of the circles are proportional to the amounts of bigeye and yellowfin caught in those 5° by 5° areas (from IATTC, Fishery Status Report No. 4, 2006).

3.8 Southern bluefin tuna - CCSBT

Fleets and catches

Fishery for the southern bluefin tuna is very small compared to the fisheries of other regions. The total catch amounted in 2005 to some 16,000 t. However, according the CCSBT "*Reviews of SBT farming and market data during 2006 suggest that southern bluefin tuna catches may have been substantially under-reported over the past 10-20 years.*"

The fleet register contains 1,700-2,100 vessels (depending on the reference date, between 2005 and 2007). However, a recent workshop[17] puts the 'entire fleet' at about 100 vessels. This seems more consistent with the value of this fishery which could be estimated at some 100 million Euro.

Table 3.8.1 Production by country and gear, 2005

Country	Tonnes		Gear	Tonnes
Australia	5,244		Longline	10,933
Japan	7,855		Purse seine	5,210
Indonesia	1,726		Troll	3
Other	1,320			
Total	16,146		Total	16,146

According to ABARE[18] the average price of southern bluefin tuna in Australia amounted in 2004-5 to 4,960 Euro/tonne. This means that the value of Australian production amounted to about 26 million Euro. If the entire fishery would be value at this price it would generate a total turnover of 80 million Euro and an approximate income of 44 million Euro.

Other topics

There is insufficient information to discuss other aspects of this fishery in detail. Some information on Taiwanese and Japanese catches is given in Figure 3.8.1 and 3.8.2.

[17] Report of the Second CPUE Modelling Workshop, 21 – 25 May 2007, Shimizu, Japan

[18] ABARE, Australian Fishery Statistics, 2005

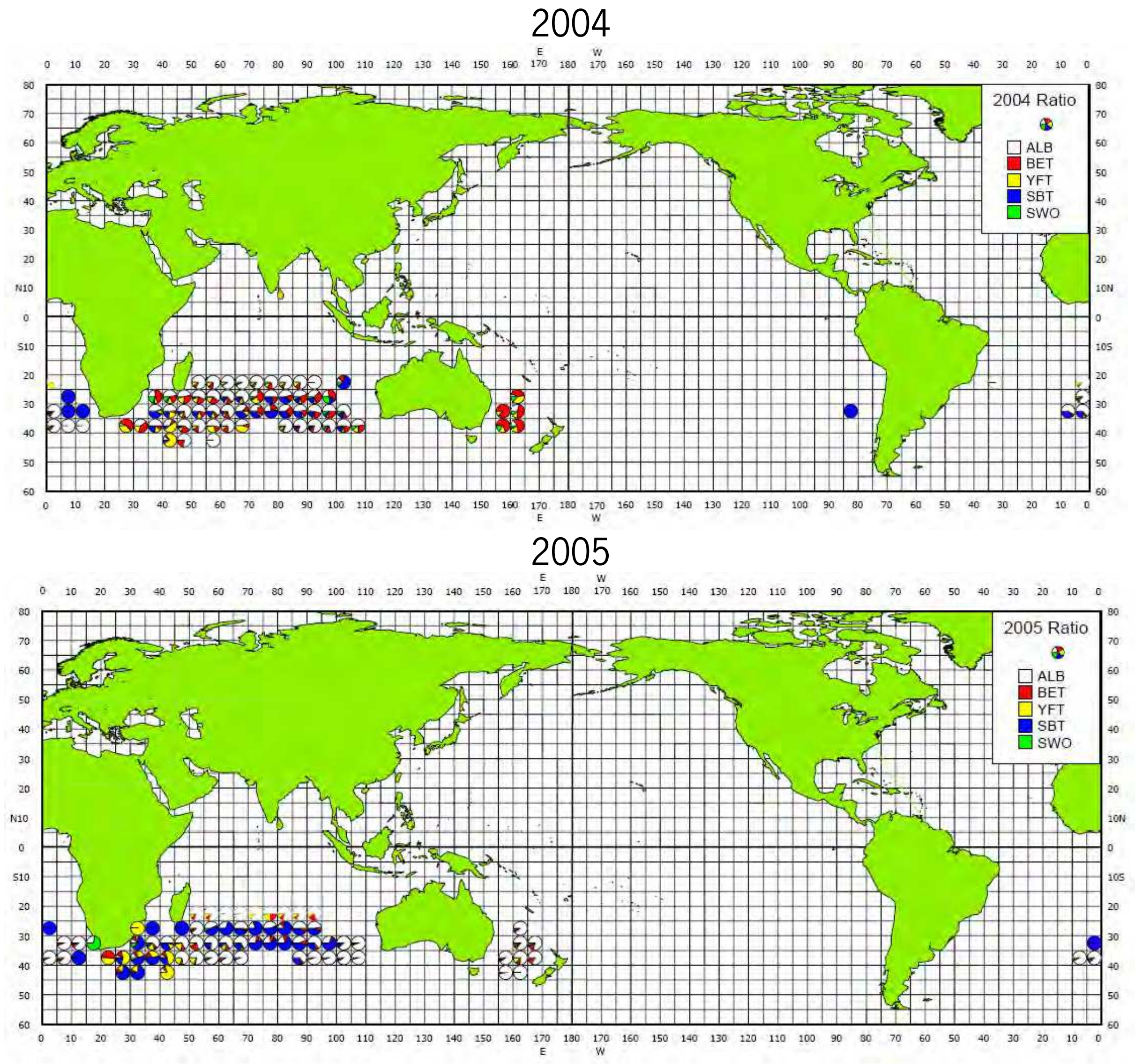

Figure 3.8.1 Catch composition of the Taiwanese fleet in 2004 and 2005. ALB albacore, BET bigeye tuna, YFT yellowfin tuna, SBT southern bluefin tuna, SWO swordfish (from CCSBT 2207, Report of the second CPUE modelling workshop).

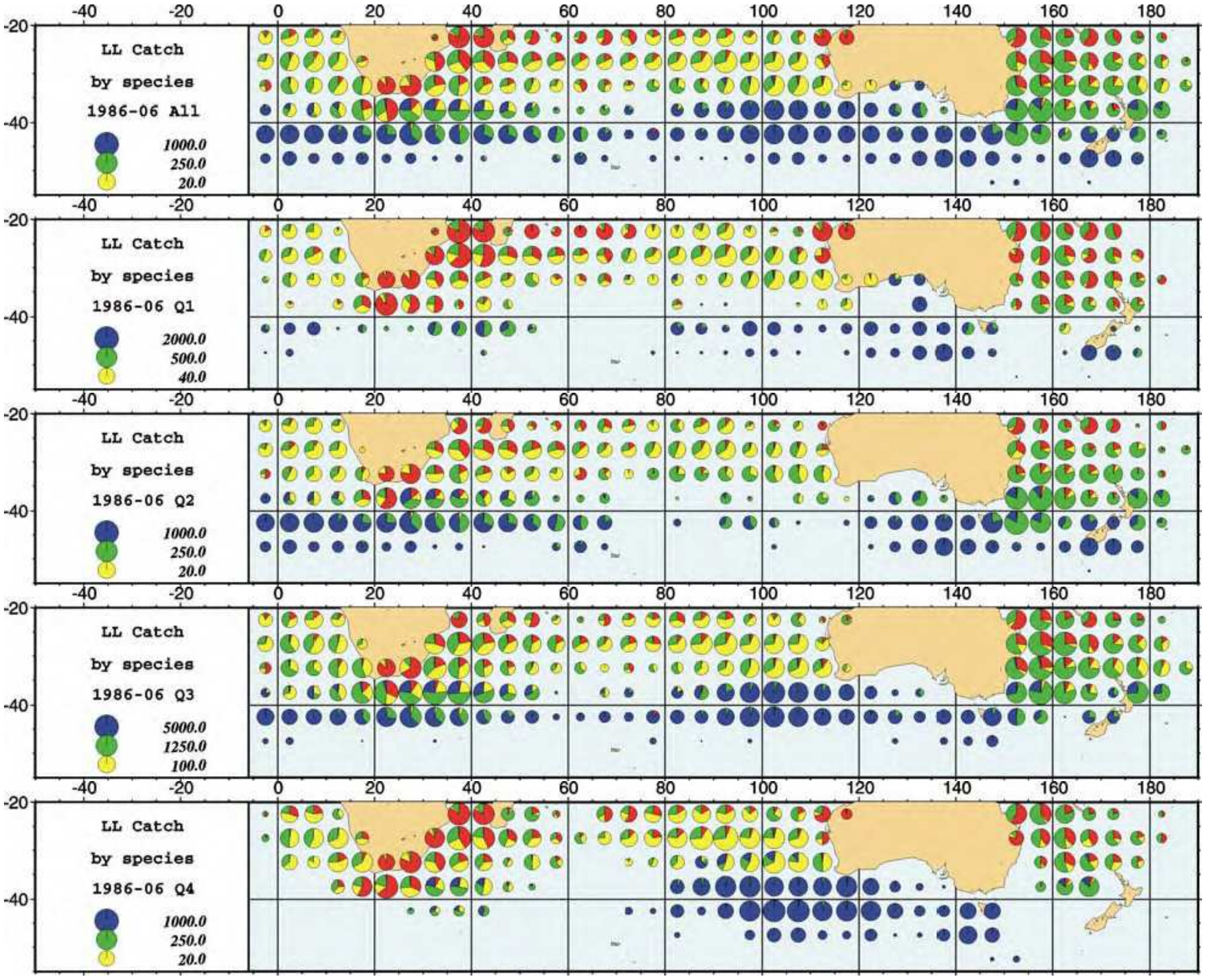

Figure 3.8.2 Species composition of the catch in the Southern Bluefin Tuna (SBT) fishery by Japan. Catch and effort-weighted mean latitude and month, based on 5x5 degree data. Blue : southern bluefin tuna; green: albacore; yellow: bigeye tuna; red: yellowfin tuna. (from CCSBT 2207, Report of the second CPUE modelling workshop).

3.9 Antarctic Fisheries - CCAMLR

Two specific, relatively small fisheries are carried out in the CCAMLR area, the fishery for krill and the fishery for toothfish. A limited number of countries are involved and the management is carried out by CCAMLR. Data on catches and effort by country, gear and area are available from the CCAMLR website and were used here together with price data from fishing companies. As the fishing season and reporting period does not coincide with the calendar year, data is presented here for the 2005-2006 season and fleet data for the 2006-2007 season.

Summary for 2005 for CCAMLR area:

- Total landings: 130,000 t, 17,000 t of toothfish
- Catches in international waters: 125,000 t
- Countries involved: Krill: Korea Japan, Norway, Toothfish: France, Australia, UK
- Total value production: 180 million Euro
- Total income generated: 100 million Euro
- Total employment: 1500
- IUU 15-20% of toothfish catches

Fleet and effort

A total of 40 vessels have been registered in the CCAMLR area in 2006. With regard to the vessels registered in the area the following comments can be made:

- The number of registered vessels gives no information on the activity of the vessels and can thus only be used as a maximum number of vessels active in the area
- The registered fleets differ considerably between 2005 and 2006: No vessels were registered for France, the Russian Federation and Ukrain in 2006 whereas these countries (especially France) were important fishing nation in CCAMLR in economic terms in 2005. On the other hand, four vessels from Uruguay were registered in 2006 but catches were small in 2005

Table 3.9.1 Active fleet (number of vessels), 2006

Country	Long line	Trawl
France		
Korea	3	3
Australia	1	1
UK	4	2
Japan	2	1
New Zealand	4	
Chile	1	2
Spain	2	
Norway	2	1
Russian Fed.		
Ukrain		
Other	10	1
Total	29	11

Source: vessels register CCAMLR.

On fishing effort the following comments can be made:

- Effort in hours is underestimation: Effort on toothfish for 2004 and 2005 estimate around 26,000 hours.
- Effort is not publically available by country and gear.

Table 3.9.2 Fishing effort CCAMLR, *2005*

Target species	Trawl (*1000hours fishing)	Longline (hours fishing)	Longline (1000 hooks)
Krill	2,395		
Toothfish		3,266	62,851

Source: catch and effort data CCAMLR

Catches

Fishing vessels from Korea, Japan, Norway and Ukrain mainly target krill using trawls. Vessels from France Australia UK and New Zealand catch most of the toothfish in CCAMLR, using predominately trawls and longlines.

Table 3.9.3 Catches by country and species in CCAMLR, 2005 (1000 t)

Country	Krill	Patagonian toothfish	Arctic toothfish	Mackerel icefish	Other	Total
France		5.9			1.1	7.0
Korea	43.0	0.2	0.3	0.6		44.2
Australia		2.5		0.7	0.1	3.2
UK		1.6	0.4	0.3	0.1	2.4
Japan	32.7	0.1	0.1			32.9
New Zealand		0.4	1.4		0.1	1.9
Chile		0.4	0.1	1.2		1.7
Spain		0.5	0.5			1.0
Norway	9.2	0.0	0.4			9.6
Russian Fed.			0.9			0.9
Ukrain	15.2					15.3
Other	6.4	0.7	0.6		0.1	7.9
Total	106.6	12.4	4.6	2.8	1.6	128.1

Source: catch and effort data CCAMLR

Table 3.9.4 Catches by gear and species in CCAMLR, 2005 (1000 t)

Species	Longline	Trawls	Traps and pots	Total
Krill		106.6		106.6
Patagonian toothfish	10.3	2.0	0.1	12.4
Arctic toothfish	4.6			4.6
Mackerel icefish		2.8		2.8
Other	1.5	0.1		1.6
Total	16.4	111.5	0.1	128.1

Source: catch and effort data CCAMLR

Value, income and employment

The total value of the catches in the CCAMLR area are estimated at 176 million Euro. The most important species is the Patagonian toothfish representing a total catch value of 86 million Euro. Despite the massive catches of krill, this species only contributes to 20% to the total income. Price information on this species is, however hard to collect so the estimate of the value is highly uncertain. Most important countries involved in the fisheries in the arctic are France, Korea, Australia and the UK.

Table 3.9.5 Value by country and species in CCAMLR, 2005 (million Euro)

Country	Krill	Patagonian toothfish	Arctic toothfish	Mackerel icefish	Total
France		41.5			41.5
Korea	15.1	1.6	2.0	4.5	23.1
Australia		17.5		4.6	22.1
UK		11.0	2.9	2.4	16.2
Japan	11.4	0.7	0.4		12.6
New Zealand		2.8	9.8		12.6
Chile		3.1	0.5	8.3	11.9
Spain		3.2	3.8		7.0
Norway	3.2		2.7		5.9
Russian Fed.			6.3		6.3
Ukrain	5.3	0.0		0.1	5.4
Other	2.2	5.2	4.1		11.6
Total	37.3	86.6	32.5	19.9	176.3

Source: own estimate

Table 3.9.6 Value by country and gear in CCAMLR, 2005 (million Euro)

Country	Long line	trawler toothfish	Trawler krill	Total
France	41.5			41.5
Korea	8.1		15.1	23.1
Australia	11.1	11		22.1
UK	16.2			16.2
Japan	1.1		11.4	12.6
New Zealand	12.6			12.6
Chile	3.6	8.3		11.9
Spain	7.0			7.0
Norway	2.7		3.2	5.9
Russian Fed.	6.3			6.3
Ukrain	0.1		5.3	5.4
Other	9.3		2.2	11.6
Total	119.7	19.3	37.3	176.3

Source: own estimate

The total income generated is estimated at around 100 million Euro. Information on employment is given in the CCAMLR fleet register from 2006 onwards per vessel. Thus, employment be estimated quite accurately for those countries for which vessels are registered. However, as no vessels were active for France, the Russian Federation and Ukrain in 2006 no information on employment is available for these countrys.

Table 3.9.7 Income and employment by country in CCAMLR, successively in 2005 and 2006

Country	Income (million Euro)	Employment (persons)
France[1)]	22.8	
Korea	12.7	302
Australia	12.2	48
UK	8.9	208
Japan	6.9	128
New Zealand	6.9	99
Chile	6.5	156
Spain	3.9	72
Norway	3.3	20
Russian Fed[1)]	3.5	
Ukrain[1)]	3.0	
Other	6.4	351
Total	97.0	1497

Sources: own estimation and CCAMLR fleet register [1)]No fleet and employment information is available for these countries

IUU

As IUU fishing is found to be a considerable problem in the toothfish fisheries, several studies have been undertaken by International NGO's on this subject using alternative data such as trade statistics.

Illegal landings have been estimated by a number of authors using different methods. CCAMLR has estimated the IUU catches based on sightings of vessels in CCAMLR waters and estimates of Catch per unit of effort. These estimates of the IUU landings within the convention area show a decrease over the recent period to 15%-20% of the total legal catch (around 3000 t). However, CCAMLR noted that pressure from surveillance operations around sub-Antarctic islands had possibly pushed IUU fishing into high-seas areas of the Convention Area (CCAMLR, 2005). Based on trade statistics, Lack and Sant (2001)[19] estimated significant higher IUU landings for the period 1998-2000. However, no information is available for recent years to update this estimate.

EEZ and international waters

Besides the reported catches in the CCAMLR area, considerable catches have been realised outside the area. Around 8000 t of toothfish are caught outside the area and the majority of these is caught inside the EEZ of Argentine, Chile and the UK. Another 2600 t are caught in international waters.

Table 3.9.8 Catches of toothfish inside and outside the CCAMLR area, 2005

	Inside EEZ	Outside EEZ	IUU fisheries	Total
Inside CCAMLR	6081	10932	3080	20093
Outside CCAMLR	5443	2605		8048
Total	11524	13537	3080	28141

Source: Estimated catches from IUU fisheries and outside the area from CCAMLR 2006.

19 M. Lack and G. Sant, 2001. Patagonian toothfish, are conservation and trade measures working? TRAFFIC Bulletin offprint *Vol. 19 No. 1 (2001)*

3.10 Indian Ocean - IOTC

Tuna fisheries in the Indian Ocean (IO) are managed by IOTC. Presented data on catches and landings originates from the IOTC database. The database provides information on catches of all main tuna species, as well as various species of billfish and seerfish. The database makes also detailed comment on the quality of the data. These comments can be only taken into account in a far more detailed analysis and have been disregarded at this stage.

Summary for 2005:

- Total landings (incl. accompanying catch): 1.7 million t
- Catches in international waters: not available
- Main countries involved: Indonesia, Spain, Maldives and Iran
- Total value of production: 1.5 billion Euro
    - Artisanal fisheries 700 million Euro
    - Industrial fisheries 760 million Euro
- Industrial / international fleet
    - Total income: 420 million Euro
    - Total employment: 40-66,000 people
- IUU not available

Fleet and effort

IOTC distinguishes artisanal and industrial fleet on the basis of the size of the vessels. The division is presented in Table 9.1. The fleet most likely to operate in international waters originates evidently from countries outside the region: Taiwan, Japan and the EU.

Table 3.10.1 Active fleet (number of vessels), 2005

Industrial fleet				
	Longline	Purse Seine	Other	**Total**
Indonesia	1,338			**1,338**
Taiwan	341			**341**
Japan	172	1		**173**
European Union	76	37		**113**
India	82			**82**
China	67			**67**
Seychelles	36	11		**47**
Korea rep	28			**28**
Philippines	25			**25**
Australia	6	11	4	**21**
Malaysia	18			**18**
Other	386	14	13	**413**
Total industrial	**2,575**	**74**	**17**	**2,666**

Artisanal fleet						
Fleet	Baitboat	Gillnet	Line	Other	Purse seine	**Total**
Yemen Ar. Rp.		10,682				**10,682**
Oman		9,614				**9,614**
Iran		6,576	206			**6,782**
Maldives	1,007		96			**1,103**
Bahrain		163	869			**1,032**
Thailand		84		666	257	**1,007**
Other		10	1,121			**1,131**
Total artisanal	**1,007**	**27,129**	**2,292**	**666**	**257**	**31,351**

Source: IOTC – Fishing craft statistics (FC 20071127)

Information on artisanal fleet is presented for the sake of completeness. Assessment in this report focuses on the industrial fleet, as that is relevant from the perspective of the high seas fishery.

Table 3.10.2 Fishing effort – not available

The IOTC database presents data on fishing effort based on many different dimensions and definitions. It is not possible to ascertain how complete the data is and it is not possible to present it in a concise manner, relevant in the context of this study.

Catches

Skipjack and yellowfin represent 60% of the total catches. Eleven countries catch more than 50,000 t. The data allows to assess the volume of accompanying catch. Tunas account for 83% of the total, seerfish for about 8%, billfish 4% and other species 6% (sharks, etc.). Details of the catches of bigeye, yellowfin and skipjack tuna are given in Figure 3.10.1 – 3.10.3.

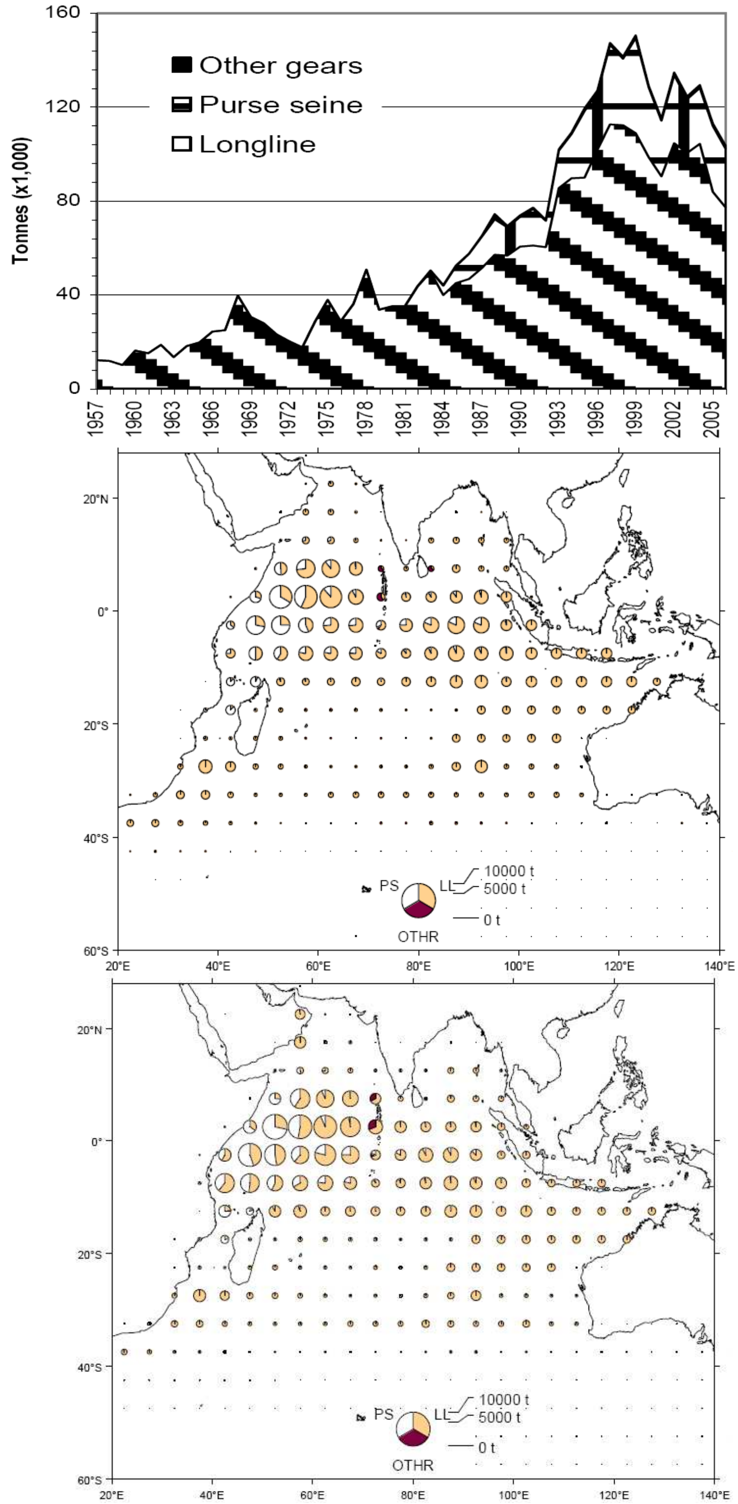

Figure 3.10.1 Annual catches of bigeye tuna by gear from 1957 to 2006 (top). Mean annual catches of bigeye tuna by longline and purse seine vessels operating in the Indian Ocean over the period 1990 to 1999 (middle) and 2000 to 2005 (below). From: IOTC 2007. Report of the ninth session of the IOTC Working Party on tropical tunas.

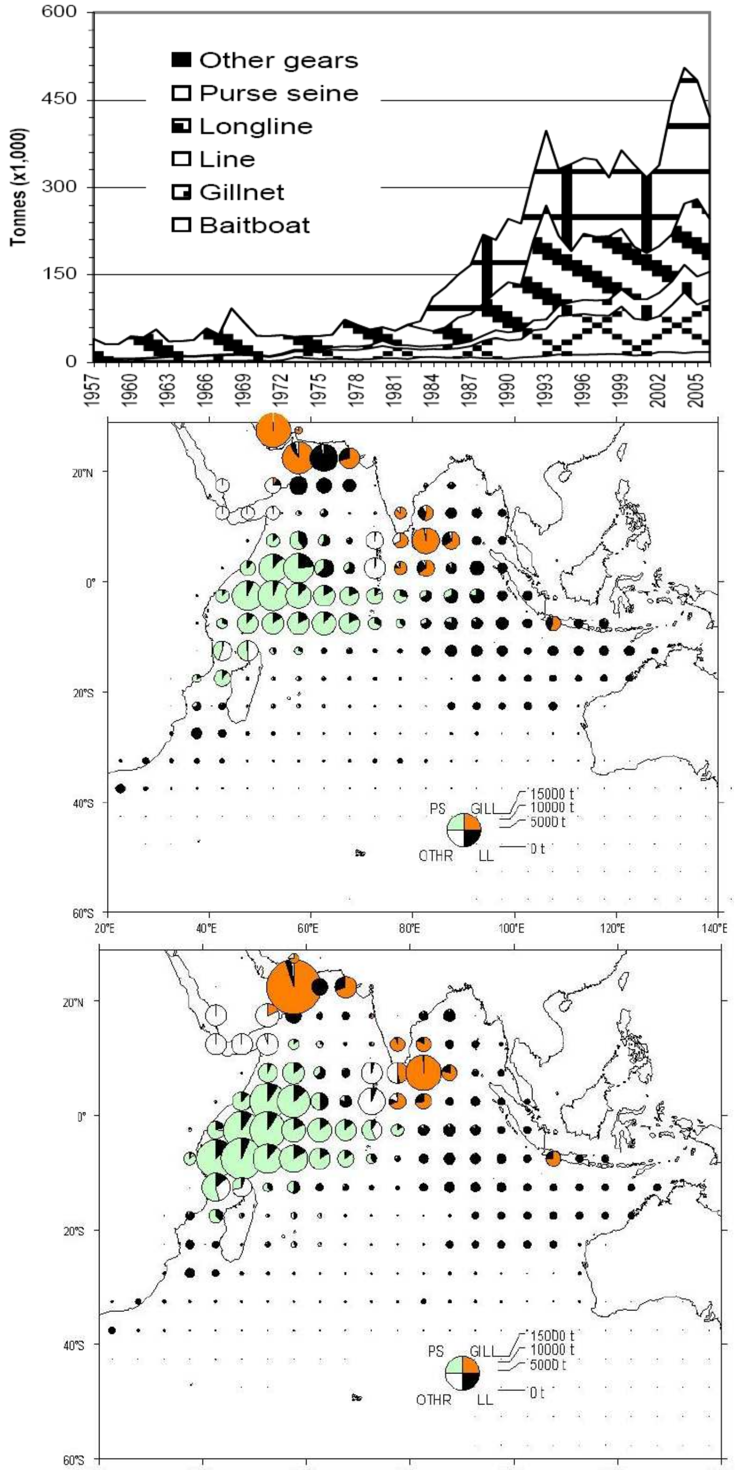

Figure 3.10.2 Annual catches of yellowfin tuna by gear from 1957 to 2006 (top). Mean annual catches of bigeye tuna by longline and purse seine vessels operating in the Indian Ocean over the period 1990 to 1999 (middle) and 2000 to 2005 (below). From: IOTC 2007. Report of the ninth session of the IOTC Working Party on tropical tunas.

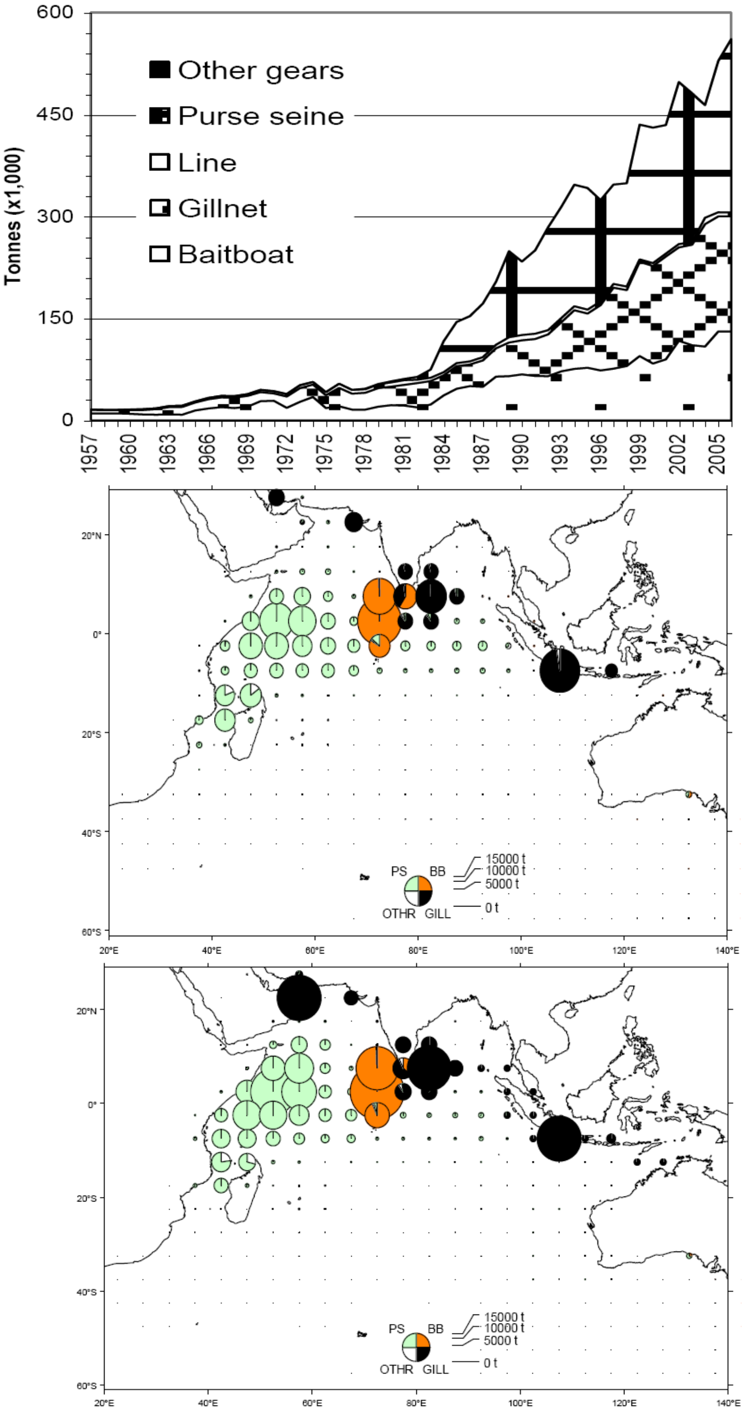

Figure 3.10.3 Annual catches of skipjack tuna by gear from 1957 to 2006 (top). Mean annual catches of bigeye tuna by longline and purse seine vessels operating in the Indian Ocean over the period 1990 to 1999 (middle) and 2000 to 2005 (below). From: IOTC 2007. Report of the ninth session of the IOTC Working Party on tropical tunas.

Table 3.10.3 Catches by country and species in IOTC region, 2005 (1000 t)

	Skipjack	Yellow-fin	Bigeye	Kawakawa	Spanish macker.	Long tail tuna	Other	Total
Indonesia	51.2	14.5	8.8	39.1	21.4	29.5	51.8	**216.3**
Spain	94.3	77.5	10.6				9.5	**192.0**
Maldives	132.1	20.5	1.0	2.7			26.6	**183.0**
Iran	80.7	43.6		11.8	6.2	18.5	17.3	**178.0**
Taiwan	0.1	67.6	40.2				27.1	**135.1**
France	43.2	57.2	6.5				0.1	**107.0**
Seychelles	46.0	43.9	10.2	0.1			2.1	**102.3**
India	1.6	7.3		22.2	28.2	4.5	22.4	**86.2**
Sri Lanka	32.5	18.8	0.1	0.6	0.3		18.7	**70.9**
Japan	3.2	22.7	13.4				12.0	**51.3**
Yemen	0.0	26.4		2.8	1.8	6.1	13.9	**51.0**
Pakistan	3.6	4.9		1.9	7.2	4.4	19.0	**40.9**
Oman	0.1	16.1	0.1	2.2	2.7	7.5	1.2	**29.7**
Thailand	8.0	2.3	1.7	6.5		3.2	7.4	**29.2**
Other	30.8	52.9	21.8	10.2	26.8	6.3	46.2	**194.9**
Total	**527.3**	**476.1**	**114.4**	**100.1**	**94.6**	**80.0**	**275.2**	**1,667.7**

Purse seining appears to be quite a 'clean' fishery, with little by-catch. Longlining and gillnetting, on the other hand, catches substantial amounts of other species.

Table 3.10.4 Catches by gear and species in IOTC region, 2005 (1000 t)

	Baitboat	Gillnet	Line	Longline	Purse seine	Other	Total
Skipjack	130.8	116.5	5.7	0.4	222.8	51.0	**527.3**
Yellowfin	16.9	77.2	40.6	134.6	203.7	3.1	**476.1**
Bigeye	1.0	0.1		85.2	28.0		**114.4**
Kawakawa	2.0	36.9	5.7		14.7	40.8	**100.1**
Spanish mackerel		39.6	17.1		0.1	37.7	**94.6**
Long tail tuna		40.8	1.4		7.5	30.3	**80.0**
Sharks		28.1	0.3	15.0		23.8	**67.2**
Swordfish		0.7	0.1	27.1			**28.0**
King mackerel		10.3	1.3			13.8	**25.4**
Other	16.5	44.0	18.2	44.5	8.9	22.5	**154.7**
Total	**167.3**	**394.0**	**90.6**	**307.0**	**485.8**	**223.1**	**1,667.7**

Value, income and employment

Total value of the IO tuna fishery is estimated at 1.46 billion Euro. Of this, some 760 million Euro can be attributed to industrial fisheries and about 700 million euro to artisanal fisheries. The total income generated in industrial fisheries is estimated at some 420 million Euro, of which about 30% can be attributed to the EU and 20% to Japan. Employment in industrial fisheries can be estimated at 40-66,000 persons.

Table 3.10.5 Value by country and species in IOTC region, 2005 (million Euro)

	Skipjack	Yellowfin	Bigeye	Kawakawa	Other	**Total**
Indonesia	30.7	15.9	10.6	47.0	82.7	**186.9**
Spain	56.6	85.3	12.7	0.0	7.9	**162.5**
Iran	48.4	47.9	0.0	14.2	43.9	**154.4**
Taiwan	0.1	74.4	48.3	0.0	29.6	**152.3**
Maldives	79.2	22.6	1.3	3.2	16.9	**123.2**
France	25.9	62.9	7.8	0.0	0.1	**96.7**
Seychelles	27.6	48.3	12.3	0.1	2.2	**90.5**
India	1.0	8.1	0.0	26.6	37.5	**73.2**
Sri Lanka	19.5	20.7	0.1	0.7	18.5	**59.4**
Japan	1.9	25.0	16.0	0.0	14.0	**56.9**
Yemen	0.0	29.0	0.0	3.3	13.2	**45.5**
Oman	0.0	17.7	0.1	2.6	11.3	**31.7**
Pakistan	2.1	5.3	0.0	2.3	20.6	**30.4**
Thailand	4.8	2.6	2.1	7.9	7.2	**24.5**
Other	18.5	58.1	26.1	12.3	57.4	**172.4**
Total	**316.4**	**523.8**	**137.3**	**120.1**	**362.9**	**1,460.5**

Source: own estimate

Table 3.10.6 Value by country and gear in IOTC region, 2005 (million Euro)

	Artisanal				Industrial		
	Baitboat	Gillnet	Line	Other	Longline	Purse seine	**Total**
Indonesia				151.3	35.6		**186.9**
Spain					7.8	154.7	**162.5**
Iran		143.5	0.7			10.2	**154.4**
Taiwan					152.3		**152.3**
Maldives	109.7	1.3	11.6	0.2	0.3		**123.2**
France						96.7	**96.7**
Seychelles			0.2		16.6	73.8	**90.5**
India	2.5	42.4	13.6	11.9	2.1	0.6	**73.2**
Sri Lanka		53.4	5.8			0.2	**59.4**
Japan					53.0	3.9	**56.9**
Yemen		16.5	29.0				**45.5**
Oman		31.3			0.4		**31.7**
Pakistan		30.4					**30.4**
Thailand		0.8		1.3	0.3	22.0	**24.5**
Other		9	21	9	68	65	**172**
Total	**112.2**	**328.9**	**82.0**	**173.5**	**336.4**	**427.4**	**1,460.5**

Table 3.10.6 splits roughly the fisheries production into artisanal and industrial[20]. However, employment in artisanal tuna fisheries cannot be estimated as the declarations of the involved fleets are very incomplete. Therefore, Table 3.10.7 regards only the industrial fishery (longlines and purse seines).

Table 3.10.7 Income and employment by country in IOTC region, 2005

Country	Income (million Euro)	Employment (1000 persons) Minimum	Employment (1000 persons) Maximum
Indonesia[14]	19.6	20.1	33.5
European Union[15]	142.6	1.8	2.8
Taiwan	83.7	5.1	8.5
Japan	31.3	4.7	7.8
Other[16]	142.9	8.4	13.9
Total	420.1	40.1	66.5

[14]This is most likely a fishery inside Indonesian EEZ.
[15]Spain and France.
[16]In view of the estimated employment, it seems likely that part of this value should be attributed artisanal longline and purse seine fleets.

IUU

Extent of IUU is unclear. The IUU vessel list maintained by IOTC specifies only 2 vessels as November 2007.

EEZ and international waters

Division of catches between national and international waters is not available. At least 30% of the cathes fo the EU fleet are realized with EEZ, mainly of countries with fisheries agreements with the EU[21].

3.11 Concluding remarks

The previous sections give an overview of the high sea fisheries in the most important regions., In many cases, however it is almost impossible and even unwanted from a fisheries management point of view to distinguish between the fishery inside and outside the EEZ. First of all most available data from RFMOs do not distinguish between EEZ and non EEZ catches and effort. Thus, in many RFMOs described here, no distinction could be made. In many cases there is also no use in making this distinction from a fisheries management perspective as most stocks exploited in international waters are straddling stocks and have a distribution area which covers both EEZ and international waters. Therefore, international TACs are in most cases also set for both EEZ and international waters together.

Having said this, the fisheries described here represent a considerable economic value and source of employment for tens of thousands of fishermen. Two large groups can be distinguished: the tuna fisheries and the North Atlantic fisheries. The most important fishing nations in the tuna fisheries are Japan, Indonesia, Taiwan and Spain but many others are also heavily involved in these fisheries. The main players in the fisheries in the

[20] We must stress that all production of each type has been classifies as either artisanal or industrial. This is an approximate assumption, due to lack of more detailed data.

[21] Oceanic Development, private communication.

North Atlantic are Norway, Iceland, UK and the Russian Federation. Besides, the fisheries around the Antarctic represent a special case because of the target species and the area. These fisheries are dominated by France, Australia, and the UK (for toothfish) and Korea and Japan (for Krill).

With their economic importance many of these fisheries seem to be of considerable importance to the total national fisheries (Appendix 3.1). Especially for many northern European countries like Norway, Iceland and Faroe Islands the dependency on the fish stocks managed under NEAFC is high. For Norway and the Faroe Islands even around 50% of the total value of the national landings is generated in these fisheries and for many other countries (Iceland, UK and France) this percentage is between 20-30%. For the major countries involved in the tuna fisheries the dependency on these fisheries is generally lower. Japan depends for less than 10% on the tuna fisheries described here, and other important countries like Indonesia, Mexico and the Philippines between 10 and 20%. Many other countries involved hardly depend on these fisheries at all. France and Spain represent special cases because their fleets are involved in both the fisheries in the North Atlantic, the tuna fisheries and the toothfish fisheries. Their total dependency on these fisheries is around 20% for France and 10% for Spain. It should be noted that these dependency numbers are only crude estimates as they are mostly based on (rough) FAO estimates of total production value of recent years.

From the analyses in this report the IUU fisheries, seems to be a multi million business, but relatively small in comparison to the total fisheries in the different areas. For most of the areas the total value of the IUU fishery is less than 15% of the total catch. Only for redfish in the NEAFC area and toothfish estimated IUU catches are higher, 25% and 20% of the total legal catch respectively.

Appendix 3.1: Overview of the total landings value (MILLION EURO) of high sea fisheries in relation to the total value of the national fisheries sector (from FAO fact sheets). For several countries (e.g. Ecuador, Maldives) national totals are out of date and most probably inaccurate.

Country	NAFO	NEAFC*	ICCAT	IATTC EPO	WCPFC	CCSBT	CCALRM	IOTC	Total high sea	National fishery	% of total
Grand Total	279.6	1,786.4	633.9	726.4	1,676.8	80.1	176.3	1,460.5	6,819.9	**127,695.5**	**5%**
Angola			4.6						4.6	**198.6**	**2%**
Argentine			12.6				1.5		14.1	**169.9**	**8%**
Australia						26.0	22.1	7.2	55.3	**1,791,1**	**3%**
Bahrain								0.0	0.0	**n.a.**	**n.a.**
Bangladesh								0.0	0.0	**n.a.**	**n.a.**
Barbados			0.1						0.1	**n.a.**	**n.a.**
Belgium		0.2							0.2	**106.3**	**0%**
Belize			0.4	4.5				1.3	6.1	**42.7**	**14%**
Brasil			38.5						38.5	**1,630.4**	**2%**
Canada	47.5		7.1	5.3					60.0	**1,332.7**	**4%**
Cape Verde			3.4						3.4	**13.8**	**25%**
Chile				5.4			11.9		17.3	**2,079.8**	**1%**
China			10.8	5.0				16.6	32.3	**37,016.1**	**0%**
Chinese Taipei			36.0						36.0	**n.a.**	**n.a.**
Colombia			0.1						0.1	**n.a.**	**n.a.**
Comoros								10.0	10.0	**24.3**	**41%**
Costa Rica				10.9					10.9	**41.1**	**27%**
Côte D'Ivoire			1.7						1.7	**78.8**	**2%**
Cuba			0.1						0.1	**210.0**	**0%**
Denmark		82.0							82.0	**381.0**	**22%**
Djibouti								0.0	0.0	**n.a.**	**n.a.**
Dominica			0.3						0.3	**14.1**	**2%**
Dominican Republic			0.2						0.2	**11.8**	**2%**
East Timor								0.0	0.0	**n.a.**	**n.a.**

Country	NAFO	NEAFC*	ICCAT	IATTC EPO	WCPFC	CCSBT	CCALRM	IOTC	Total high sea	National fishery	% of total
Ecuador				163.8					163.8	**1.2**	**14115%**
Egypt								0.5	0.5	**3.3**	**16%**
El Salvador				12.3					12.3	**52.2**	**24%**
Eritrea								0.2	0.2	**6.0**	**4%**
Estonia	27.5	9.6							37.1	**n.a.**	**n.a.**
Faroe Islands	10.4	92.3							102.7	**231.6**	**44%**
Finland[1]		27.4							27.4	**24.0**	**114%**
Fr.St Pierre et Miquelon			0.1						0.1	**n.a.**	**n.a.**
France		64.9	67.3				41.5	96.7	270.5	**1,140.0**	**24%**
France - Polynesia				3.6					3.6	**n.a.**	**n.a.**
France-Reunion								4.5	4.5	**n.a.**	**n.a.**
France-Territories								1.1	1.1	**n.a.**	**n.a.**
Gabon			0.0						0.0	**n.a.**	**n.a.**
Germany	0.4	63.1							63.5	**282.3**	**23%**
Ghana			71.3						71.3	**264.2**	**27%**
Grenada			1.3						1.3	**4.3**	**30%**
Guatemala			8.2						8.2	**16.0**	**52%**
Guernsey		0.1							0.1	**n.a.**	**n.a.**
Guinea								1.6	1.6	**n.a.**	**n.a.**
Guyana			4.6						4.6	**n.a.**	**n.a.**
Honduras				10.2					10.2	**103.3**	**10%**
Iceland	2.3	190.9	0.0						193.1	**1,181.1**	**16%**
India								73.2	73.2	**4,325.9**	**2%**
Indonesia					199.4	8.6		186.9	394.9	**2,445.3**	**16%**
Iran								154.4	154.4	**414.9**	**37%**
Ireland		37.7	0.4						38.1	**279.6**	**14%**
Japan	7.3		50.8	38.5	367.8	39.0	12.6	56.9	572.9	**12,799.1**	**4%**

Country	NAFO	NEAFC*	ICCAT	IATTC EPO	WCPFC	CCSBT	CCALRM	IOTC	Total high sea	National fishery	% of total
Jersey		0.0							0.0	**n.a.**	**n.a.**
Jordan								0.1	0.1	**0.6**	**17%**
Kenya								1.8	1.8	**234.1**	**1%**
Korea. Republic of			2.0	15.6	182.9		23.1	8.0	231.7	**6,425.6**	**4%**
Kuwait								0.1	0.1	**25.4**	**0%**
Latvia	5.2	5.6	0.4						11.2	**118.6**	**9%**
Libya			0.1						0.1	**88.5**	**0%**
Lithuania	9.7	1.9							11.6	**329.2**	**4%**
Madagascar								6.0	6.0	**n.a.**	**n.a.**
Malaysia								18.9	18.9	**1,200.0**	**2%**
Maldives								123.2	123.2	**27.6**	**447%**
Malta							0.4		0.4	**9.2**	**4%**
Maroc			25.6						25.6	**n.a.**	**n.a.**
Mauritius								2.4	2.4	**85.5**	**3%**
Mexico			13.3	178.2					191.5	**1,444.4**	**13%**
Namibia			13.8						13.8	**462.5**	**3%**
Netherlands		70.7							70.7	**663.3**	**11%**
Netherlands Antilles			0.0						0.0	**n.a.**	**n.a.**
New Zealand							12.6		12.6	**1,423.9**	**1%**
Nicaragua				9.8					9.8	**n.a.**	**n.a.**
Norway		608.1	1.5				5.9		616.9	**1,400.9**	**44%**
Oman	1.4							31.7	31.7	**145.2**	**22%**
Pakistan								30.4	30.4	**347.4**	**9%**
Panama			17.6	70.1					87.8	**271.7**	**32%**
Papua NG					163.3				163.3	**92.5**	**176%**
Peru				12.8					12.8	**n.a.**	**n.a.**
Philippines			2.6		261.0			5.1	268.7	**2,444.2**	**11%**

Country	NAFO	NEAFC*	ICCAT	IATTC EPO	WCPFC	CCSBT	CCALRM	IOTC	Total high sea	National fishery	% of total
Poland	2.0	7.6					1.9		11.4	**45.3**	**25%**
Portugal	6.9	34.4	26.6					2.0	69.9	**2,782.1**	**3%**
Qatar								1.0	1.0	**29.9**	**3%**
Russian Federation	26.2	178.7	0.4				6.3		211.6	**2,277.8**	**9%**
S. Tomé e Príncipe			1.7						1.7	**n.a.**	**n.a.**
Saint Kitts and Nevis			0.0						0.0	**n.a.**	**n.a.**
Saudi Arabia								5.5	5.5	**77.8**	**7%**
Senegal			5.4					0.1	5.5	**n.a.**	**n.a.**
Seychelles								90.5	90.5	**187.6**	**48%**
South Africa			6.2				3.2	0.6	10.0	**n.a.**	**n.a.**
Spain	42.9	64.5	127.4	12.0			7.0	162.5	416.3	**3,779.7**	**11%**
Sri Lanka								59.4	59.4	**183.9**	**32%**
St. Vincent and Grenadines			1.0						1.0	**13.3**	**8%**
Sta. Lucia			0.7						0.7	**5.8**	**12%**
Sudan								0.0	0.0	**n.a.**	**n.a.**
Sweden		47.0							47.0	**106.2**	**44%**
Taiwan				17.7	190.6			152.3	360.5	**n.a.**	**n.a.**
Tanzania								2.4	2.4	**513.3**	**0%**
Thailand								24.5	24.5	**2,142.9**	**1%**
Trinidad and Tobago			6.7						6.7	**18.6**	**36%**
UK		199.6	0.0				16.2	0.8	216.6	**1,092.6**	**20%**
UK.Bermuda			0.2						0.2	**n.a.**	**n.a.**
UK.British Virgin Islands									0.0	**n.a.**	**n.a.**
UK.Sta Helena			0.0						0.0	**n.a.**	**n.a.**
UK.Territories								0.0	0.0	**n.a.**	**n.a.**
Ukrain							5.4		5.4	**266.7**	**2%**
United Arab Emirates								7.4	7.4	**35.6**	**21%**

Country	NAFO	NEAFC*	ICCAT	IATTC EPO	WCPFC	CCSBT	CCALRM	IOTC	Total high sea	National fishery	% of total
Uruguay			2.9				4.7		7.5	**55.6**	**14%**
USA	89.9		32.4	15.2	63.7				201.3	**27,876.1**	**1%**
Vanuatu			2.6	1.5	62.8				66.8	**5.4**	**1229%**
Venezuela			7.7	55.1					62.8	**125.7**	**50%**
Yemen								45.5	45.5	**116.8**	**39%**

*: Landings value in NEAFC area is the total value of the landings of species under NEAFC regulation, only about one third of this is caught within the NEAFC regulatory area. [1] Landings from Finland represent Baltic herring from inside EEZ.

4 Mining[22]

4.1 Introduction

Mining is the extraction of minerals like coal, uranium, salt, gold, rock, oil or gas. Considering mining rights on the high seas (see Figure 4.2), there is a distinction between the seabed of the high seas that is part of the continental shelf and the seabed beyond the continental shelf ('the Area'). A coastal State has the right to exploit minerals and other non-living material in the subsoil of its continental shelf, to the exclusion of others. For the seabed and subsoil of the oceans beyond the outer limits of the continental shelf, Part XI of the U.N. Convention on the Law of the Sea (UNCLOS) provides for a regime relating to minerals on the seabed. It establishes an International Seabed Authority (ISA) to authorize mining and collect and distribute the seabed mining royalty.

<u>Oil and gas extraction</u>

Oil and gas activities currently take place within areas under national jurisdiction (UNEP, 2006). Generally, offshore activities take place on the continental shelf within 200 miles of the coast. However, the continental shelve may extend the 200 miles. For example, the continental shelve of the United States extends beyond 200 miles in a variety of areas, including notably the Atlantic coast, the Gulf of Mexico, the Bering Sea and the Arctic Ocean. Other States with broad margins include Argentina, Australia, Brazil, Canada, Iceland, India, Ireland, Madagascar, Mexico, New Zealand, Norway, the Russian Federation and the United Kingdom. Oil and gas development beyond 200 miles from the coastal baselines currently takes place in the Gulf of Mexico and the Atlantic Ocean. The Chukchi Plateau, located more than 600 miles north of Alaska, may be rich in oil and gas resources, but fields are not yet in production. Oil and gas activities may some day extend beyond the continental shelf (UNEP, 2006).

Waterdepth remains one of the limiting parameters when it comes to oil and gas production, with technical solutions allowing mining up to 3 km waterdepth. Drilling can now reach depths of over 3000 meters (UNEP, 2006).

Oil and gas development involves several stages: exploration (seismic surveys, drilling), exploitation (drilling, installation of platform, production) and abandonment. For development in the deep seas floating installations, such as FPSO's (Floating Production, Storage and Overload vessels), are used for the mining process. In these cases there is no platform required. The FPSO vessels are (retrofitted or build-on-purpose) able to produce, treat, store and offload oil from the field and wells they are connected with. Usually, the wells are equipped with remotely operated valve systems.

Other potential sources of energy are gas hydrates. Gas hydrates are ice-like crystalline solids formed by the entrapment of gas molecules in a hydrogen-bonded cage of water molecules. Methane is the gas that is most commonly entrapped, and its flammable nature suggests that hydrates could serve as a potential source of energy - once problems related to its commercial extraction are resolved (Plantegenest *et al.,* 2005).

<u>Minerals</u>

There are several seafloor mineral resources of the deep ocean floor (Thiel, 2001):

- Polymetallic nodules
- Polymetallic crusts

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- Polymetallic sulphides
    - metalliferous muds
    - consolidated sulphides
- Phosphorites

The existence of mineral resources on the deep ocean floor has been known for more than a century. The first resources found were polymetallic nodules, also known as manganese nodules. They contain valuable metals such as nickel, manganese, copper and cobalt, are about the shape and size of potatoes and are dark-coloured. They lie strewn atop the seabed, notably in the central Pacific and Indian oceans. Polymetallic nodules are located in very deep water, more than 5,000 metres below the ocean surface. In the late 1970s, researchers learned of two other mineral resources in the deep oceans, containing many of the same metals, along with gold and silver. These are polymetallic sulphides and cobalt-rich crusts. Polymetallic sulphides are formed around hot springs in active volcanic areas. Cobalt-rich crusts are found around ridges and seamounts[23] in all the world's oceans, fused to the underlying rock. Figure 4.1 shows seabed features associated with mineral resources.

As mentioned above, mineral-rich deposits can be found at subsea volcanic sites. These sites in turn are mostly found at areas in deep sea spreading centres, where tectonic plates are at a constant move and new seabed is formed by upwelling magma. Seawater seeping into the deep cracks between the moving plates gets to boil by the magma, and starts to react with elements in the hot rock (minerals etc). As the temperature of the water rises up to 500°C , buoyancy increases and the water flows back up to the ocean floor where dissolved elements under the enormous pressure are precipitated by the turbulent and cold ocean water. The minerals form drifts that grow into chimneys around these vents, so called "black smokers". Fine particles from the chimney plumes fall to the ocean floor and build up as concentrated metalliferous deposits, forming an extreme environment. The minerals over time form small nodules scattered around these areas, and can be harvested.

Seabed massive sulphides (SMS) lie at extinct hydrothermal vents and contain copper, gold, zinc and other metals. They are extracted using remotely operated vehicles to scrape the deposits from the seabed and pump them to a barge (POST, 2007).

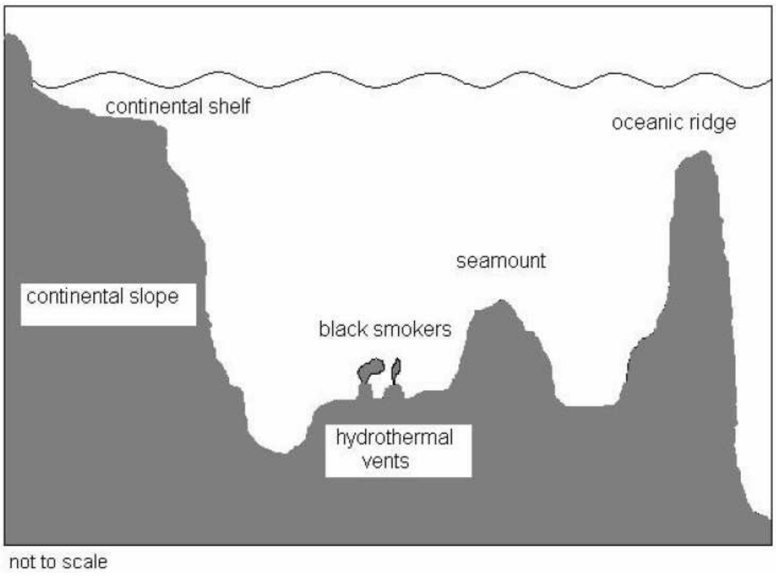

Figure 4.1 Seabed features (POST, 2007).

[23] Seamounts are steep-sided conical topographic features, mostly extinct volcanoes, rising from the seafloor (Koslow, 2001).

Because at present mining activities do not occur in the Area, only general principles and potential activities and impacts are described in this chapter.
The assessment of the ecological impact of mining in the high seas involves the following steps:

- Assessment of the mining intensity on the high seas;
- Assessment of the emissions due to these activities;
- Assessment of the effects of these emissions.

International regulation

A main task of ISA is managing the mineral resources of the Area. Mining of these resources under the Convention is only possible in agreement with part XI and the rules, regulations and procedures as set up by the ISA. The ISA has no or limited authorities on other activities in the Area. For example, the laying of cables and pipelines, or conducting scientific research in the Area, is not part of the ISA. Providing the relevant rules and regulations are taken into account, States are free to conduct those activities within the Area.

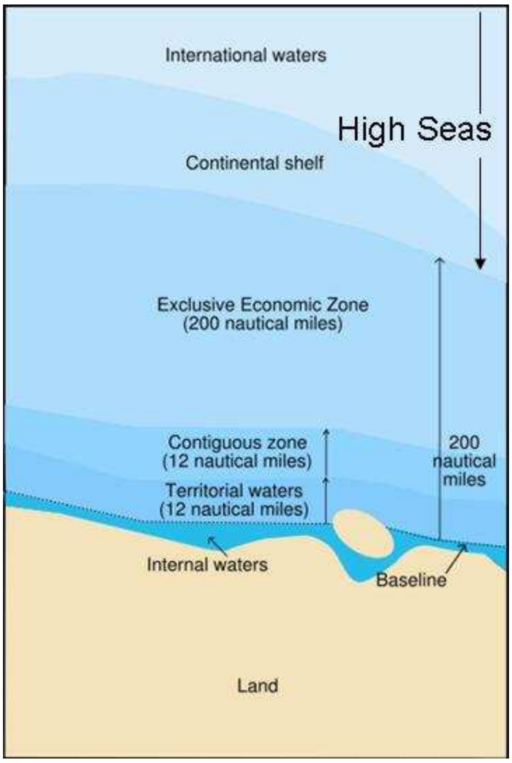

Figure 4.2 Sea areas in international rights

Article 160(2)(g) of the Convention states that the ISA Assembly determines on the distribution of the financial and other economical advantages from the Area, in agreement with the Convention and the rules, regulations and procedures of the ISA. These rules, regulations and procedures are to be established provisionally by the Council, taking into account the advice of the financial comity (UNCLOS, article 162 (o) and Agreement regarding part XI, section 9.7) and to be approved by the Assembly. Up to now such rules, regulations and procedures have not been established. It can be expected that this will not occur until the mining of minerals in the Area is actually proposed.

4.2 Assessment of mining intensity

Oil and gas

At present, offshore oil and gas activities are limited to the area within national borders. As the main restriction is the water depth (operational limit is currently ca. 3 km), the deepest areas of the high seas are assumed to be the least interesting for future developments. Furthermore, with increasing distance to shore, the costs for oil and gas production also increases, making it less interesting for development. Figure 4.3 shows that most of the high seas have water depths of more than 3 km. 76% of the oceans beyond the continental shelves have depths of 3-6 km (UNEP, 2006).

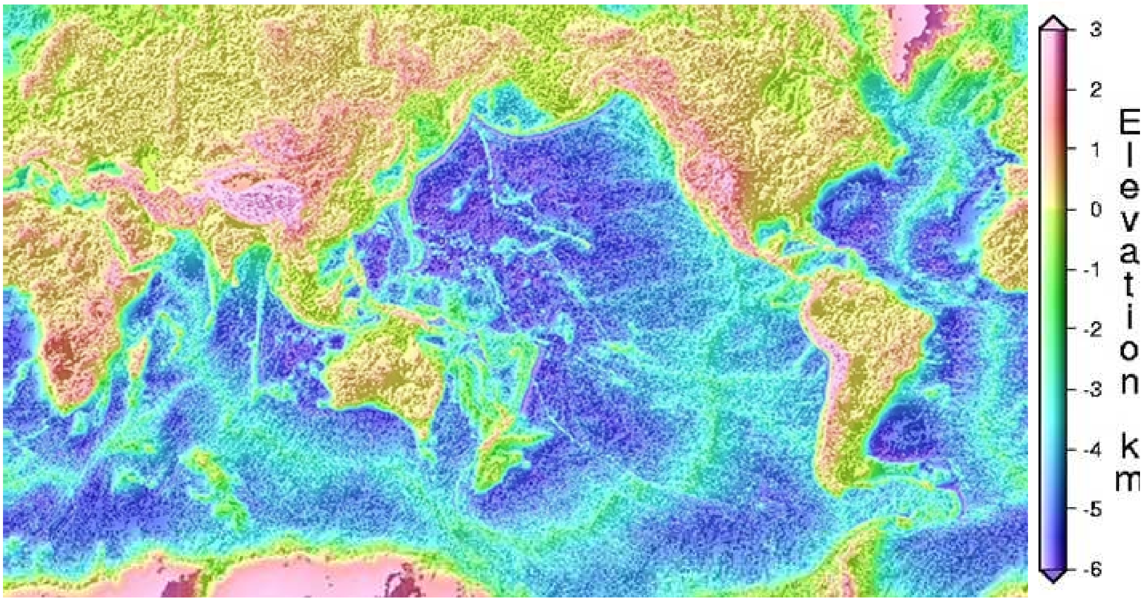

Figure 4.3 Water depth (Smith *et al.*, 1997).

Minerals

There is currently only limited commercial activity in mining of polymetallic nodules. Exploitation of SMS is currently the only economic source of seabed minerals (POST, 2007). However, these activities take place within national borders. The polymetallic sulphide deposits can reach sizes ranging from several thousand to about 100 million tons (UNEP, 2006). Figure 4.4 shows the global distribution of marine mineral resources. There are an estimated 30,000 seamounts over 1000 m in height in the Pacific Ocean, only about 810 that are > 100 m in height in the North Atlantic and an indeterminate number in the Indian Ocean (Koslow, 2001). Potentially, all sites as presented in Figure 4.4 could be exploited in future.

Conclusions on intensity

- Mining activities are currently limited to the area within national borders;
- Main limiting factors for oil and gas activities on the High Seas are water depth and distance to shore;

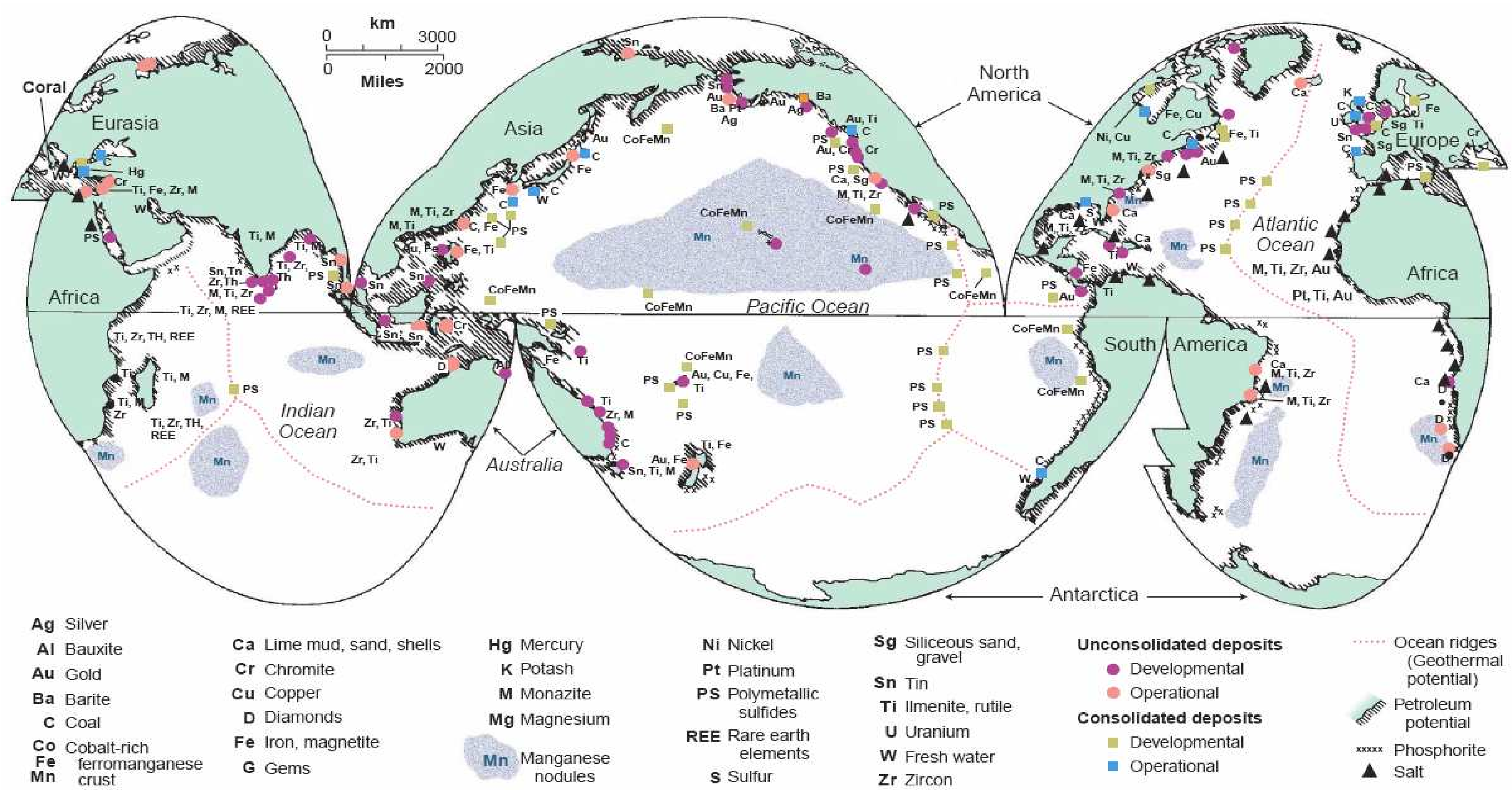

Figure 4.4 Global distribution of marine mineral resources known at this early stage of ocean exploration (Rona, 2003).

- Many mineral resources (such as polymetallic sulfides and manganese nodules) are located in the Area and could potentially be exploited.

4.3 Assessment of emissions

As mining activities do not take place on the high seas, there are currently no emissions from mining. This paragraph describes the potential emissions resulting from extraction of oil and gas or mineral deposits on the high seas.

In general, the main potential emissions from mining are:

- Emissions to the water column
  - Drilling mud and cutting from drilling exploration and production wells for oil and gas development
  - Produced water from oil and gas production
  - Debris after separating minerals from extracted material
- Emission to air
  - Exhaust emission from mining vessels, transport vessels and machinery on board
- Noise emissions
  - Drilling and mineral mining
  - Vessels
- Light emissions
  - Vessels

Besides emissions, mineral mining causes physical damage to the seafloor. In the sub-paragraphs below, emissions and other disturbances by oil and gas development and mineral mining are further described.

<u>Oil and gas</u>

In Table 4.1 an overview of the main environmental risks of oil and gas exploitation is presented. As mentioned before, vessels will be used for potential oil and gas development in the high seas, instead of fixed platforms. Installation of platform and pipelines and decommissioning could therefore be considered as not relevant for the high seas. After drilling the well(s), the oil and/or gas will be exploited with the FPSO vessel. The produced mixture will be separated on board of the vessel into oil, gas and water. The stabilised oil/gas will be stored in a tank. This oil/gas will be transported to shore by means of a shuttle tanker when the storage tank is full.

Although exploitation of subsea gas hydrates is probably many decades away, their extraction could involve large scale disturbance of the seabed and consequent effects on seep communities (Juniper, 2001).

Table 4.1 Overview of the main environmental risks of oil and gas exploitation (based on Holthaus *et al.*, 2004).

Activity	Relevant environmental risk	Affected area	Time period of recovery
Transport and installation of the platform and pipelines	Disturbance of benthic biota	Mooring of the floating production unit	long
Drilling activities	Elevated concentration of suspended material in the water phase	Local	short
	pH effects in the water phase	Local	short
	Disturbance of benthic biota	Local	short
	Emissions to air	Global/regional	long
	Noise emissions	Local	short
	Light emissions	Regional	short
Production activities	Toxicity in the water phase	Local	short
	Emissions to air	Global/regional	long
	Noise emissions	Local	short
	Light emissions	Regional	short
Export of oil and gas	Emissions to air	Global/regional	long
	Noise emissions	Local	short
Transport activities	Emissions to air	Global/regional	long
Decommissioning activities	Disturbance of benthic biota	Local	short
	Emissions to air	Global/regional	long

Minerals

Although commercial mineral mining does not take place in the Area, there are techniques available that could potentially be used for future developments. In national seabed areas use is made of a remotely operated mining vehicles (ROV), which by adding a cutterhead and a (floating) surface-connection chain are suitable for mineral mining on the ocean floor. A specially build vessel transports, stores and partially processes the sludge that is being pumped up by the ROV. The sludge and minerals will be separated onboard with various techniques available, resulting in an amount of debris to be discharged.

Direct adverse impacts of mineral mining may include physical damage and destruction. Indirect adverse impacts may include sedimentation and disrupted water circulation systems, elevated concentration of suspended material in the water phase and (re-)introduction of sediment substances in the water column.

The sulfurous waste-products of mineral mining are of risk to the environment when deliberately or accidentally released into the marine environment, along with the waste-water from some treatments.

The actual mining or collecting of nodules will, site dependent, cause sediment plumes by disturbing the seafloor.

Conclusions on emissions

- There are currently no emissions from mining activities;
- Main emissions from oil and gas activities will be drill cuttings and –fluid and produced water;
- Main emissions from mineral mining will be debris after separation on board;
- Besides emissions mineral mining causes physical damage of the seabed.

4.4 Assessment of ecological effects

Certain characteristics of deep-sea habitats make them particularly vulnerable to human impacts. They generally have low productivity, growth and colonisation rates and are therefore highly sensitive to disturbance. They also tend to be long-lived and to reproduce late in life, which means that the removal of large numbers of individuals can potentially drive them to extinction (POST, 2007). The critical habitats of the high seas with the potential threats from mining activities are presented in Table 4.2.

Table 4.2 Overview of the habitats present within the high seas, the potential threats to those resources resulting from mining activities, and potentially affected ecological resource (adapted from Cripps & Christiansen, 2001)

Critical habitats	**Impacts from mining**	**Ecological resource**
Hydrothermal vents	Sea-bed mineral extraction	Benthic
Cold-water seeps	Petroleum exploitation	Benthic
Manganese nodules	Deep-sea quarrying[24]	Benthic
Gas hydrate zones	Methane exploitation	Geological features / benthic
Trans-boundary stock breeding / juvenile areas	Petroleum exploration and production	Benthic / demersal / pelagic

In the sections below, potential ecological effects of oil and gas development and mineral mining are further described.

Oil and gas

Exploitation of subsea petroleum reservoirs in proximity to seeps is already underway in the Gulf of Mexico. The nature of platform- or vessel-based oil exploration and production tends to limit disturbance to local effects. A more widespread impact may come from the exploitation of subsurface gas hydrate deposits. These reserves of methane ice occupy significant volumes within the seabed of continental margins worldwide. Recent global estimates of gas hydrate reserves greatly surpass total known world petroleum reserves. As mentioned before, exploitation of subsea gas hydrates could involve large scale disturbance of the seabed and consequent effects on seep communities (Juniper, 2001).

Minerals

Seamounts create their own micro-environment by enhancing local currents, which winnow away sediments, enhance local productivity and aggregate prey. They often have a unique fauna dominated by corals and other suspension feeders on the seafloor and fishes, such as orange roughy (*Hoplostethus atlanticus*) and pelagic armourhead (*Pseudopentaceros wheeleri*), that aggregate above the bottom (Koslow, 2001).

Deep-sea hydrothermal vents and seeps contain a large number of endemic and unusual species and are refuges for close relatives of ancient forms of life. Hydrothermal vents in particular show a unique range of habitat diversity such that adaptations of organisms to some niches are not, today, paralleled at other sites on the planet. Vent organisms have the genetic potential to grow and survive in an extreme range of conditions which were formerly present at various times on Earth over millions of years (Juniper, 2001).

Environmental issues of deep-seabed mineral mining, centre on damage to seabed habitats, alteration of geological processes and the release of plumes of material into the water column. A Background Paper on Deep-sea Hydrothermal Vents (Juniper, 2001) describes the ecological effects of mineral mining as follows: "Extracting minerals will result in removal of the substratum and production of a plume. Some organisms will be directly killed by mining machinery, while others nearby risk smothering by material settling from the plume. Individuals surviving these perturbations would be subject to a radical change in habitat conditions

[24] A quarry is a type of open-pit mine from which rock or minerals are extracted

with hard substrata being replaced by soft particulates settling from the mining plume. These particulates could also clog hydrothermal conduits, depriving established vent communities of their vital fluid supply. Removal of sections of the sulphide deposits will also change the subsurface hydrology beneath the vent openings, possibly decreasing or stopping hydrothermal fluid flow to remaining vents. At sediment covered hydrothermal sites, where much of the ore body lies within a sediment overburden, digging out the deposit would produce a much more extensive plume that could completely eradicate the local vent fauna. It is not currently possible to predict how rapidly sites may recover from mining operations. This will in part depend on the extent to which local sites of hydrothermal vent fauna have been destroyed and also on whether there are other sites within larval recruitment range to allow re-colonisation of suitable sites. It is important to realise that the long-lived vent fields that host the largest mineral deposits are likely to be the most ecologically stable and have the highest biodiversity. Such sites may be regional sites of species origin and dispersal." The author concludes that there is no imminent threat to the global vent or seep faunae from mining or any other human activity. Concentration of activities at certain sites could, however, produce local and even regional effects on biological processes and organism abundance, to the point where the scientific value of the site could be compromised and, eventually, the survival of some species could become an issue (Juniper, 2001).

Semi-quantitative estimation

A semi-quantitative estimation of the impact of mining on the high seas is presented in Table 18.1.

Conclusions

- Main effects of oil and gas activities are expected to be local;
- A more widespread impact may come from the exploitation of subsurface gas hydrate deposits;
- Mineral mining will cause damage to seabed habitats, alteration of geological processes and the release of plumes of material into the water column;
- The long-lived vent fields that host the largest mineral deposits are likely to be the most ecologically stable and have the highest biodiversity;
- Mineral mining activities could produce local and even regional effects on biological processes and organism abundance.

4.5 Assessment of socio-economic importance

With advances in technology by the late 1960s, it appeared that harvesting of the polymetallic nodules in the deep oceans would become a commercial reality. The results from mining polymetallic nodules would however economically benefit only a few developed countries that possess the necessary capital and technology, in view of the fact that the resource lies in international waters (ISA brochure). Many persons thought that this would be unfair.

Interest in mining deepsea metallic deposits dates back to the 1970's when metal prices rose, partially as a result of a concern for shortage of these deposits. This shortage did not evolve, and the predicted financial and technical barriers restrained companies from actual mining efforts (G.P. Glasby, Science 289, 2000). In line with this the regulatory environment was limiting too. Part XI of the UN Convention of the law of the sea (UNCLOS) established an international legal regime governing deep-sea mining, ensuring that the profits of deep sea mining in international waters are equitably shared with an emphasis on developing countries. The sharing as laid down in the Convention does not concern the profits of deep seabed mining. Mining companies are to pay fees which may be part of the moneys that will be distributed. Several industrialized countries however refused to sign this convention, considering it an obstacle to the practical development of ocean mineral resources. However, the convention as modified by a 1994 Agreement relating to the implementation of Part XI entered into force in 1996. At present there are only 3 countries worldwide with existing legislation to grant and administer exploration and mining licenses for sub sea mining: Japan, New Zealand and Papua New Guinea.

Seabed minerals in international waters are legally defined as belonging to all nations and are therefore subject to a benefit-sharing scheme through the ISA. The intention is to share commercial benefits with developing countries, especially land-locked ones. The benefit-sharing regime has not been tested in practice, as there is currently no active deep-seabed mining in international waters. It may deter investment in international waters compared with areas within national jurisdiction, due to the increased cost of investment (POST, 2007). There are, however, a number of companies working in the Area (exploratory activities), as indicated in the next section.

4.6 National activities

In 2001, 2002 and 2006, the ISA signed contracts with eight investors for fifteen year of exploration for polymetallic nodules in the deep seabed (ISA, 2007):

- The Government of India
- Institut français de recherche pour l'exploitation de la mer / Association française pour l'étude et la recherche des nodules (IFREMER/AFERNOD) of France
- Deep Ocean Resources Development Company (DORD) of Japan
- State Enterprise Yuzhmorgeologiya of the Russian Federation
- China Ocean Mineral Resources Research and Development Association (COMRA) of the People's Republic of China
- Interoceanmetal Joint Organization (IOM), a consortium formed by Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia
- The Government of the Republic of Korea
- Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany

These contractors are allowed to explore for polymetallic nodules in specified parts of the deep oceans outside national jurisdiction. Under the Regulations, each contractor has the exclusive right to explore an initial area of up to 150,000 square kilometres. Over the first eight years of the contract, half of this area is to be relinquished. Seven of the exploration areas are in the Central Pacific Ocean south and southeast of Hawaii, and one is in the middle of the Indian Ocean.

Although not active in the Area, Nautilus Minerals Inc. is the first company to commercially explore the seafloor for high grade massive sulphide deposits. The company, with its home office in Canada, holds more than 300,000 km^2 of tenement licences and exploration applications in the territorial waters of Papua New Guinea, Fiji, Tonga, the Solomon Islands and New Zealand along the western Pacific Ocean's Rim of Fire.

4.7 Trends

<u>Productivity and economics</u>

Halfway the 19th century subsea oil and gas extraction became technically and economically feasible due to technological improvements and increasing fuel prices. Transport to shore distances and water depth were restricting parameters and restrained the majority of the offshore industry projects from the open sea. With ongoing technological improvements deeper waters came in reach, with nowadays oil production up to 3 kilometers depth (Gulf of Mexico).

Fossil fuels stocks however are diminishing, and with the depletion of current terrestrial and subsea sources the search for new mining areas and sources has started. With depleting stocks and uncertainty in availability, prices have gone up and explorations are being conducted far out of conventional areas. In terms of depth and distance-to-shore the oil companies are forced to extend their search area seawards, into deeper water.

Environmental regulations

The International Seabed Authority (ISA) is engaged in the tasks of organizing and promoting the development of deep-sea mining in the high seas, and protecting the marine environment from any adverse effects. The function of controlling this potentially valuable industry was assigned to the Authority by the 1982 UNCLOS. The Authority has begun by adopting (in 2000) regulations covering prospecting and exploration for polymetallic nodules in the international area, which apply to all private and public entities under contract with the Authority. It is now working on a similar set of regulations for polymetallic sulphides and cobalt-rich crusts. As at July , 2007, 154 States (including the Netherlands) and the European Community were members of the Authority (ISA, 2007).

For regulating the environmental impact of deepseabed mineral extraction, the ISA has developed an environmental framework for the mining of polymetallic nodules in the international seabed. However, at the moment, the only type of commercial mining being undertaken is of SMS, for which no environmental framework has been developed, as it largely occurs in countries' EEZs (POST, 2007).

ISA rules require prior environmental impact assessments of mining activity, while in national waters rules vary between countries (POST, 2007).

4.8 Future developments

Oil and gas

As mentioned before, there are already oil and gas activities on the continental shelves beyond 200 nautical miles of some States (e.g. Gulf of Mexico and the Atlantic Ocean). Plantegenest *et al.* (2005) report four developments that could draw further attention to the resource beyond 200 nautical miles: (a) the more accessible EEZ resources will be exhausted; (b) exploration could confirm the presence and locations of hydrocarbons beyond 200 nautical miles; (c) continuing improvements to drilling technology will support operations in ever deeper water; and (d) the escalating price of oil could justify the increased cost and complexity of operating in this area.

Much remains to be learned about gas hydrates, and their exploitation as a source of energy will require significant research and development. There is no doubt, however, that hydrates are perceived as a successor to gas and oil once supplies of the latter run out, or once they become to costly to produce (Plantegenest *et al.,* 2005).

Minerals

Mineral mining activities in the coming decades are likely to be concentrated in very limited areas where polymetallic sulphide deposits of commercial size are known to occur (Juniper, 2001). The development of minerals in the Area is not expected to become commercially feasible until at least the second decade of the 21st century (Kimball, 2001). However, continuous technical improvements on the subject of positioning, underwater technology and positioning (JC Wiltshire, 2000) and a growing demand for minerals and oil makes the exploration and actual mining of until now economically not-feasible areas feasible, not in the last since the discovered deposits are highly rich on gold, copper and base metals. Contents of 10 times the average value for economically feasible mineable deposits on land have been prospected off the coast of Papua New Guinea, Fiji, Japan etc in relatively shallow waters (100-2000 m) and within their EEZ's. (ISA "Seafloor polymetallic Sulphide Deposits"ISA tech. 2000). Harvesting them is only possible around "dead" smokers, since the extreme watertemperatures would damage the equipment.

For minerals like copper, mangan, cobalt and nickel the seabed is a pristine mining area. With the depletion of their terrestrial sources and an increasing demand for minerals the deep-sea mining becomes a realistic alternative.

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5 Shipping[25]

5.1 Introduction

Shipping is traditionally an important economic activity at sea. The intensity and importance of the shipping industry is still increasing. It is, however, mainly coastal shipping that will grow intensively. Because this study is focused on the biodiversity of the high seas, coastal shipping is outside the scope of the assessment. Shipping activities in the high seas are related to merchandise trades (tankers, bulk carriers and containerships) and the tourist industry (transcontinental shipping and cruises). Emissions from these activities may affect the biodiversity of the high seas.

The international regulation of maritime safety, security and the environmental impact of international shipping takes place within the International Maritime Organization (IMO). Relevant specific rules are laid down in the International convention on the prevention of pollution from ships (MARPOL 73/78). Other IMO Conventions also contribute indirectly to the protection and preservation of the marine environment against marine pollution, for instance SOLAS (Survival Of Life At Sea), COLREG (Collision Regulations), etc.

Depending on the type of ship and/or the cargo, the following categories of shipping can be distinguished (Figure 5.1):

- Oil tankers;
- Bulk carriers;
- Container ships;
- General cargo (refrigerated cargo, specialized cargo, ro-ro cargo, general cargo (single- and multi-deck) general cargo/passenger);
- Tankers (liquid gas, chemicals and other fluids);
- Passenger ships;
- Other ships.

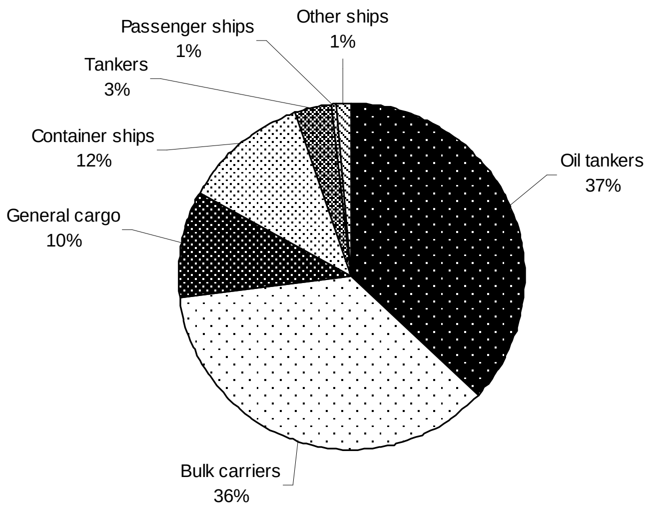

Figure 5.1 Structure of the world fleet by principle types of vessel (based on UN, 2006).

25 Authors: C.C. Karman and J.E. Tamis

The assessment of the ecological impact of the shipping industry on the high seas involves the following steps:

- Assessment of the shipping intensity on the high seas;
- Assessment of the emissions/discharges due to these activities;
- Assessment of the effects of these emissions.

The level of detail and reliability of the assessment differs for each of these steps. The first step can be quantitatively performed with a high level of detail and reliability. Detailed information on vessel movements is available at Lloyd's register. In order to derive the required data, i.e. the shipping intensity per region, a very extensive analysis is required. The second step can also be quantitatively performed, but with a marginal level of detail and reliability. The final step however, can only be performed qualitatively or semi-quantitatively, based on (rough) estimates and thus having a low level of detail and reliability. Because a high level of detail for the effect assessment is not possible, it is not relevant to strive for such a level in the assessment of shipping intensity and emissions. An extensive analysis of vessel movements is therefore not performed. Alternative data on shipping intensities is used from available literature. The same approach is used for the assessment of emissions.

5.2 Assessment of the shipping intensity

The main indicators of operational productivity for the world fleet are the tons of cargo carried per deadweight ton (DWT) and the ton-miles[26] performed per DWT (UN, 2006). Figure 5.2 represents the monthly density plot (October 2007) provided by Amver[27]. The average daily number of ships as reported to Amver in 2006 is 3,185. The highest number of vessels that were on plot for any given day for that year is 3,376 (source: www.amver.com). The world total number of vessels, as of January 2006, is 32,814 (UN, 2006). This indicates that ca. 10% of the total world vessels participate in the Amver system. It is therefore likely that, when multiplying the density numbers from the plot below by 10, more realistic shipping activities are derived. Applying the corrected numbers, the density plot shows that in large parts of the oceans the density is 40 or less vessels per one-degree cell per month. The North Atlantic Ocean has a higher density of 50-140 vessels per one-degree cell per month, as for the major shipping routes in the Indian Ocean and Pacific Ocean. The highest shipping activities occur within the maritime zones of coastal States (coastal shipping). The density of shipping within these maritime zones ranges from 40 or less to more than 500 vessels per one-degree cell per month.

World seaborne trade increased considerably in 2005, reaching 7.11 billion[28] tons of loaded goods (UN, 2006). The majority of trade is shared by Asia, Europe and (North) America. This corresponds with the main navigation and trade routes for international exchange, that are concentrated between 60°N and 30°S (website UN atlas of the world). Figure 5.3 shows the main international maritime routes. Maritime routes are spaces of a few kilometers wide. They are a function of obligatory points of passage (which are strategic places), physical constraints (coasts, winds, marine currents, depth, reefs, ice) and political borders (Rodrigue *et al.*, 2006). The maritime routes are supporting the bulk of the traffic. Although numerous other routes exist, depending on the origin and the destination of the maritime shipment, these are mainly for coastal shipping. Ship traffic on the high seas is thus mainly concentrated within the maritime routes. Pendulum routes[29] have emerged as the favorite form of containerized maritime circulation. The

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26 A ton-mile represents one ton of cargo transported over one mile.

27 Amver is a computer-based, voluntary global ship reporting system used worldwide by search and rescue authorities to arrange for assistance to persons in distress at sea.

28 Billion ton = Giga ton (GT) = 10^9 metric ton = 10^{12} kilogram

29 Involves a set of sequential port calls along a maritime range, commonly including a transoceanic service from ports in another range and structured as a continuous loop. They are almost exclusively used for container transportation with

pendulum route across the Atlantic Ocean, for example, takes ca. 27 days to return in the same port of departure (Figure 5.4).

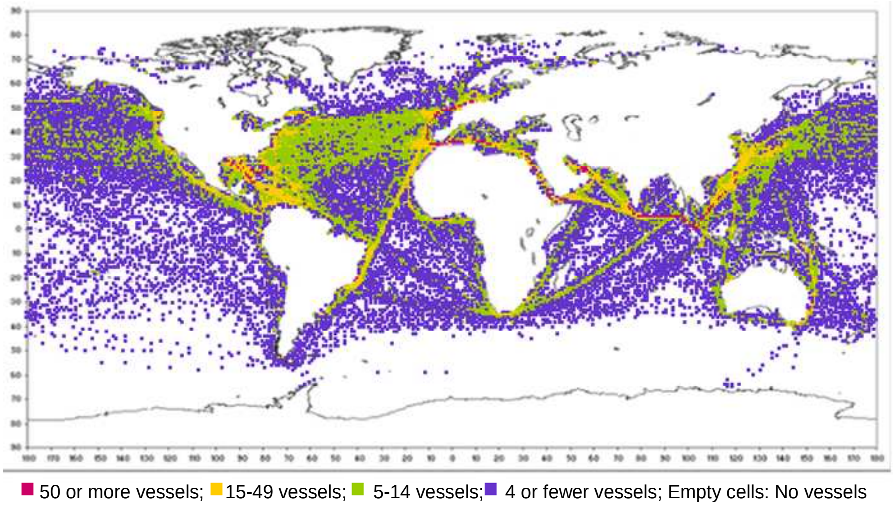

Figure 5.2 Global shipping densities as reported to Amver (source: www.amver.com). This graphic represents the monthly density in October 2007. Each colored dot displayed on the chart approximates a one-degree cell (60 minutes of latitude by 60 minutes of longitude) and is referred to as a "cell" in the legend above.

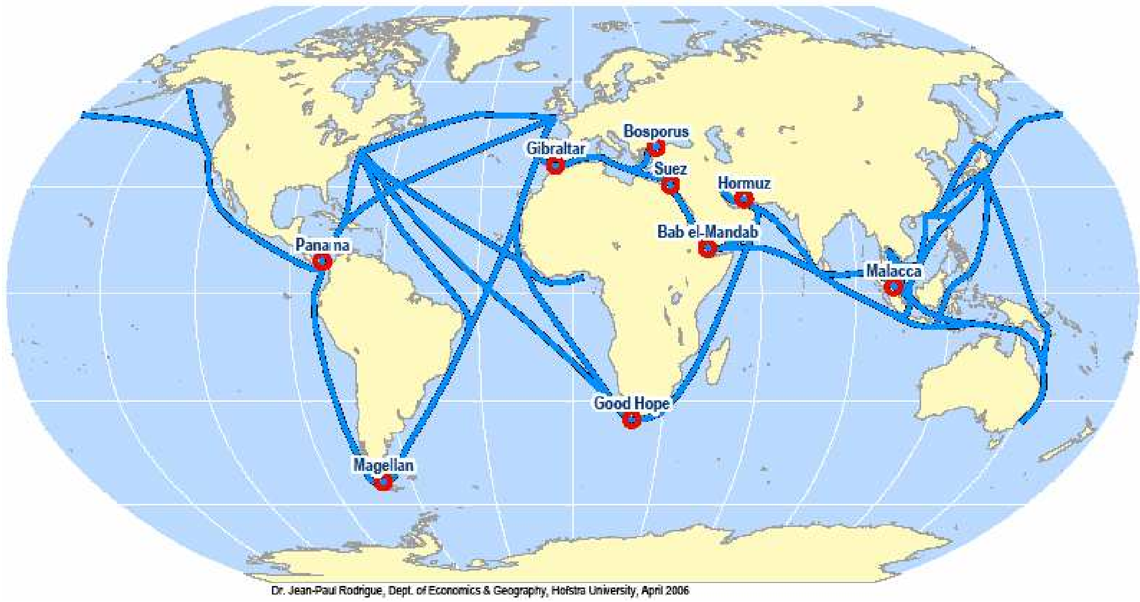

Figure 5.3 Maritime routes (Rodrigue *et al.*, 2006).

the purpose of servicing a market by balancing the number of port calls and the frequency of services (Rodrigue *et al.*, 2006).

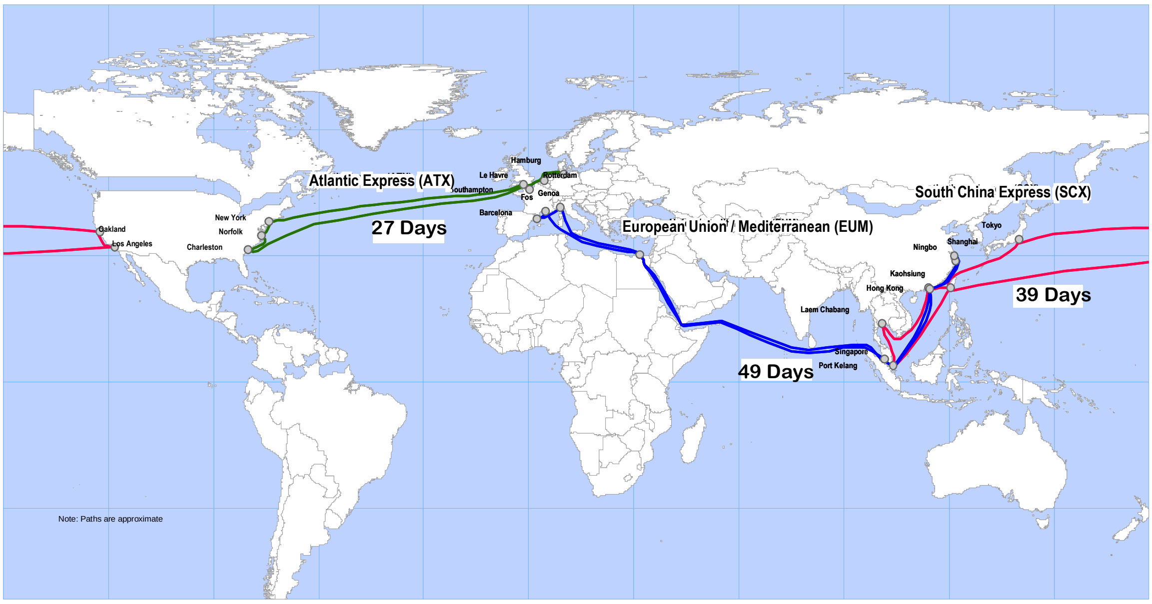

Figure 5.4 Three major pendulum routes (Rodrigue *et al.*, 2006).

A large diversity of goods is shipped in several forms (liquids and solids in packages and bulk). The main cargo is oil, representing 37% of the total goods in 2005. The trade of iron ore, coal, grains and other dry bulk, represents the second largest cargo (UN, 2006). De total productivity of the world fleet in 2005 is 29045 GT mile (Table 5.1). The maritime productivity has increased considerably over the years, as presented in Figure 5.5.

Table 5.1 Productivity of the total world fleet in 2005 (UN, 2006)

Type	**Productivity (GT mile)**	**Cargo (million ton)**
Oil tankers	11471	2373 *
Bulk carriers	8524	1684 **
Combined carriers (bulk + oil)	320	65 **
Remaining fleet	8730	2986
Total	29045	7109

* only including oil tankers of > 50,000 dwt
** only including ships of > 18,000 dwt

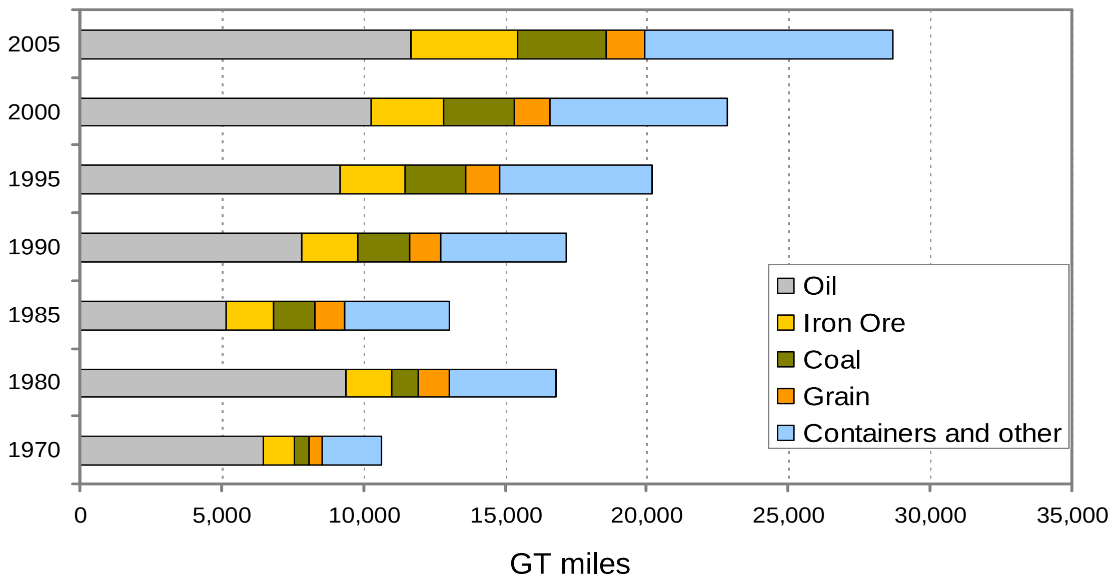

Figure 5.5 Productivity of maritime transport from 1970 to 2005 (Rodrigue *et al.*, 2006).

A schematic of the total amount of the main cargo, oil, transported geographically by sea in one year, clearly shows high traffic intensity on the Atlantic Ocean (Figure 5.6). Over 30 million barrels per day are going through shipping lanes (Rodrigue *et al.*, 2006). These routes are known as chokepoints due to their potential for closure. Disruption of oil flows through any of these export routes could have a significant impact on world oil prices.

Transportation of bulk materials is presented in Figure 5.7. Again, the Atlantic Ocean shows the highest traffic intensity but transport intensity of coal and grain is also high in the Pacific Ocean.

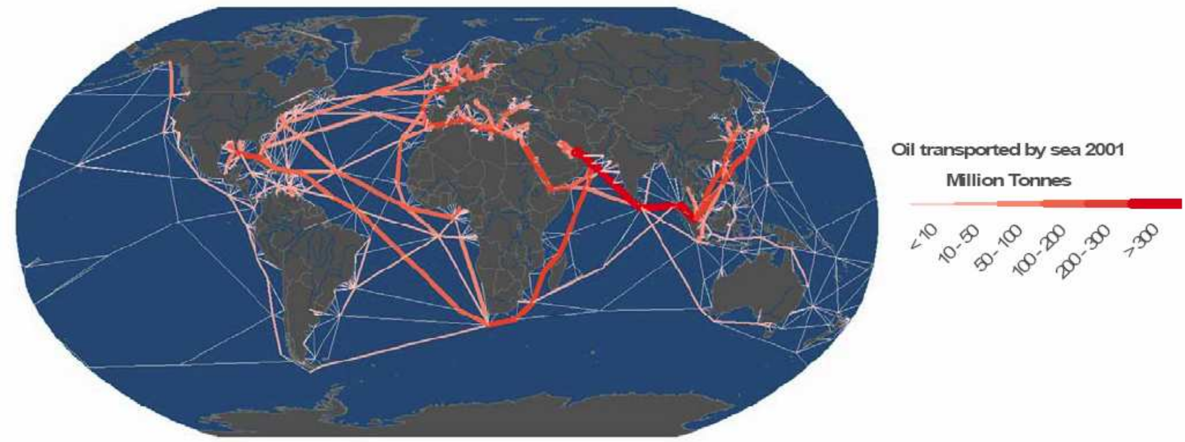

Figure 5.6 Oil transported by sea (O'Hagen, 2007).

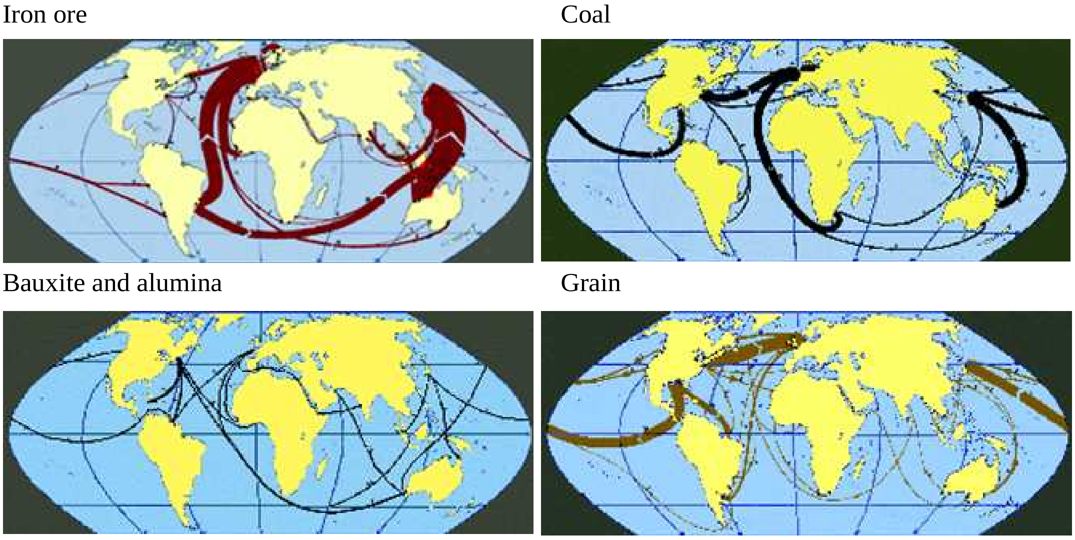

Figure 5.7 Transportation by bulk carriers (UN atlas of the world)

Conclusions on intensity

- The most shipping activities occur on national waters (coastal shipping);
- Ship traffic on the high seas is mainly concentrated within the maritime routes;
- The main navigation and trade routes for international exchange are concentrated between 60°N and 30°S;
- The Atlantic Ocean shows the highest traffic intensity;
- In large parts of the oceans the density is estimated to be 40 or less vessels per one-degree cell per month;
- The North Atlantic Ocean has a higher estimated density of 50-140 vessels per one-degree cell per month, as for the major shipping routes in the Indian Ocean and Pacific Ocean;
- The main cargo is oil, representing 37% of the total goods in 2005.

5.3 Assessment of emissions

Approach

Most of the emission values found in literature are based on world wide shipping activities. These values should thus be corrected to derive the emissions that occur on the high seas. An estimated 64 percent of the oceans lies beyond national jurisdiction (WWF high seas factsheet). Applying a factor 0.64 to derive emission values for the high seas would be too simple, as the traffic density is not equally distributed over all waters (see Amver density plot, Figure 5.2). A rough estimate, based on the Amver density plot, is that the density on national waters is four times higher than on the high seas. Combined with the factor of 0.64 (correction for the surface area) this results in a correction factor of (0.64 * 0.25) 0.16.

Emission sources

The environmental impact is represented by the emission sources and related substances given in Table 5.2. Ship wastes disposed of on land are outside the scope of this study. Sewage water discharge is also a source of pollution from ships. However, on the high seas this is not considered an issue due to the relatively small amounts generated by ships, its organic, biodegradable nature and the open, deep nature of the high seas (Raaymakers, 2003).

Table 5.2 Overview of emission sources and related substances during operational ship activities (MKC, 2006)

Emissions to the air	**Discharges to the sea**	**Wastes to land**
Energy related:	*Hull related:*	
- CO_2	- Bilge water	
- SOx_x	- Ballast water	
- PAH	- Dirty oil	
- NOx	- Tank residues	
- Volatile Organic Components (VOC)	- Antifouling	
	- Cathodic protection	
- Particulate matter (PM)		
System related:	*System related:*	*System related*
- Halons	- Sewage water	- Sludge
- CFC	- Propeller shaft lubrication	
- HCFC	- Fouled cooling water	
Cargo related:	*Cargo related*	
- oil vapours	- Cargo residues	
- chemicals, mainly VOC		
	Crew related	*Crew related*
	- Garbage	- Garbage

Oil: Accidental spills

Accidental spills can be caused by many factors, such as heavy storms or technical failure. Pollution by accidental spills is mainly related to oil. This is not surprising as appr. 37% of the seaborne cargo is oil.

Most spills from oil tankers result from routine operations such as loading, offloading and bunkering which normally occur in ports or at oil terminals. These are mainly small spills, which do not contribute as much as major oil spills to the overall amount of oil entering the sea by accidental cause (ITOPF, 2007). Large spills are often caused by collisions or groundings and therefore many of those do not occur on the high seas. Fire and explosions could also occur at the high seas. However, the main cause of oil spills on the high seas is technical failure (Raaymakers, 2003).

Because no information on the amount of oil that is spilled on the high seas has been found in available literature, this emission has to be estimated. The estimated emission is based on all oil spills since 1974 and assumptions on the occurrence of accidents on the high seas (Table 5.3). As mentioned above, it is assumed that incidents caused by operations and groundings do not occur on the high seas. Collisions may occur, but since traffic intensity is relatively low, this is assumed to be only 10% of the total incidents. Because technical failure is the main cause of all incidents on the high seas, it is estimated that 75% of all hull failures occurs at the high seas. Because for fire and explosions and other causes there seems to be no relation to the location, is assumed that 50% occurs on the high seas. The assumptions lead to the overall estimate that 20% of the oil spills occur on the high seas. To check whether this estimate is realistic, a list of major oil spills has been analyzed. Of the top twenty oil spills since 1976, only 3 occurred on the high seas (Figure 5.8 and Table 5.4). A total of 2526 thousand tons of oil was spilled, of which 487 thousand ton was spilled on the high seas. In percentages this equals 15% of the number of spills and 20% of the spill size. Our estimate, that 20% of all oil spills occur on the high seas, seems therefore realistic.

Since 2000, a yearly average quantity of approximately 25 thousand tons of oil enters the sea by oil spills from tankers (ITOPF, 2007). Based on the estimation above, it is assessed that the yearly emission by accidental spills on the high seas is approximately 5,000 ton of oil.

Table 5.3 Cause of oil spills, worldwide from 1974 to 2006, based on ITOPF (2007)

Cause	**Number of incidents**	**Assumed occurrence on the high seas**	**Estimated number of incidents on the high seas**
Loading / discharging	3183	0	0
Bunkering	574	0	0
Other operations	1235	0	0
Collisions	566	10%	57
Groundings	575	0	0
Hull failure	709	75%	532
Fire and explosions	133	50%	67
Other or unknown	2353	50%	1177
Total	*9328*	*20%*	*1831*

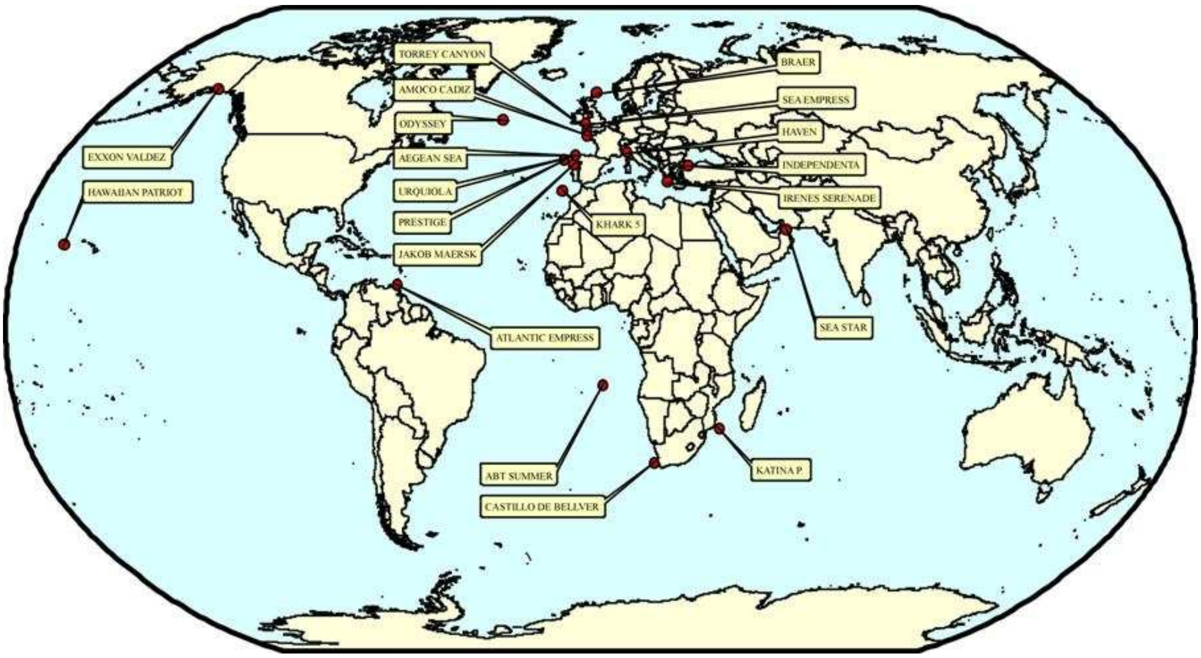

Figure 5.8 Location of major oil spills (ITOPF, 2007).

Table 5.4 Major oil spills on the high seas (ITOPF, 2007)

Ship	**Year**	**Location**	**Spill size (tonnes)**
ABT Summer	1991	700 nautical miles off Angola	260,000
Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132,000
Hawaiian Patriot	1977	300 nautical miles off Honolulu	95,000

Oil: Operational discharges and emissions

Operational discharges of oil into the marine environment by ships depend on several factors, such as type and age of ship; level of maintenance of ship and engines and presence of oil-water separators (GESAMP, 2007). Under MARPOL 73/78, Annex I, discharges of oil are strictly regulated (IMO, 1997). The main discharge regulations are: the total quantity of oil which a tanker may discharge in any ballast voyage whilst under way must not exceed 1/30,000 of the total cargo carrying capacity of the vessel; the rate at which oil may be discharged must not exceed 30 litres per mile travelled by the ship; and no discharge of any oil whatsoever must be made from the cargo spaces of a tanker within 50 miles of the nearest land. As from 1997, for non-tankers of 400 grt and above, the permitted oil content of the effluent which may be discharged into the sea is 15 parts per million.

The GESAMP[30] (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2007) estimated that the total amount of oil entering the sea annually from operational activities would be approximately 208 thousand tons (Table 5.5). This estimated amount is for both national as international waters. This value should thus be corrected to derive the emissions that occur on the high seas. Applying the correction factor 0.16 (as explained before) to the total amount of oil entering the sea annually from operational activities, it is calculated that ca. 33,265 ton/yr enters the high seas by operational discharges.

Table 5.5 Operational oil discharges from ships (GESAMP, 2007)

Source	**Oil quantity (tons/yr)**
Ship related	
Fuel oil sludge	186,120
Bilge oil	1,880
Oily ballast from fuel tanks	907
Cargo related tanker activities	19,000
Total	207,907

Chemicals: Accidental spills

Only 1% of the cargo transported by sea consists of chemicals (UN, 2006). Dangerous substances transported by sea can have the following properties: flammable, explosive, corrosive, reactive, toxic, carcinogenetic, mutagen and/or radioactive. The fate and behaviour of substances released into the ocean can also be very diverse, such as persistent or biodegradable, sinking, floating, volatile and/or dissolving. Because transport of chemicals and chemical spills are not substantial and the diversity of substances is

30 The Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) is an advisory body, established in 1969, that advises the United Nations (UN) system on the scientific aspects of marine environmental protection. At present it is jointly sponsored by eight UN organizations, such as the International Maritime Organization (IMO), the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO-IOC). GESAMP functions are to conduct and support marine environmental assessments, to undertake in-depth studies, analyses, and reviews of specific topics, and to identify emerging issues regarding the state of the marine environment (source: http://gesamp.net).

high, as are the behaviour and effects of those substances, it is considered not feasible to include accidental spills of chemicals within the scope of this assessment.

Chemicals: Operational discharges

The discharge of dangerous substances is regulated by MARPOL 73/78 Annex II (IMO, 1997). Substances are categorised and regulated according to their category. As of 1 January 2007, a revised Annex II has entered into force. The revision includes a new four-category categorization system for noxious and liquid substances (Cat. X, Y, Z and other). The revised Annex also requires vegetable oils, which were previously categorized as being unrestricted, now to be carried in chemical tankers. For ships constructed on or after 1 January 2007 the maximum permitted residue in the tank and its associated piping left after discharge will be set at a maximum of 75 litres for products in categories X, Y and Z - compared with previous limits which set a maximum of 100 or 300 litres, depending on the product category. Approximately 1% of the total world fleet consists of chemical and miscellaneous tankers (0.9% and 0.1% respectively) (UN, 2006).

The world total number of vessels, as of January 2006, is 32,814 (UN, 2006). The discharge from chemical and miscellaneous tankers would than be (32814*1%*(75 to 300)/1000=) 25 to 100 ton/year per voyage. The voyage frequency of tankers is between 8 and 40 voyages per annum (IMO, 2007). Assuming an average voyage frequency of 24, this results in 600 to 2400 tons/year of chemicals, including vegetable oils.

A different approach for estimating the emission of chemicals is to use the estimated quantity of operational oil discharge, based on cargo related oil discharges (e.g. tank washings). It has been estimated that 19000 tons oil/year is released by cargo related operational discharge (IMO, 2007). Approximately 37% of the total world fleet consists of oil tankers (UN, 2006). Based on the ratio of maritime trade in oil/chemical of appr. 37/1, it can be estimated that 514 ton/year of chemicals is discharged. This estimate is slightly lower than the above, resulting in an overall estimate of ca. 500-2400 ton chemicals per year.

Litter

The discharge of garbage is regulated by MARPOL 73/78 Annex V (IMO, 1997). The amount of litter that is yearly dumped into the oceans is estimated to be 5.6 million ton (Raaymakers, 2003). Although it is hardly possible to assess the exact amounts, it is clear that plastics form an important contribution to this discharge (Derraik, 2002). Of particular concern are mass concentrations of marine debris in high seas 'sink' areas, such as the equatorial convergence zone. In some such areas, 'rafts' of assorted debris, including various plastics, ropes, fishing nets, cargo-associated wastes such as dunnage, pallets, wires and plastic covers; drums and shipping containers along with accumulated slicks of various oils, often extend for many kilometers (Raaymakers, 2003).

Various organic micro-pollutants (i.e., polychlorinated biphenyls: PCBs, DDE, and nonylphenol) have been detected in plastic resin pellets (Mato *et al.*, 2001). Plastic resin pellets could therefore serve as both a transport medium and a potential source of toxic chemicals in the marine environment.

Based on estimates of the amount of marine litter found in literature (Derraik, 2002; Raaymakers, 2003), it is concluded that ca. 5 million pieces of garbage which are thrown overboard or lost from ships enters the seas and oceans every day. Approximately 60% to 80% of the garbage in sea is plastics. Approximately 13,000 to 46,000 pieces of plastic per square mile float daily on the oceans. As much as 70% of the entire input of marine litter could sink to the bottom and is found on the seabed, both in shallow coastal areas and in much deeper parts of the oceans. This means that ca. 3,5 million pieces of litter could accumulate on the seafloor per day. When correcting these values for the surface area (64%) and shipping density (25%) to estimate the amount of litter that is dumped into the high seas, the following values are derived (Table 5.6):

Table 5.6 Amount of litter entering the marine environment

Litter	Oceans and seas	High sea
Total pieces of litter	5 million per day	800 thousand per day
Pieces of plastic	3 to 4 million per day	480 to 640 thousand per day
Pieces of plastic floating on the surface	13,000 to 46,000 per square mile	2,080 to 7,360 per square mile
Pieces of litter sinking to the sea floor	3,5 million per day	560 thousand per day

Antifouling

To reduce fouling of the hull during the operations of a ship, a special anti-fouling coating is applied to the ship's hull. These coatings inhibit the growth of organisms through the controlled release of biocides. The most common and effective chemical used to date in anti-fouling paints has been tributyl tin (TBT). However, TBT causes many environmental problems. In 2001, IMO adopted a new International Convention on the Control of Harmful Anti-fouling Systems on Ships, which will prohibit the use of harmful organotins in antifouling paints used on ships and will establish a mechanism to prevent the potential future use of other harmful substances in anti- fouling systems. This Convention will enter into force on September 15, 2008.

DNV (Det Norske Veritas) calculated the TBT emission from ships to be (DNV, 1999): Tankers 252.8 ton/yr, bulk carriers 220.5 ton/yr, general cargo 150.2 ton/yr, containers 57.1 ton/yr and other ships 119.1 ton/yr. The TBT emission by worldwide shipping (above 100 GRT) is estimated between 750 and 1500 ton per year.

Another study, by Meijerink (2003), estimated the TBT release from coatings on the Dutch Continental Shelf (DCS). The average wet surface of a ship was calculated at approximately 3500 m^2 with a TBT emission of 4 $\mu g/cm^2$/day. This equals an emission of 140 gram TBT per ship per day. In 2006, the world total number of vessels (of 1000 grt and above) was 32,814 (UN, 2006). The worldwide TBT release from ships is therewith calculated at 5.6 ton/day or 1677 ton/year. An emission of 1500 ton TBT per year, as described above, seems therefore realistic. When correcting this value for the surface area and traffic density, a total amount of ca. 240 ton/yr enters the high seas.

Exotic species

A species is considered to be an exotic species to a certain area when it originally never occurred in that area. Natural barriers prevented the settlement of exotic species by natural dispersion. Only when human activities (e.g., shipping, shellfish transfers, digging canals etc.) transport such species across these natural barriers, they may establish themselves in new areas. In these new areas, these species are called exotics. Many exotic species are transported across natural barriers, but only a minority establishes itself in the newly reached region. Of the established exotic species most remain uncommon, but again a minority shows strong population development. And of the strongly developing exotic species a few appear to be harmful to the receiving ecosystem and to functions of this ecosystem (Wijsman & Smaal, 2006).

Examples of invasive species are: the North American comb jelly in the Caspian Sea which feeds excessively on zooplankton, depleting stocks and altering the food web and ecosystem function; the golden mussel in South America, which fouls up structures and affects the feeding patterns of local fish, causing fish stocks to fall; and toxic algae (red tides), such as toxic dinoflagellates, that can cause massive kills of marine life through oxygen depletion, release of toxins and/or mucus (IMO, 2006). Most of the invasions have taken place in coastal habitats and have been attributed to the release of ballast water by ships (Briggs, 2007).

The introduction of invasive species into new environments through ships' ballast and the fouling of ships' hulls is considered one of the main threats to the world's oceans (White & Molloy, 2001). It is estimated that at least 7,000 to possibly more than 10,000 different species of marine microbes, plants and animals may be carried globally in ballast water each day (Raaymakers, 2003).

The potential risk of species that are introduced in a new environment is based on the probability (chance of successful introduction) and consequence (impact). The introduction of exotic/non-indigenous species does not in all cases cause damage to the receiving marine environment as the majority of the species that manage to survive the voyage are unable to establish viable communities in the new area. The significance of the effect that the establishment of exotic species may have on the local ecosystem depends on the life history of the species involved and a chain of events and coincidences within the system. It is not feasible to get a complete knowledge of this system and to forecast the future development. However, it has been estimated that ca. 10% of introduced species will lead to an invasion and that ca. 10% of these invasions will lead to a plague (Van der Wijden *et al.*, 2005).

Besides an ecological impact, the introduction of exotic species can also have economic, social and safety related impacts. Substantial ecological impact will in many cases also affect the other aspects. Reduction of the fishery/aquaculture production or tourist attraction will, for instance, have economic and social impacts. Safety could be at risk when, for instance, toxic algal blooms occur in areas that are used for swimming or shellfish production. On the other hand, there are circumstances possible where economic impact can occur without a substantial change of the ecosystem. This is for instance the case when exotic fouling organisms are clogging cooling water pipes. However, most of these problems are only relevant for coastal areas. With ballast water also bacteria, viruses and parasites can be introduced, causing diseases of wild flora and fauna. These introductions can have an important effect on the ecosystem (Wijsman & Smaal, 2006).

Ballast water is discharged in harbours when the ship is receiving its load. However, to reduce the risk of exotic species within coastal waters, it is recommended to exchange ballast water on open sea, assuming that coastal bound species do not survive in the oceans. The text of Regulation B-4 of the Ballast Water Convention (not in force) is: "whenever possible, conduct such Ballast Water exchange at least 200 nautical miles from the nearest land and in water at least 200 metres in depth, taking into account the Guidelines developed by the Organization" (IMO, 2004). However, there are always exceptions and such species may be carried by ocean currents to be dispersed into new areas (Raaymakers, 2003).

Sea dumping

Sea dumping, as defined by the London Convention, involves the dumping at sea of wastes that have been loaded onto a vessel or aircraft specifically for the purpose of disposal. Under the 1996 Protocol to the London Convention, those wastes are now restricted to 'clean' dredge materials, sewage sludge, fish wastes, vessels and platforms, inert inorganic geological material, organic material of natural origin, and bulky items comprising iron, steel, concrete and similarly unharmful materials. For practical reasons (time and costs), sea dumping is mainly restricted to the area within the national boundaries.

It has to be noted that this type of pollution is not related to operational discharges from shipping activities and can be considered as a separate activity. Therefore this emission category is not further included in this assessment. Furthermore, because of the 1996 Protocol, the potential effects of these emissions are mainly related to physical impacts, assuming full compliance.

Emissions to air

There are many studies on air pollution from ships, as emissions from shipping contribute significantly to the concentrations and fallout of harmful air pollutions. In 1996, ships contributed 1.8 % of the world's total carbon dioxide (CO_2) emissions (IMO, 2007). For NO_x and SO_x, the contribution from shipping in the year 2000 was 11% and 7%, respectively (Eyring et al., 2007). In a recent unpublished IMO study on air pollution from ships it is calculated that annual emissions from the world's merchant fleet have already reached 1.12 billion tonnes of CO_2, or nearly 4.5% of all global emissions of the main greenhouse gas (source: the Guardian of Wednesday February 13, 2008, at

http://www.guardian.co.uk/environment/2008/feb/13/climatechange.pollution).

Applying the correction factor of 0.16 (as described before), it is estimated that 179 million ton/yr CO_2 is emitted by shipping on the high seas. The global ocean absorbs most of the anthropogenic CO2 released to the atmosphere (Bates & Peters, 2007). It has been reported that the oceans absorb 102 billion tonnes of CO_2 per year and release 100 billion tonnes back into the atmosphere (The Royal Society, 2005). A yearly amount of 2 billion tonnes of CO_2 is thus retained in the oceans, making the oceans an important CO_2 sink. Assuming all CO2 released from shipping on the high seas will be absorbed in the oceans, it contributes with nearly 0.2% to the total oceanic CO_2 absorption.

The 1997 Protocol to MARPOL 73/78 (containing its Annex VI) was put in place by the IMO to restrict emissions of SO2 and NOx from international shipping. This included a global sulphur cap of 4.5% for bunker fuel and a 1.5% limit for the Baltic Sea and North Sea (Dore et al., 2007). Estimated numbers on emissions of gas from ships are provided in Table 5.7

Table 5.7 Several estimates of emissions of gas from ships (kton/jaar)

NOx (kton/yr)	**SOx (kton/year)**	**Reference**
11704	8480	Davies *et al.* (2000)
9800	5500	DNV (1999)
7070	5780	Takarada (1996)
	6300	Endresen *et al.* (2005)
9525	*6515*	*Average*

Based on the average values of the estimates found in literature (Table 5.7) and a correction for the emissions on the high seas versus the global ship emissions, an estimated value of 1524 kton NOx/yr and 1042 kton SOx/yr is emitted from ships on the high seas. Assuming the emissions to air will be deposited over the entire high seas surface, the deposition can be estimated at 1.4 $mg/m^2/yr$ for nitrogen and 2 $mg/m^2/yr$ for sulphur. No deposition values were found in literature for the high seas. Comparing our estimated values with literature values for the area within and outside the territorial waters, it shows that our estimates are relatively low. The maximum deposition of sulphur from shipping outside the territorial waters is estimated between 101 and 350 $mg/m^2/yr$ (Davies *et al.*, 2000). In the study of Dore *et al.* (2007), wet deposition numbers from shipping activities within the UK are reported at 95 $mg/m^2/yr$ for sulphur and 169 $mg/m^2/yr$ for nitrogen. The difference is mainly caused by our assumption that the emissions are distributed over the entire high seas surface and because the literature values are for the area within the EEZ where shipping densities are higher. In the proximity of shipping routes, the deposition will be much higher than the rest of the surface. Sulphur for example only stays a few days in the atmosphere (Endresen *et al.*, 2005). The deposition numbers for sulphur and nitrogen are therefore estimated at 2 to 350 $mg/m^2/yr$ and 1 to 169 $mg/m^2/yr$ respectively.

Noise and physical disturbance

A threat to biodiversity that is diffuse and hard to assess but, nonetheless, of great concern is marine noise pollution. There is a vast collection of evidence of cetacean reactions to boat traffic and shipping noise, which is summarized by Simmonds *et al.* (2004). Noise from ships dominates marine waters and originates from the ships' propellers, machinery, the hulls passage through the water and the increasing use of sonar and depth sounders. Most marine shipping has a low frequency range i.e. less than 1kHz (Table 5.8) that coincides with the frequencies used, in particular, by baleen whales for communication and other biologically important activities. In general, older vessels produce more noise than newer ones and larger vessels produce more than smaller ones. It has been noted in literature that noise from a supertanker (at 6.8 Hz) could be detected 139-463 km away (Simmonds *et al.*, 2004). Effects of noise on marine mammals are briefly described in section 5.4 of this chapter and further dicussed in chapter 15.6.

Table 5.8 Frequencies produced by shipping and their source levels (Simmonds *et al.*, 2004)

Type of vessel	Frequency (kHz)	Source level (dB re 1µPa)
Tanker (135m)	0.43	169
Tanker (179m)	0.06	180
Supertanker (266m)	0.008	187
Supertanker (340m)	0.007	190
Supertanker (337m)	0.007	185
Containership (219m)	0.033	181
Containership (274m)	0.008	181
Freighter (135m)	0.041	172

The physical presence of a vessel poses a risk for marine mammals by disturbance and potential collisions. Most collisions occur in the waters above the continental shelf, reflecting high usage by both vessels and cetaceans. Of 58 collision accounts examined, over 90% of incidents (53 accounts) occurred either above the continental shelf or shelf slope (Dolman *et al.*, 2006). Since collisions do not often occur and most are within the national boundaries, physical disturbance is not further included in this study.

Summary and conclusions on emissions

Table 5.9 summarises the emissions from shipping on the high seas, as described in the sections above. The table also indicates the reliability of the values.

- Operational shipping activities lead to a range of emissions to the sea, from slow release of anti-fouling substances from the hull to the discharges of tank sludges;
- Emissions of oil are mainly related to operational discharges;
- Two of the main threats to the world's oceans are invasive species and litter;
- Invasive species can be introduced into new environments through ships' ballast and the fouling of ships' hulls. It has been estimated that ca. 10% of introduced species will lead to an invasion and that ca. 10% of these invasions will lead to a plague;
- ca. 5 million pieces of garbage which are thrown overboard or lost from ships enters the seas and oceans every day. Of particular concern are mass concentrations of marine debris in high seas 'sink' areas;
- Emissions of noise and physical presence of the ships could also affect ecological resources;
- Shipping contributes significantly to the world's total greenhouse gas emissions.

Table 5.9 Emissions from shipping on the high seas

Emission type	Assessed quantity	Reliability
Oil	5,000 ton/yr by accidental spills 33,265 ton/yr by operational discharges	Medium
Chemicals	500 to 2,400 ton/yr	Medium
Litter	800 thousand pieces per day	Low
Antifouling	240 ton TBT per year	Medium
Invasive species (ballast water, fouling)	Not assessed	-
Sea dumping	Not assessed	-
Emissions to air	1042 kton SOx/yr 1524 kton NOx/yr 179 million ton CO_2/yr	Medium
Noise and physical disturbance	169 - 190 dB re 1µPa	High

Low reliability: the value is derived on the basis of rough estimates from literature in combination with additional assumptions/estimates;
Medium reliability: the value is derived on the basis of thorough estimates or calculations from literature in combination with additional assumptions/estimates;
High reliability: the value is derived on the basis of thorough estimates or calculations from literature.

5.4 Assessment of ecological effects

Oil

According to the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) oil is not regarded as a significant pollutant on global scales, although it is a highly visible pollutant and when spilled in large quantities can cause severe local effects (GESAMP, 1997). The effects of an oil spill are mainly limited to the water surface and the upper layer of the water column. Because of the ocean depths and the floating properties of oil, benthos and benthic habitats will hardly be exposed. In general, oil spilled at sea will be dispersed up to 10 meter depth. The main risk of oil at sea is the smothering of birds. If a bird comes into contact with an oil slick it will most likely die of the consequences. Fish and marine mammals could be affected by dispersed oil in the water column. For marine mammals, a floating oil slick is also a threat when they come to the water surface for breathing. It is estimated that ca. 5,000 ton/yr of oil enters the high seas by accidental spills and ca. 33,265 ton/yr by operational discharges. Only the oil from spills is relevant for oil slicks as operational discharges involve the emission of dispersed oil that remains mainly within the water column. Based on the threshold value for smothering of 50 µm oil layer thickness (Scholten *et al.*, 1996) and an oil density of 0.7 ton/m^3, a total water surface of 70 km^2 could pose a risk for birds (and marine mammals) due to accidental oil pollution. This is ca. 0.00003% of the high seas surface. It has to be noted, that as the slick floats and moves with wind and currents, it affects a larger area.

Acute toxic effects of operational oil discharges are minimal because of the MARPOL 73/78 regulations and the high dilution at the open ocean. With accidental spills, the concentration in the water column can reach (sub)lethal toxic levels for fish and marine mammals. In general, most species can metabolise organic compounds with their detoxification system but there are differences in the activity of this system. These differences are between groups of species, species and even between individuals of a species. Most of the hydrocarbons in oil are metabolized through the detoxification system, in contrast to the chlorinated hydrocarbons, such as PCB's. Therefore, birds and marine mammals will generally be protected against biomagnification of oil through the food chain (Scholten *et al.,* 1996).

Chemicals

An evaluation of the MARPOL regulation concluded that in general there will be no acute toxic effects by the regulated discharges (Scholten *et al.*, 1993).

The discharge of vegetable oils (palm oil, soybean oil, coconut oil, etc.) is also included in this category. Effects of vegetable oils are mainly physical. As for mineral oil, it can cause severe local effects. It is however not expected to have a significant impact on high seas biodiversity.

Litter

The main ecological effects of litter are physical (trapping or ingestion of litter). Plastic can also be a source of PCB and other pollution (Mato *et al.*, 2001; Derraik, 2002). Furthermore, the litter can accumulate at the bottom of the oceans where it can suffocate fauna. Of particular concern are the high seas 'sink' areas, such as the equatorial convergence zone. In some of these areas 'rafts' of assorted debris often extend for many kilometers (Raaymakers, 2003; UNEP, 2006).

Harmful effects caused by the ingestion of plastics by birds are reduced food consumption (thus reducing fitness), internal injury, blockage of intestinal track and/or gastric enzyme secretion, diminished feeding stimulus, lowered steroid hormone levels, delayed ovulation and reproductive failure (Derraik, 2002). These effects can lead to mortality or to sub-lethal effects, see also chapter 14 (seabirds). Reduced fitness, for example, could adversely affect long-distance migration and reproduction. Not only seabirds are affected by ingestion of plastics. Turtles, marine mammals and fish are also known to be affected (Derraik, 2002). It has been determined that worldwide at least 267 species are affected by litter (plastic) at sea, 86% of all sea turtles, 44% of all seabirds and 43% of all marine mammals (Derraik, 2002). The ingestion of (plastic) litter has been observed for 111 marine bird species. Birds that feed on the water surface and plankton eating divers are most at risk of ingesting litter (Fanshawe & Everard, 2002).

It has been proven that oceans are contaminated with microscopic fragments and fibres of plastic, which are degradation/disintegration products of larger plastic marine litter items. These fragments and fibres were found in beach and bottom sediments and in the water column. In the study it was also demonstrated that marine organisms, such as barnacles and lugworms, eat the microscopic pieces of plastic (UNEP, 2005).

Because most litter (plastic) is hardly biodegradable, most of the affected ecological resources are considered not to recover. Also, the affected area is considered large (regional) because of this and the fact that it can be distributed easily with currents.

Antifouling

The most harmful emission from antifouling paint on ships' hulls is TBT. IMO (2002) provides an overview of the harmful effects of TBT on the environment. TBT is a broad spectrum algicide, fungicide, insecticide and miticide used in anti-fouling paints since the 1960s. TBT can be broken down in water under the influence of light (photolysis) and micro-organisms (biodegradation) into less toxic di- and monobutyltin. Half-life varies from a few days to a few weeks, but decomposition is slower when TBT has accumulated in sediment - if oxygen is completely excluded, TBT's half-life may be several years. Therefore waters with heavily sedimented bottoms - such as harbours, ports, estuaries - are at risk of being contaminated with TBT for several years (IMO, 2002). The high seas do not fall into this category and it is therefore not likely that TBT will accumulate considerably in the oceans' sediments. However, biomagnification and related effects of TBT on marine mammals and seabirds could be considered relevant for the high seas. Biomagnification of butyltin compounds (including TBT) has been identified for a marine mammal species (harbour porpoise), several bird species (diving ducks) and fish (Strand & Jacobsen, 2005).

Exotic species

An important feature of the ecological impact of harmful aquatic bio-invasions is that they are virtually always irreversible and generally increase over time (Raaymakers, 2003). The initial impacts may be non-existent to minor and invisible. UNEP (United Nations Environment Programme) has identified invasive species in general as the second greatest threat to global biodiversity after habitat loss. GESAMP considers alterations in marine biodiversity due to exotic species introduction highly likely (GESAMP, 1997). However, up to now, there have been no studies found in literature that indicate any species extinctions or loss of biodiversity due to effects of marine invaders (Briggs, 2007).

As mentioned before, the Ballast Water Convention (not in force) describes to exchange ballast water outside the coastal areas, assuming most species will not survive when discharged in the open ocean. If the treaty will be enforced including this provision, this will increase the risk for the high seas. There are indications of an increasing occurrence of mid-ocean algae bloom in the north Atlantic Ocean, in areas where open ocean exchange is undertaken (Raaymakers, 2003).

Emissions to air

Gaseous emissions are mainly CO_2, and NOx, SOx. Some of the gaseous emissions lead to global impacts such as global warming, while others may (also) have a local impact. The emissions of CO_2, SOx and NOx from shipping can cause acidification and eutrofication.

Bates & Peters (2007) found that the absorption of anthropogenic CO2 and atmospheric deposition of sulfur and nitrogen compounds can both contribute to the acidification of the global ocean. They estimated that direct atmospheric acid deposition contributed 2% to 5% to the acidification of surface waters in the subtropical North Atlantic Ocean.

On the high seas there are hardly any sources of sulphur, except for DMS (dimethylsulfide). It is therefore likely that the SOx emissions from shipping would have an impact at the high seas (Endresen *et al.*, 2005). In large areas of the Northern Hemisphere SO_2 emissions from ships are comparable to DMS emissions (Eyring *et al.*, 2007). A global DMS emission of 28,000 kton(S)/yr is calculated by Kloster *et al.* (2005). In comparison, our estimated global ship emission is 6,515 kton SOx or 3,258 kton S/yr. This means that on a global scale, ship emissions of SOx are only ca. 12% of the DMS emissions.

The most sensitive ecosystems can tolerate acidification up to a yearly deposition of 3.2 kg S/ha or 320 mg $S/m^2/yr$ (Davies *et al.*, 2000). The maximum estimated deposition of 350 mg S/m2/yr exceeds this threshold level. Acidification could therefore occur in the proximity of major shipping lanes.

Eutrofication can lead to (toxic) algal blooms, loss of habitat for fish, change in plankton communities, destruction of food chains and lethal effects for fish and bivalves (UN, 1999). No threshold values have been found in literature for nitrogen deposition in oceans. However, for wetlands a threshold value of 5 to 20 kg N/ha/yr, or 500 to 2000 $mg/m^2/yr$, is reported (Davies *et al.*, 2000). The maximum deposition from shipping of 169 $mg/m^2/yr$ does not exceed this limit. It has to be considered however, that the input of nitrogen by atmospheric deposition is relatively small for the oceans. But, during short periods of time (several days), the atmospheric input can be significant in certain areas by heavy rain (Moore *et al.*, 2002). Bates & Peters (2007) found that nitrate deposition did not increase oceanic primary production in the North Atlantic Ocean.

Noise

Besides affecting birds and some fish and invertebrates, noise impacts mainly marine mammals (see also Chapter 15). Simmonds *et al.* (2004) report the possible impacts of noise on marine mammals as follows:

- Physical (damage to ears and body tissue, induction of the “bends”);
- Perceptual (masking of communication and/or other biologically important noises, decreased ability to interpret environment, etc.);
- Behavioural (change in behaviour, displacement from area);
- Chronic/Stress (decreased viability, increased vulnerability to disease, etc.);
- Indirect Effects (reduced availability of prey, increased vulnerability to predation or other hazards, such as collisions with fishing gear, strandings, etc.).

Effects of noise on birds and marine mammals are expected at noise levels above 60 db (A) (TNO, 1994). Noise emitted from ships generally exceeds this level considerably and effects could therefore be expected.

To assess the area in which species could be affected by shipping noise, the distance to which they are disturbed (based on behavioural effects) can be used. Avoidance and changes in behaviour of marine mammals occur over a range from less than one to tens of kilometers (Simmonds et al., 2004). Maximum avoidance distances are reported for beluga whales. Beluga whales observed in the Arctic travelled up to 80km away from the vessel's course and remained displaced for 1-2 days. For fish (cod) this distance is 80 meters (Jak *et al.,* 2000). The disturbance of birds by ships reaches 25 to 500 m distance, depending on the bird species (Jak et al., 2000). Based on these numbers, it can be estimated that the disturbed area per ship is ca. 3 to 20 000 km2 for marine mammals, 0.02 km2 for fish and a maximum of 1 km2 for birds. Because ship traffic on the high seas is mainly concentrated within the maritime routes, which are a few kilometers wide, the main effects of shipping noise are to be expected within those routes. However, for marine mammals effects can occur at much greater distance.

Food chains

Food chains can be affected by ship emissions through biomagnification or disturbance/destruction of the chain by affecting key species. Biomagnification means that the internal concentration of toxic substances increases with each step in the food chain. Toxic substances released to the oceans by shipping are oil and chemicals. Biomagnification of oil is considered not significant. Biomagnification does occur with chemicals, such as chlorinated hydrocarbons and TBT. The emissions of chemicals in general are not included in this study. Emissions of TBT by shipping are considered significant and traces of this compound have been found in marine mammals, absorbed via the food chain.

Semi-quantitative estimation

A semi-quantitative estimation of the impact of shipping on the high seas is presented in Table 18.1.

Conclusions on effects

- Oil is not regarded as a significant pollutant on a global scale, although it is a highly visible pollutant and, when spilled in large quantities, can cause severe local effects;
- As for mineral oil, effects of vegetable oils are mainly physical and can cause severe local effects. It is however not expected to have a significant impact on high seas biodiversity;
- The main ecological effects of litter are physical (trapping or ingestion of litter). Birds, turtles, marine mammals and fish are known to be affected. Litter can accumulate at the bottom of the oceans where it can suffocate fauna or form floating 'rafts'. Ecological resources are considered not to recover and the affected area is considered large;
- Although it is unlikely that TBT will accumulate considerably in the oceans' sediments, biomagnification and related effects of TBT on marine mammals and seabirds could be considered relevant for the high seas;
- Invasive species in general have been identified as the second greatest threat to global biodiversity. The impacts are virtually always irreversible and generally increase over time;
- Acidification caused by gaseous ship emissions could occur in the proximity of major shipping lanes;
- Effects of shipping noise on birds and fish are to be expected within the maritime routes (few kilometers wide). Marine mammals can be affected by noise up to tens of kilometers distance.

5.5 Assessment of socio-economic importance

There are many stakeholders within the maritime industry (Figure 5.9). To describe the economic importance of the shipping industry, the activities can be expressed in trade numbers (cargo turnover) and fleet ownership. Port activities and ship building/decommissioning are also important but these are not relevant for the high seas, since these activities occur close to, or on land. More than 90% of global trade is carried by sea (IMO, 2007). The United Nations Conference on Trade and Development (UNCTAD) estimates that, in 2003, the operation of merchant ships contributed about US$380 billion in freight rates within the global economy, equivalent to about 5% of total world trade (source website IMO, accessed on the 6th of November 2007 at: http://www.imo.org/Safety/mainframe.asp?topic_id=1028&doc_id=5300).

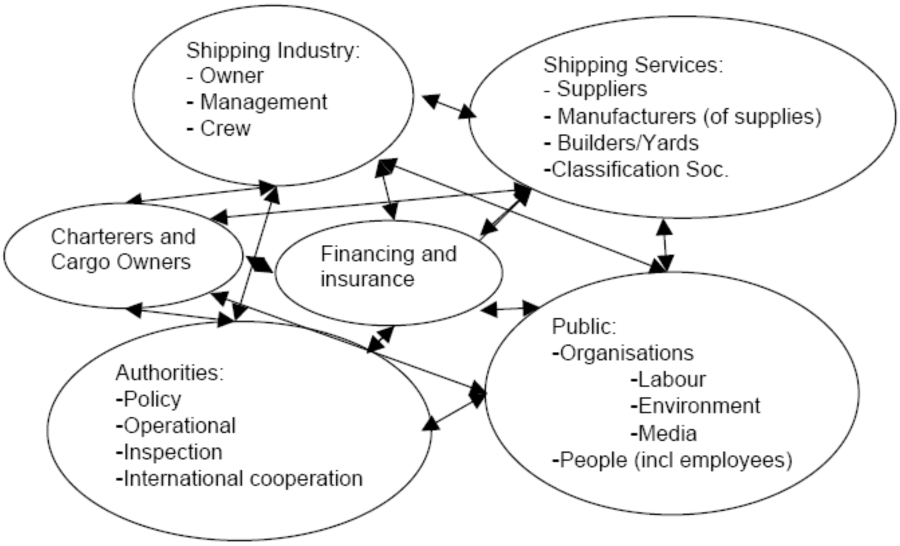

Figure 5.9 Stakeholders in the maritime industry (MKC, 2006).

5.6 Regional distribution

As presented in Figure 5.10, the main continents involved in maritime trade are Europe, North America and Asia.

Atlantic Ocean

Most of the worldwide shipping activities (40%) take place on the Atlantic Ocean (Figure 5.10). Nearly all of these activities take place on the Northern part of this ocean. This means that emissions and effects of the worldwide shipping activities, as described in the sections above, mainly take place on the North Atlantic Ocean. The activities are mainly related to the seaborne trade between the United States and Europe (Transatlantic trade route).

Indian Ocean

The Indian Ocean has the second highest regional shipping activities, with ca. 25% of the world total in the year 1990. This is almost entirely attributable to oil traffic from the oil reserves of the Middle East.

Pacific Ocean

In 1990, 15% of the world total shipping activities take place on the Pacific Ocean (Figure 5.10). The main continents involved with seaborne trade on the Pacific Ocean are America and Asia. In this region the Trans-Pacific route (Asia-USA and visa versa) is located. Nearly all of the activities take place on the Northern part of the Pacific Ocean.

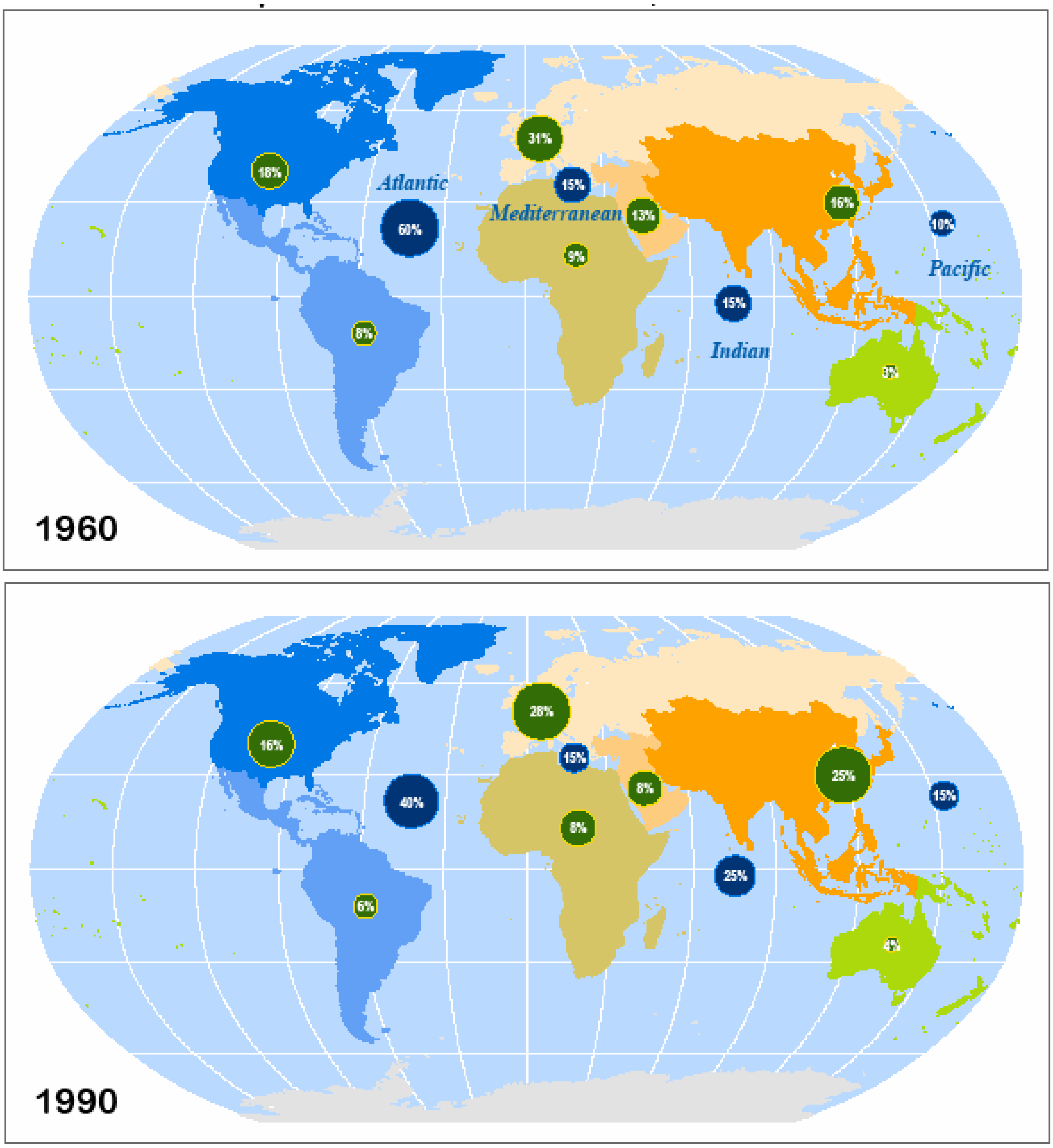

Figure 5.10 Maritime traffic per continent and ocean, 1960-1990 (Rodrigue *et al.*, 2006).

Arctic and Antarctic Ocean

The Arctic Ocean is not an important domain of maritime circulation (Rodrigue *et al.*, 2006) as a large part is covered with ice. There are no main maritime routes that cross the Arctic Ocean (Figure 5.3), however, due to melting of ice (global warming) this could change in future (see section 5.8). Since shipping in general mainly takes place along the coasts (Rodrigue *et al.*, 2006), shipping activities that do take place on the Arctic Ocean are probably mainly located on national waters. Shipping activities in the Antarctic are mainly related to the tourism industry and are discussed elsewhere in this report (Chapter 4.5).

5.7 National activities

The shipping industry has a very international character. This is reflected particularly in terms of ownership and flagging. The ownership of ships is very broad. While a ship may be owned by a Greek family or a US Corporation, it may be flagged under another nationality. By using flags of another nationality, ship owners can obtain for example lower registration fees, lower operating costs and fewer restrictions. Figure 5.11 shows the 15 largest trading countries with the US having the largest share of world trade and Japan the largest share of the world fleet.

Not every country has direct access to the ocean. Land-locked countries (maritime enclaves) have difficulties to undertake maritime trade since they are not part of an oceanic domain of maritime circulation. This requires agreements with neighboring countries to have access to a port facility through a road, a rail line or through a river. However, being an enclave does not necessarily imply an exclusion from international trade, but substantially higher transport costs which may impair economic development (Rodrigue *et al.*, 2006).

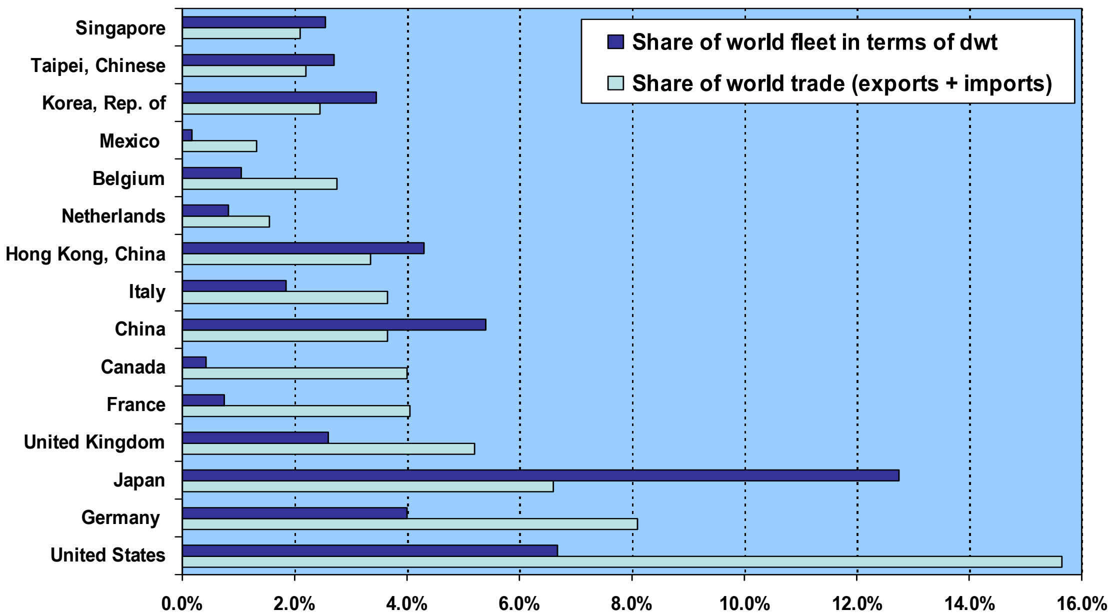

Figure 5.11 Maritime engagement of the 15 largest traders in the year 2000 (Rodrigue *et al.*, 2006).

Early 2006, European countries (Germany, France, UK, Netherlands, Italy, Belgium, Spain, Austria, Switzerland and Sweden) have a total share of 34% of the world trade in terms of value, ranging from 1% for Sweden, Switzerland and Austria to 8% for Germany. The share of world fleet in terms of dwt is 20%, with a range of 0% for Austria to 7.5% for Germany (UN, 2006). Compared to the year 2000 (Figure 5.11), the German share of the world fleet has increased considerably while their share of the world trade has remained stable.

The United States has a 12.5% share of the world trade in terms of value with a 10% share of world fleet in terms of dwt (UN, 2006). The main maritime Asian countries (China, Japan, Korea, Singapore, Taiwan, Malaysia and Thailand) have a total share of 22% of the world trade in terms of value, ranging from 1% for Thailand and Malaysia to 9.5% for China. The percentage share of world fleet in terms of dwt is relatively high with 40%, with a range of 0.5% for Thailand to 14.1% for Japan (UN, 2006). Japan is the country with the highest percentage share of world fleet in terms of dwt, followed by the US.

5.8 Trends

Productivity and economics

The share of Europe and North America (via the Atlantic) has shown a relative decline from 1960 to 1990. There are two main reasons for this relative decline: strong growth of Asian maritime trade and increase of the intra-continental exchanges that generally occur by land transport (Rodrigue, et al., 2006). More recent numbers show continuance of this trend. Asia is now by far the continent with the largest share of seaborne loaded goods with nearly 39% of the world total in 2005 (UN, 2006). Europe and America each have a share of ca. 22%, Africa and Oceania each have nearly 9% share of the world total.

The relative growth of maritime traffic on the Indian Ocean, compared to the other regions from 1960 to 1990, is almost entirely attributable to oil traffic. Considering that 65% of the known global oil reserves are in the Middle East, the weight of the Indian Ocean will remain an important component of maritime transport (Rodrigue *et al.*, 2006).

The share of maritime traffic of Pacific Asian countries relatively increased from 1960 to 1990 compared to other countries. The industrial activities of Japan, South Korea, and Taiwan require an increasing quantity of oil products (from the Middle East and Southeast Asia), of iron ore (Australia) and coal (Canada and United States). Besides, the growth of the industrial production in China and in several newly industrialized countries increased their dependence on maritime transportation (Rodrigue *et al.*, 2006).

The melting of the ice due to global warming is making the so-called 'Northwest' and 'Northeast' passages (the shipping routes through the northern-most latitudes) more navigable. Passing right across the centre of the Arctic Ocean may be possible within a decade or so. This would considerably shorten the trip from the North Atlantic to the North Pacific. Therefore, in future, the Arctic region could become a major trade route (Rodrigue *et al.*, 2006)

Environmental regulations

According to part XII of the United Nations Convention on the Law of the Sea (UNCLOS), states have a general obligation to protect and preserve the marine environment. The convention addresses several sources of ocean pollution, including vessel-source pollution. However, as mentioned before in this Chapter, the most important convention regulating and preventing marine pollution by ships is the IMO International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).

Oil

Preventing pollution by oil from ships are contained in Annex I of MARPOL 73/78. In 1992, the "double hull" amendments were adopted, making it mandatory for large oil tankers to have double hulls. As from 1997, the maximum legal operational discharge of oil is 15 ppm per nautical mile (nm), beyond 50 nm off a coastline.

Dumping

In 2006, the 1996 Protocol (London Protocol) to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention) went into force. The 1996 Protocol prohibits (in essence) dumping, except for materials on an approved list.

Air pollution

The 1997 Protocol to MARPOL 73/78 (Annex VI) sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances.

Garbage

Regulations for the Prevention of pollution by garbage from ships are contained in Annex V of MARPOL 73/78. Annex V totally prohibits of the disposal of plastics anywhere into the sea, and severely restricts discharges of other garbage from ships into coastal waters and "Special Areas". Except for the Antarctic Area, the special areas established under the Annex are all seas, i.e. no oceanic regions. These are areas which have particular problems because of heavy maritime traffic or low water exchange caused by the land-locked nature of the sea concerned. In 2006, IMO has setup a comprehensive review of MARPOL regulations for the prevention of pollution by garbage (Annex V). Additional regulations are therefore to be expected in the near future.

Anti-fouling

The IMO Anti-fouling Convention, adopted in 2001, aims at preventing the introduction of toxic chemicals in the aquatic system, and ultimately the human food chain. The Antifouling Convention regulates the chemical content of paint that is used on ships' hulls to prevent fouling.

Exotic species

IMO ballast water Guidelines (1997) are a tool to minimize the risks associated with ballast water discharge. Furthermore, the GEF/UNDP/IMO Global Ballast Water Management Programme (GloBallast) is assisting developing countries to reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water, implement the IMO ballast water Guidelines and prepare for the new IMO ballast water management convention. This convention will require all ships to implement a Ballast Water Management Plan, which will demand that new vessels be fitted with equipment for treating ballast water after 2009 and that all ships be fitted from 2016. In the meantime, ships will be required to exchange ballast water 200 nautical miles from land before entering a port. A decrease in transfer of harmful aquatic organisms is therefore not expected in the near future.

Sensitive areas

A Particularly Sensitive Sea Areas (PSSA) is defined by IMO as "an area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic or scientific reasons and which may be vulnerable to damage by international shipping activities" (Gjerde, 2001). In 1991, IMO first adopted guidelines for designation of such areas. IMO adopted revised guidelines for the designation of PSSAs in December 2005. PSSAs may be designated within and beyond areas under national jurisdiction to gain international recognition of the sensitivity of a specific area to impacts from international shipping. At the moment, PSSAs have only been approved for areas within national jurisdiction. As designation per se does not introduce legally binding requirements, associated protective measures (APMs) have to be introduced and approved separately. Specific measures that can be used to control the maritime activities in that area are, for example, routeing measures, strict application of MARPOL discharge and equipment requirements for ships, such as oil tankers; and installation of Vessel Traffic Services (VTS).

5.9 Future developments

Main factors

International trade is likely to continue to be dominated by maritime transport (in terms of weight) and air transport (in terms of value). This has already led to a concentration of traffic. For example, the 20 largest container ports handled more than 52% of global traffic in 2002. International trade is expected to grow at a faster rate than the global economy (Rodrigue *et al.*, 2006).

Because oil is the main cargo of maritime transport, the most important factor in future development of shipping is the oil production and demand. Dry bulk materials are the second largest seaborne cargo. The annual growth rate for 2005 reached 3.8% (UN, 2006). Forecasts for 2006 indicate that annual growth rates will probably be slightly lower than those of the previous year, while the distributions of world tonnage by continent are expected to fluctuate marginally (UN, 2006).

Regional shifts are expected, i.e. a substantial increase in ship traffic is expected in the Arctic (due to melting of ice) and South-East Asia (increased production and therewith increased transport due to e.g. oil demand).

Environmental impact
Scenarios for future activities indicate a significant increase in energy consumption and emissions (Endresen *et al.*, 2008). Results for the year 2050 indicate fuel consumptions between 453 and 810 Mt (2-3 times present level), with appurtenant emissions ranging from 1308 to 2271 million tonnes (CO2), 17 to 28 million tonnes (NOx) and 2 to 12 million tonnes (SO2). This indicates that emissions could be doubled within decades (see section 5.3 for current emissions). Most scenarios for the near future, the next 10-20 years, indicate that regulations and measures will be outweighed by an increase in traffic leading to a significant global increase in emissions from shipping. Relative contribution to pollutants from shipping compared to land based sources could increase, especially in regions like the Arctic and South-East Asia, where a substantial increase in ship traffic is expected (Endresen *et al.*, 2008). However, regulations such as limiting the sulphur content in the fuel in the North Sea and English Channel (IMO regulations), could have positive effects.

Technological developments

There are several technological developments that could reduce emissions from ships in future. The Clean Ship approach, an integrated approach towards sustainable shipping, describes a number of such developments (Stichting de Noordzee, 2005):

- Engines: The use of clean combustion engines and clean(er) (bio)fuels is a first step towards clean engines.
- Propulsion: Although conventional propulsion by propellers has been in existence for more than a century, it is not the most efficient method. Alternative propulsion methods could reduce ships' emissions.
- Air lubrication: Reducing the friction of a vessel through the water is a very effective way to reduce fuel consumption and thus emissions. A very promising method for this is air lubrication: the introduction of millions of tiny air bubbles underneath the ship. Innovative hull design can improve the sustainability of shipping significantly.
- Cargo handling: Loss of cargo should be tackled by improving the stripping capacity of tankers and by securing all deck cargo as best as possible. Innovative solutions for cleaning residues on board are required.
- Logistics: Optimised logistics operations often lead to lower emissions. Another element is adjusting the ship's speed according to weather (weather routing). This is of even greater importance when ships use wind-propulsion.

5.10 Overall conclusions on shipping

- Ship traffic on the high seas is mainly concentrated within the maritime routes. The main navigation and trade routes for international exchange are concentrated between 60°N and 30°S. The Atlantic Ocean shows the highest traffic intensity;
- The main cargo is oil, representing 37% of the total goods in 2005. Emissions of oil are mainly related to operational discharges. Oil is not regarded as a significant pollutant on a global scale, although severe local effects occur;
- One of the greatest threats to the world's oceans is litter. Birds, turtles, marine mammals and fish are known to be affected by trapping or ingestion of litter. Litter can accumulate at the bottom of the oceans where it can suffocate fauna or form floating 'rafts'. Ecological resources are considered not to recover and the affected area is considered large;
- Another main concern is invasive species. Impacts are virtually always irreversible and generally increase over time;

- Shipping contributes significantly to the world's total greenhouse gas emissions. Acidification caused by gaseous ship emissions could occur in the proximity of major shipping lanes;
- Although it is unlikely that TBT will accumulate considerably in the oceans' sediments, biomagnification and related effects of TBT on marine mammals and seabirds could be considered relevant for the high seas;
- Shipping noise mainly affects marine mammals, up to distances of tens of kilometers. Effects of shipping noise on birds and fish could occur within the maritime routes (few kilometers wide).

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6 Iron fertilization[31]

6.1 Introduction

A number of measures designed to increase draw-down of CO2 to the oceans through enhanced biological fixation have been proposed, based on widespread fertilization of ocean areas with nutrients (e.g. nitrogen, iron). The goal of ocean fertilization at sea is to stimulate phytoplankton growth in order to draw carbon dioxide out of the atmosphere into the ocean and thereby sequestering the carbon dioxide in the form of particulate organic carbon[32]. This would be achieved by spreading iron in the sea in those locations where iron is currently in such low concentrations that it limits phytoplankton growth (Sagarin *et al.*, 2007). Other nutrients that limit primary productivity (e.g. nitrogen) can also be used for ocean fertilization. Nutrient fertilization programs such as MARICULT[33] are being developed primarily to enhance fisheries production (Johnston *et al.*, 1999). According to the Intergovernmental Panel on Climate Change (IPCC), iron fertilization of the oceans may offer a potential strategy for removing carbon from the atmosphere (IMO, 2007). However, the IPCC also stated that ocean iron fertilization remains largely speculative, and many of the environmental side effects have yet to be assessed.

The Scientific Groups of the London Convention and Protocol[34] have developed a Statement of Concern, taking the view that knowledge about the effectiveness and potential environmental impacts of ocean iron fertilization currently was insufficient to justify large-scale operations and that this could have negative impacts on the marine environment and human health (IMO, 2007). It was agreed that the consideration of ocean fertilization falls under the competences of the London Convention and Protocol, in particular, in relation to their objective to protect the marine environment from all sources. The issue from scientific and legal perspectives, with a view to its regulation will be further studied within the scope of the London Convention and Protocol. Only small-scale, experimental projects can be conducted as they are considered as data-collecting scientific activities, which are allowed under the conventions (Freestone & Rayfuse, 2008).

The Kyoto Protocol (KP) imposes binding obligations on developed countries to reduce emissions of greenhouse gasses by agreed amounts within the 2008 to 2012 commitment period. The so-called carbon credits are defined as 'emission reduction units' in the KP. Other than the KP carbon credits, there are also voluntary carbon offset schemes. The KP and other carbon offset schemes are a driving factor in the development of iron fertilization.

The assessment of the ecological impact of iron fertilization of the high seas involves the following steps:

- Assessment of the intensity of iron fertilization of the high seas;
- Assessment of the emissions due to these activities;
- Assessment of the effects of these emissions.

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31 Authors: C.C. Karman and J.E. Tamis

32 The process involving phytoplankton removing carbon dioxide from surface waters to storage in the deep ocean is known as the "biological pump" (Allsopp, 2007).

33 The European research program MARICULT (1996-2000) was a joint scientific - industrial effort consisting of several projects, initiated by the Norwegian company Norsk Hydro.

34 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 29 December 1972

6.2 Assessment of iron fertilization intensity

Iron is an essential trace element for almost all living organisms. Phytoplankton requires iron for a number of cellular functions, including the synthesis of chlorophyll. In about one third of the world oceans, the major nutrients required for phytoplankton growth, such as nitrates and phosphates, are readily available and yet the abundance of phytoplankton remains lower than would be expected (Allsopp, 2007). These areas have been called high-nutrient, low chlorophyll (HNLC) regions.

There are three recognized HNLC regions of the world's oceans: the Equatorial Pacific Ocean, the Subarctic Pacific Ocean and the Southern Ocean. Up to now, iron fertilization has only been conducted on experimental scale. In total, 12 iron-enrichment studies have been carried out over the last decade in polar, subpolar, and tropical HNLC waters (Allsopp *et al.*, 2007).

Figure 6.1 shows the locations of these experiments. All studies used a similar experimental design and virtually all experiments resulted in blooms (Boyd, 2007). Denman *et al.* (2006) reported that only one out of eight iron fertilization experiments followed the patch long enough to observe clearly a sinking flux of organic carbon from the surface layer of the ocean.

Conclusions on intensity

- Up to now, iron fertilization has only been conducted on experimental scale;
- Twelve iron-enrichment studies have been carried out over the last decade in polar, subpolar, and tropical HNLC waters.

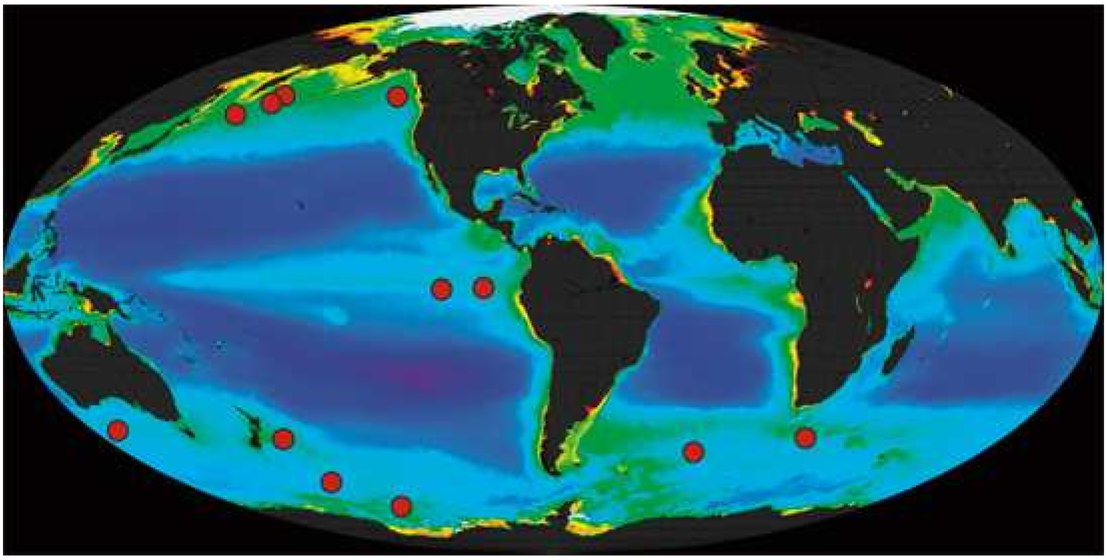

Figure 6.1 Locations of iron fertilization experiments over the past decade (WHOI, 2007).

6.3 Assessment of emissions

Conducted experiments were set up for areas ranging from 25 to 250 km^2. The original concentration was appr. 0.1 nM iron and the areas were fertilized up to concentrations of 4 nM iron. Iron was added to the water surface usually in the form of dissolved iron sulphate, in amounts ranging from 225 kg to 6000 kg

$FeSO_4$ (Allsopp *et al.*, 2007). It has been observed that an initial iron seeded patch size of 200-250 km^2 spread to about 1000 km^2 by the end of the experiment (Allsopp *et al.*, 2007).

For large scale carbon sequestering the iron emission will be considerably higher. It has been estimated that continuous iron fertilization would require 0.5 to 6 million tons of iron per year and an area of 84 to 1000 million km^2 (Johnston *et al*, 1999; Allsopp *et al.*, 2007).

Wong *et al.* (2006) conclude that the amount of CO_2 drawdown differs widely in mesoscale iron fertilization experiments carried out in different oceans. They suggest that further work should be done to understand the oceanic conditions and ecosystem structures causing the wide range of reported CO_2 drawdown in experiments undertaken in different oceans.

As mentioned above, on experimental scale iron is usually added in the form of dissolved iron sulphate. For large scale commercial operations, however, it is unclear from available literature what material will be used as fertiliser. The risk of ocean fertilisation will depend on the type and source of material used. If industrial waste is used the material could be contaminated with, for example, heavy metals. Planktos, a California based company, uses iron (nano)particles for its fertilisation operations. They do not provide further information on the origin or composition of the material.

Conclusions on emissions

- Areas were fertilized up to concentrations of 4 nM iron;
- Per experiment amounts of 225 kg to 6000 kg $FeSO_4$ were added;
- Estimations of future large scale fertilization are 0.5 to 6 million ton iron/year requiring an area of 84 to 1000 million km^2;
- Source and composition of materials used as fertilizer is unknown.

6.4 Assessment of ecological effects

Iron additions in the Southern Ocean promoted algal blooms (Bakker *et al.*, 2005). After iron fertilization, the sea surface fCO_2 evolves with blooms of flagellates and then of diatoms (Wong *et al*, 2006). Potential long-term outcomes for iron fertilization of the ocean are unknown, and could include newly productive fisheries and reduced atmospheric carbon dioxide (Figure 6.2, left) or a polluted ocean, unenhanced fisheries, and little effect on atmospheric carbon dioxide (Figure 6.2, right). However, based on the available knowledge, many researchers express their concern about large-scale iron fertilization of the oceans to have negative impacts on the marine environment and human health. Some recommend not to use iron fertilization as a strategy to reduce atmospheric CO_2 levels (Allsopp *et al.*, 2007; Cullen, 2007; SOLAS SSC[35], 2007). The Scientific Groups under the London Convention and Protocol have issued a 'statement of concern' (IMO, 2007). They recommend that any such operations be evaluated carefully to ensure, among other things, that such operations were not contrary to the aims of the London Convention and London Protocol.

35 Surface Ocean - Lower Atmosphere Study Scientific Steering Committee

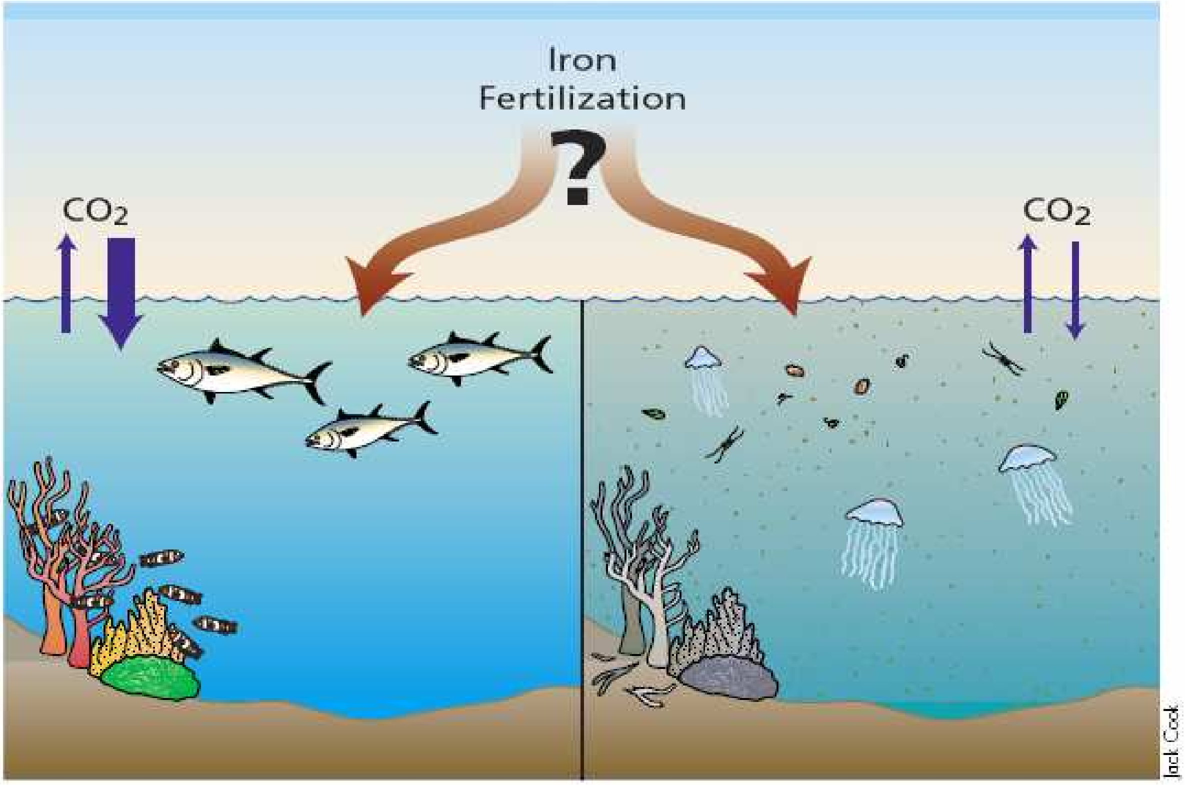

Figure 6.2 Potential long-term impact of iron fertilization (Buesseler, 1999).

A recent review of Allsopp *et al.* (2007) describes several potential ecological effects of iron fertilization of the oceans:

- Changing the composition of phytoplankton communities and marine food webs;
- Changing biogeochemical cycles;
- Reduced nutrient availability and biological productivity;
- Creating harmful algal blooms;
- Reduce oxygen levels;
- Biogenic gas production.

Some secondary effects of iron fertilization are schematically presented in Figure 6.3.

Changing the composition of phytoplankton communities and marine food webs

Iron fertilization significantly changes the composition of the phytoplankton community. In general terms it was observed in the mesoscale iron fertilization studies that the biomass of smaller phytoplankton initially increased, but then stabilized as a result of grazing pressure whereas diatoms bloomed. Changes in the plankton community would alter marine food webs and biogeochemical cycles in unintended and unpredictable ways (Allsopp *et al.*, 2007).

Changing biogeochemical cycles

Phytoplankton species that bloom in response to natural processes are adapted to a turbulent regime and a complex mixture of upwelling nutrients that are part of the natural nutrient regeneration cycle of the oceans. The carbon cycle is intimately coupled with those of other elements, some of which have critical roles in climate regulation. Therefore, it is considered not possible to sequester additional carbon without, in some way, changing coupled biogeochemical cycles (Allsopp *et al.*, 2007).

Reduced nutrient availability and biological productivity

Nutrient ratios and the limiting nutrients are factors that structure pelagic ecosystems and iron fertilization alters these factors (Cullen, 2007). Iron fertilization results in macronutrients (nitrate, phosphorous, silicate) being used up by phytoplankton. This affects communities down-current from an artificially iron-fertilized area. Reduced nutrient availability in ecosystems would result in reduced productivity. The structure of the marine food web could also be changed as a result. For example, modelling results have implied that commercial iron fertilization could result in non-local impacts on marine biology, i.e. long-term reduction in biological productivity over a much wider ocean area, which could have a significant negative impact on fisheries (Allsopp *et al.*, 2007).

Creating harmful algal blooms

There is a known link between harmful algal blooms (red tides) and iron. For example, it is thought that the iron supplied by wind-blown dust from the Sahara leads to blooms of bacteria off the West Florida coast. These bacteria release nitrogen into the water which, in turn, creates an environment favourable to toxic red algae. Fishing, aquaculture and tourism are negatively impacted by such red tides because they can cause, inter alia, fish kills and shell-fish poisoning (Allsopp *et al.*, 2007).

Reduce oxygen levels

Iron addition, and subsequent increases in phytoplankton growth, carbon export and remineralization, could also act to reduce oxygen levels in subsurface waters. It is possible that commercial long-term or large-scale fertilization programmes could create conditions with "zero oxygen concentrations" (anoxic conditions) at intermediate depths. Low oxygen levels and anoxic conditions would have a negative impact on all aerobic marine organisms (Allsopp *et al.*, 2007).

Other

Iron fertilization could also cause biogenic gas production, N_2O, which is a green house gas. Phyto-planktonic algae produce DMS (dimethylsulphide), which influences cloud formation. An increase in phytoplankton primary productivity and thus in DMS levels should lead to cooling of the sea surface waters. Other important chemicals that may also be influenced include volatile organohalogens and carbonyl sulfide (OCS). An increase in these gases would enhance stratospheric ozone depletion and lead to intensified ultraviolet levels at Earth's surface, with possible biological health consequences (Lawrence, 2002).

Furthermore, the source of the iron used for ocean fertilization is also an issue of some importance. It is possible that scrap iron and iron rich industrial wastes are used. This could cause the introduction of environmentally dangerous substances on a large scale as well as reducing the energy saved globally by recycling steel (Johnston *et al*, 1999).

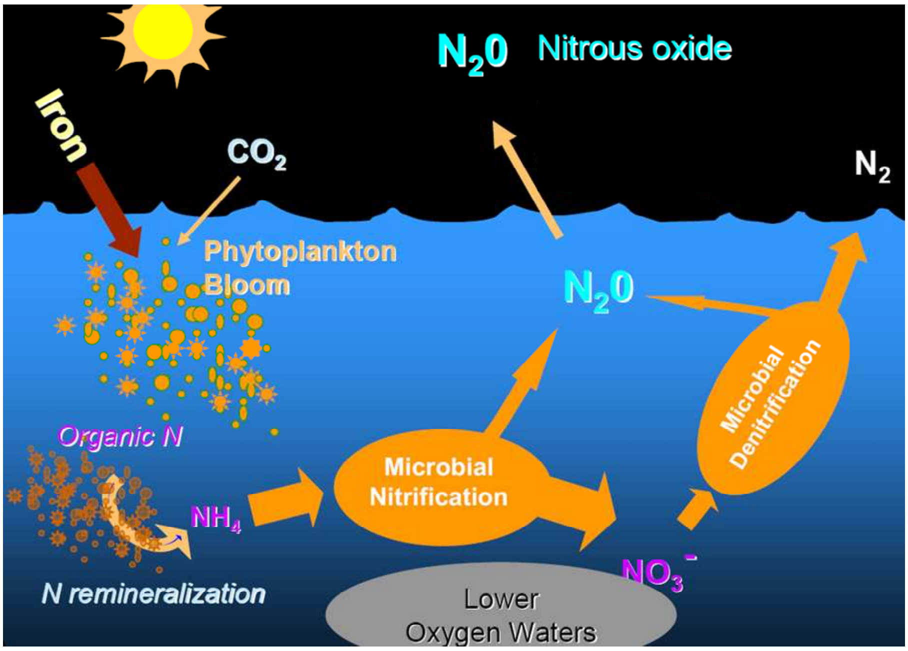

Figure 6.3 Secondary effects of iron fertilization (Based on a slide from Cullen (2007)).

Semi-quantitative estimation

A semi-quantitative estimation of the impact of iron fertilization on the high seas is presented in Table 18.1.

Conclusions on effects

- There is concern about large-scale iron fertilization of the oceans to have negative impacts on the marine environment and human health;
- Potential ecological effects are changing the composition of phytoplankton communities and marine food webs, changing biogeochemical cycles, reduced nutrient availability and biological productivity, creating harmful algal blooms, reduce oxygen levels, biogenic gas production and potential effects from contaminated source material.

6.5 Assessment of socio-economic importance

At the moment, no formal markets exist for carbon credits from iron fertilization. The KP regime does not include the high seas. Even the major existing carbon trading markets such as the Chicago Climate Exchange and the European Climate Exchange that allow for tradable carbon offsets have no provisions for carbon trading based on oceanic sequestration (Sagarin *et al.*, 2007).

6.6 National activities

Many countries have been involved with the iron fertilization experiments that have been conducted over the past years, such as the US, New Zealand, Australia, Canada, the UK, the EU, Germany, the Netherlands, Mexico, South Africa, China and Japan. Dutch researchers have been involved with two experiments in the

Southern Ocean: SOIREE (Southern Ocean Iron Release Experiment Expedition) in 1999 and EisenEx in 2000 (Bakker *et al.*, 2005).

At the moment, iron fertilization has only been conducted at experimental scale. There are, however, several companies with plans for industrial-scale iron fertilization projects. Most advanced in its operations is Planktos Corp, a US based company. Planktos plans to dissolve one hundred tons of iron over a 10,000-square-kilometre tract of high seas off the Galapagos Islands. This is to be the first of six large scale pilot projects conducted by Planktos from 2007 to 2009 in the Pacific and the Atlantic Oceans, each one lasting approximately four months (Rayfuse *et al.*, 2007).

6.7 Trends

Productivity and economics

Large-scale fertilization of ocean waters using micro-nutrients such as iron to stimulate phytoplankton growth in order to sequester carbon dioxide is the subject of recent commercial interest (IMO, 2007; Allsopp *et al.*, 2007; Sagarin *et al.*, 2007). Some investors, including several existing commercial ventures, hope that iron fertilization will be one method to earn carbon credits that can be traded through a market mechanism or sold as "offsets" for existing or planned greenhouse gas emissions (Sagarin et al., 2007).
The main driver of carbon credits globally, is the Kyoto protocol. The existing rules for carbon offsets under the Kyoto protocol do not allow projects outside of territorial waters. As the provisions of the Kyoto protocol are valid until 2012, it is not possible to conduct iron fertilization projects on the high seas in this regime within the next few years. If these conditions do not change in future, the potential for large-scale iron fertilization of ocean waters will be limited. A recent study notes that carbon sequestration in the oceans seems highly unlikely to be eligible for the generation of credits under the Kyoto protocol regime. One of the reasons mentioned is the lack of evidence that carbon is actually captured and retained in the oceans for a reasonable period and that there is no leakage of other greenhouse gasses, such as nitrous oxide (Freestone & Rayfuse, 2008).
Voluntary carbon offset schemes do not affect states' commitments under the Kyoto protocol.

Environmental regulations

As mentioned before in the introduction of this chapter, the Scientific Groups under the London Convention and Protocol have issued a 'Statement of Concern' regarding iron fertilization (IMO, 2007). They stated that knowledge about the effectiveness and potential environmental impacts of ocean iron fertilization currently was insufficient to justify large-scale operations. They recommended that any such operations be evaluated carefully to ensure, among other things, that such operations were not contrary to the aims of the London Convention and London Protocol. The evaluation should include, among other things, consideration of:

- the estimated amounts and potential impacts of iron and other materials that may be released with the iron;
- the potential impacts of gases that may be produced by the expected phytoplankton blooms or by bacteria decomposing the dead phytoplankton;
- the estimated extent and potential impacts of bacterial decay of the expected phytoplankton blooms, including reduced oxygen concentrations;
- the types of phytoplankton that are expected to bloom and the potential impacts of any harmful algal blooms that may develop;
- the nature and extent of potential impacts on the marine ecosystem including naturally occurring marine species and communities;

- the estimated amounts and timescales of carbon sequestration, taking account of partitioning between sediments and water; and
- the estimated carbon mass balance for the operation.

As regulatory regimes such as Kyoto are currently lacking for iron fertilization of ocean waters, all such activities fall under the voluntary carbon markets, which may not have as strict a set of quality controls and buyer protections as a regulatory system would impose. However, efforts are now underway to develop quality standards for voluntary markets (Sagarin *et al.*, 2007). A number of national and international certification programs are being developed to enhance vigilance by national authorities in states where these markets flourish and to ensure these projects offer real environmental benefits in return for the substantial investments that are being made. Nevertheless, under the rules on state responsibility, states may still be internationally responsible if projects under their jurisdiction or control cause damage to the rights and interests of other states (Freestone & Rayfuse, 2008).

6.8 Future developments

It is requested in the Statement of Concern to consider the issue of large-scale ocean iron fertilization operations with a view to ensuring adequate regulation of such operations. In particular, the Scientific Groups of the London Convention/Protocol requested that the following issues be addressed by the Contracting Parties (IMO, 2007):

- the purposes and circumstances of proposed large-scale ocean iron fertilization operations and whether these are compatible with the aims of the Convention and the Protocol;
- the need, and potential mechanisms, for regulation of such operations; and
- the desirability of bringing to the attention of other international instruments and institutions proposals for such operations.

Currently, it is assessed within the LC/LP whether it is applicable on ocean fertilization operations and/or if additional rules and regulations should be developed.

Contracting Parties to the London Convention and the London Protocol are invited to provide further information relating to proposed large-scale ocean iron fertilization operations and to take into account the 'Statement of Concern' (IMO, 2007).

Before ocean fertilization can be commercially conducted, independent, internationally peer-reviewed scientific research and assessment has to demonstrate that it is effective and that its benefits outweigh the risks to the marine environment (Freestone & Rayfuse, 2008).

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7 CO2 storage[36]

7.1 Introduction

Carbon dioxide (CO2) capture and storage (CCS) is a process consisting of the separation of CO2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere (IPCC, 2005). CCS is considered as an optional mitigation action for stabilization of atmospheric greenhouse gas concentrations. There are several forms for permanent storage of CO2:

- Gaseous storage in deep geological formations, including saline formations, exhausted gas fields and sub-seabed geological formations (CS- SSGS[37]);
- Liquid storage in deep ocean masses (ocean storage);
- Solid storage by reaction of CO2 with metal oxides to produce stable carbonates.

Various international fora have concluded that it is technically feasible to store CO2 safely in geological formations, using existing, established technologies (Karman *et al.*, 2006). Storage of gases, including CO2, in these media has been demonstrated on a commercial scale by enhanced oil recovery operations, natural gas storage and acid gas disposal (Bachu, 2007). CS-SSGS is considered an option for the area within the national borders. For the high seas, ocean storage techniques are possible. Captured CO2 could be deliberately injected into the ocean at great depth, where most of it would remain isolated from the atmosphere for centuries.

Because the development of ocean storage technology is generally at a conceptual stage, only general principles and potential activities and impacts are described in this chapter.

The assessment of the ecological impact of CO2 storage in the high seas involves the following steps:

- Assessment of the CO2 storage intensity on the high seas;
- Assessment of the emissions due to these activities;
- Assessment of the effects of these emissions.

7.2 Assessment of CO2 sequestration intensity

<u>Geological storage</u>

Three industrial-scale (i.e. in the order of 1 Mt[38] CO2 per year) storage projects are currently in operation: the Sleipner project in an offshore saline formation in Norway, the Weyburn EOR project in Canada, and the In Salah project in a gas field in Algeria (IPCC, 2005). These projects all involve geological storage. Figure 7.1 shows potential sites for CO2 storage in sedimentary basins, where suitable saline formations, oil or gas fields or coal beds may be found. As the figure shows, the high seas are not considered as prospective areas for geological storage of CO2. Therefore, this type of CO2 storage is not further assessed in this study.

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36 Authors: C.C. Karman and J.E. Tamis

37 CO_2 Sequestration in Sub-Seabed Geological Structures

38 Mt: Mega ton (10^9 kilgram)

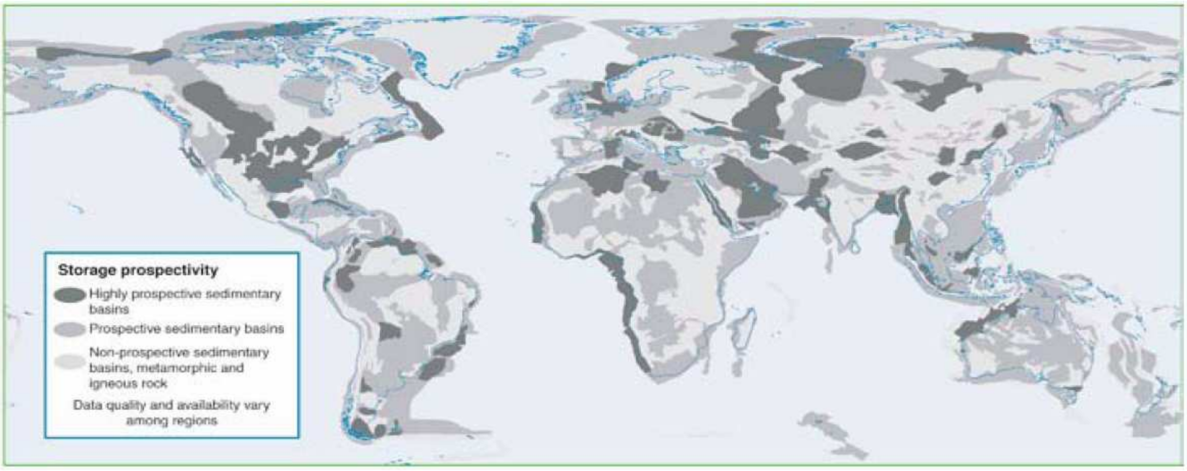

Figure 7.1 Potential sites of geological CO2 storage (IPCC, 2005).

<u>Ocean storage</u>

Ocean storage is considered a feasible option for CO2 sequestration in the high seas. As ocean storage of CO2 is not yet operational, this paragraph describes the potential intensity when ocean storage would be (fully) operational.

Ocean storage could potentially be done in two ways (see Figure 7.2): by injecting and dissolving CO2 into the water column (typically below 1,000 meters) via a fixed pipeline or a moving ship, or by depositing it via a fixed pipeline or an offshore platform onto the sea floor at depths below 3,000 m, where CO2 is denser than water and is expected to form a “lake” that would delay dissolution of CO2 into the surrounding environment (Nakashiki, 1997). With the current status of CCS technology, pipelines are preferred for transporting large amounts of CO2 for distances up to around 1,000 km. For amounts smaller than a few million tonnes of CO2 per year or for larger distances overseas, the use of ships, where applicable, could be economically more attractive (IPCC, 2005).

Ocean storage and its ecological impacts are still in the research phase (IPCC, 2005). There have been small-scale field experiments and 25 years of theoretical, laboratory, and modelling studies of intentional ocean storage of CO2, but ocean storage has not yet been deployed or thoroughly tested.

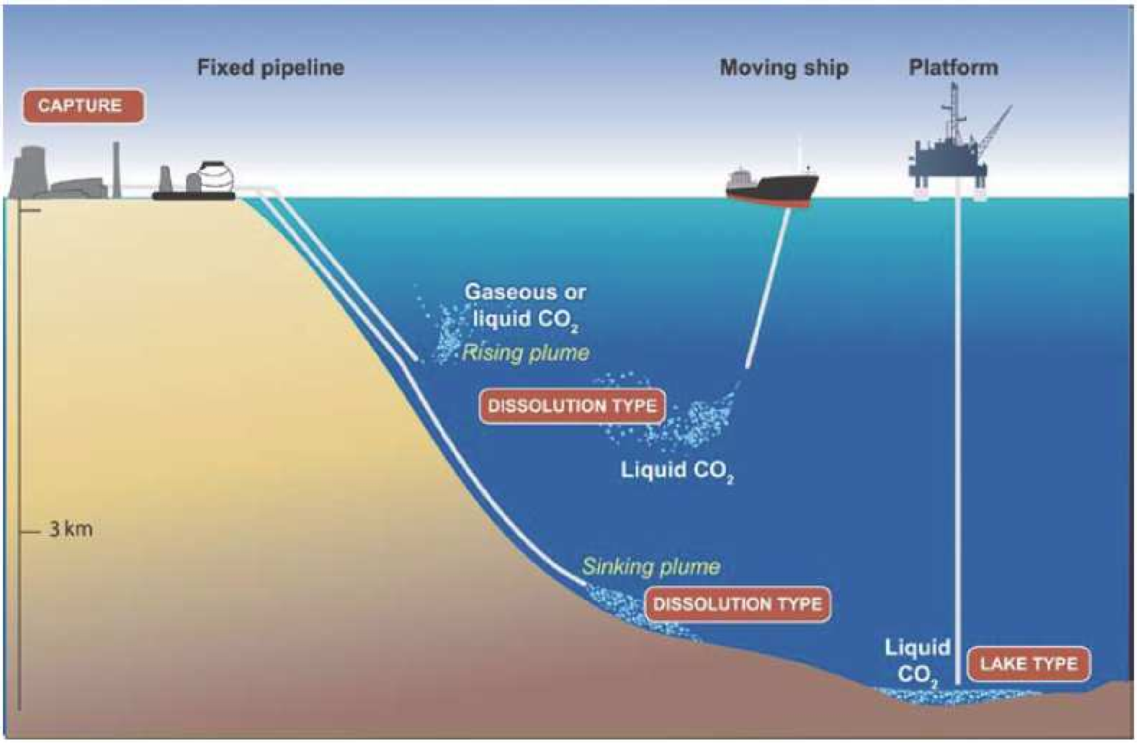

Figure 7.2 Overview of ocean storage concepts (IPCC, 2005).

The physical capacity for storage of CO2 in the ocean is large relative to fossil-fuel resources. The degree to which this capacity will be utilized may be based on factors such as cost, equilibrium pCO2, and environmental consequences (IPCC, 2005).

There is no practical physical limit to the amount of anthropogenic CO2 that could be placed in the ocean. However, the amount that is stored in the ocean on the millennial time scale depends on oceanic equilibration with the atmosphere (IPCC, 2005). Over millennia, CO2 injected into the oceans at great depth will approach approximately the same equilibrium as if it were released to the atmosphere. Sustained atmospheric CO2 concentrations in the range of 350 to 1000 ppmv imply that 2,300 ± 260 to 10,700 ± 1,000 Gt[39] of anthropogenic CO2 will eventually reside in the ocean (IPCC, 2005). The storage capacity could be increased with the addition of alkalinity to the ocean (e.g., dissolved limestone).

Potential sites for ocean storage would require a minimum depth of 3000 meter. A CO2 source that would be suitable for ocean storage is located near potential storage sites. Figure 7.3 shows locations of ocean water at least 1 km and 3 km deep and distances over land to water that is at least 3 km deep. The main part of the high seas is potentially suitable for CO2 storage.

39 Gt: Giga ton (10^{12} kilogram)

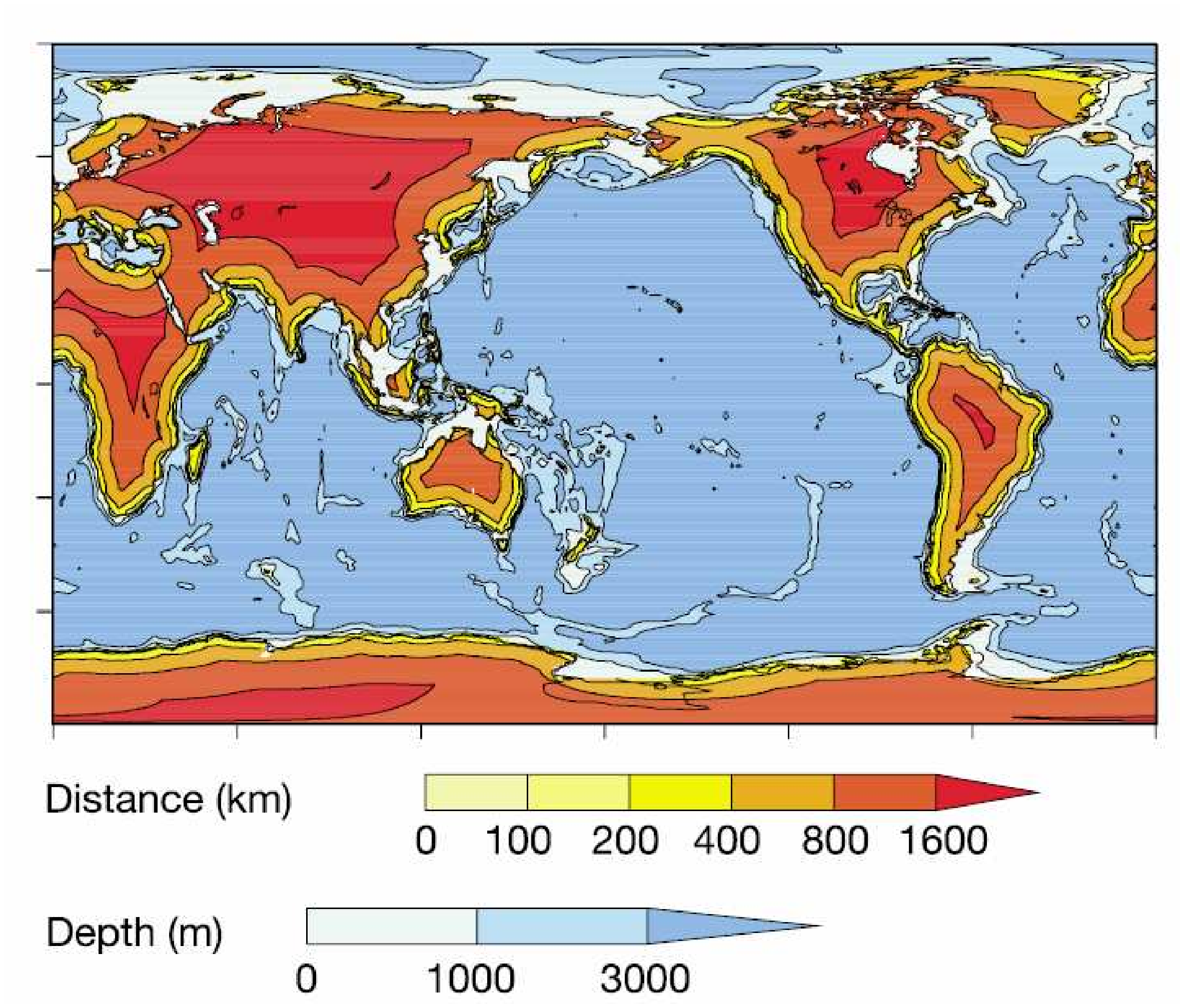

Figure 7.3 Potential sites for ocean CCS operations: locations of ocean water at least 1 km and 3 km deep and distance over land to water that is at least 3 km deep (IPCC, 2005).

Conclusions on intensity

- Currently there is no CO2 storage in the high seas;
- Geological storage of CO2 is limited to the coastal shelves;
- Technologically, ocean storage techniques is possible: captured CO2 could be deliberately injected into the ocean at great depth;
- Potential sites for ocean storage would require a minimum depth of 3000 meter.

7.3 Assessment of emissions

As ocean storage of CO2 is not yet operational, there are currently no emissions from CO2 storage on the high seas. This paragraph describes the potential emissions when ocean storage would be (fully) operational.

Over the past 200 years the oceans have taken up 500 Gt CO2 from the atmosphere out of 1300 Gt CO2 total anthropogenic emissions. The rate of CO2 uptake is approximately 7 Gt/yr (IPCC, 2005).

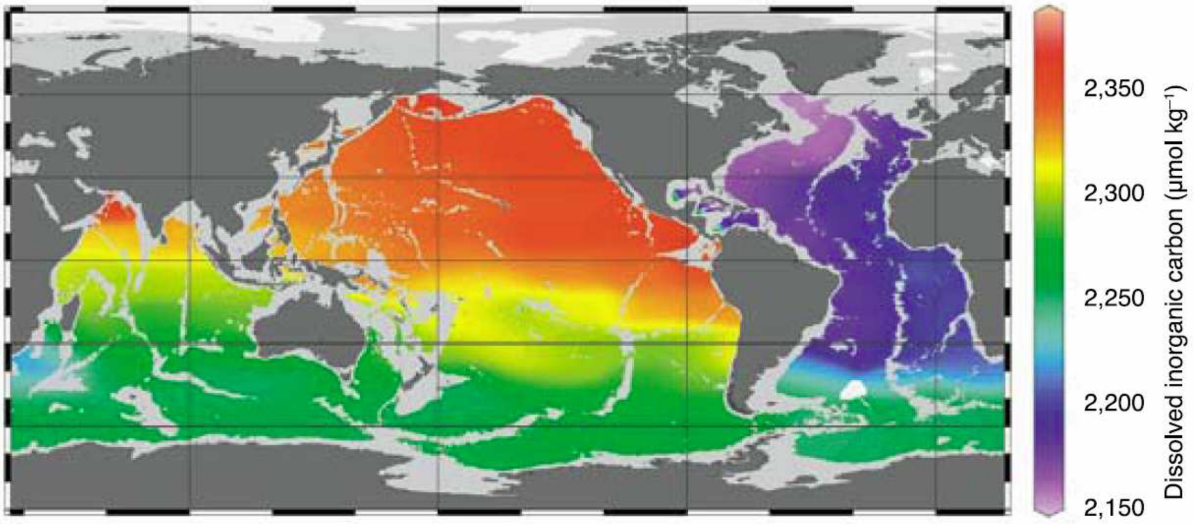

Figure 7.4 Natural variation in total dissolved inorganic carbon concentration at 3000 m depth (IPCC, 2005).

Figure 7.4 shows the natural variation in total dissolved inorganic carbon concentration at 3000 m depth. Ocean carbon concentrations increase roughly 10% as deep ocean waters transit from the North Atlantic to the North Pacific due to the oxidation of organic carbon in the deep ocean.

The age of North Pacific deep water is estimated to be in the range of 700 to 1000 years (IPCC, 2005). Other basins, such as the North Atlantic, have characteristic overturning times of 300 years or more. It can therefore be assumed that, generally, carbon injected in the deep ocean would equilibrate with the atmosphere over a time scale of 300 to 1000 years. There is no known mechanism for the sudden or catastrophic release of stored CO2 from the ocean to the atmosphere.

Most ocean storage proposals seek to minimize the volume of water with high CO2 concentrations either by diluting the CO2 in a large volume of water or by isolating the CO2 in a small volume (e.g., in CO2 lakes). Nevertheless, if deployed widely, CO2 injection strategies ultimately will produce large volumes of water with somewhat elevated CO2 concentrations (IPCC, 2005).

Conversion of molecular CO2 to bicarbonates or hydrates before or during CO2 release would reduce the pH effects and enhance the retention of CO2 in the ocean, but this would also increase the costs and other environmental impacts (IPCC, 2005). In general, with increasing CO2 levels the pH lowers.

Conclusions on emissions

- There are currently no emissions from CO2 storage on the high seas;
- Carbon injected in the deep ocean would equilibrate with the atmosphere over a time scale of 300 to 1000 years;
- There is no known mechanism for the sudden or catastrophic release of stored CO2 from the ocean to the atmosphere;
- CO2 injection strategies ultimately will produce large volumes of water with somewhat elevated CO2 concentrations.

7.4 Assessment of ecological effects

The diverse fauna that lives in the waters and sediments of the deep ocean can be affected by ocean CO2 storage, leading to change in ecosystem composition and functioning (IPCC, 2005). Strategies that release liquid CO2 close to the sea floor will be affecting two ecosystems: the ecosystem living on the sea floor, and deep-sea ecosystem living in the overlying water.

The main effects to consider in relation to the emission of CO2 are those that result from the increase of CO2 concentration in the ambient water and sediments. Increase of the CO2 concentration in (sea)water causes a decrease of pH. The uptake of anthropogenic CO2 over the past years has resulted in a decrease of pH of about 0.1 at the ocean surface with virtually no change in pH deep in the oceans (IPCC, 2005). Changes in pH are directly related to the partial pressure of CO2 and the chemical buffer capacity of the water. When the pH lowers with increasing CO2 levels, it causes a shift in acid-base and ion equilibria of fish, crustaceans and other invertebrates and therewith a (long-term) shift in metabolic equilibria. The growth, survival and reproductive success of marine animals has been found to decrease at low ambient pH. However, the effects of elevated CO2 cannot be accounted for by only considering the pH. It has been found that, at the same pH, seawater acidified with CO2 had higher acute toxicity than that acidified with HCl (Karman *et al.*, 2006).

In the case of deep ocean storage, there is a risk of greatly increasing the problem of ocean acidification, a problem that also stems from the excess of carbon dioxide already in the atmosphere and oceans (IPCC, 2005).

High CO2 levels in water may (Karman *et al.*, 2006):

- Cause lowering of pH in animal body fluids (acidosis). Elevation of CO2 in water will easily reverse the normal outward diffusion of CO2 from the body which can cause acidification in the organism.
- Impair oxygen transport in animals (asphyxiation). Efficient oxygen transport by blood pigments (haemocyanin) strongly depends on pH.
- Increase concentrations of CO2 in body fluids (hypercapnia). This internal accumulation of CO2 will be responsible for most of the effects observed in animals. Short- term effects are respiratory distress, narcosis and mortality. Abilities to acclimatise have not yet been investigated.
- Affect calcareous organisms such as corals, shellfish, and specific groups of phytoplankton (disturbed calcification rates, such as reduced levels of growth and reproduction, as well as increased mortality rates).

Long-term depression of physiological rates may, over time scales of several months, contribute to enhanced mortality rates in a population. Prediction of future changes in ecosystem dynamics, structure and functioning therefore requires data on sub-lethal effects over the entire life history of organisms. Early developmental stages of marine invertebrates and fish are more sensitive to long-term exposure to elevated CO2 concentrations than adult stages.

There are indications that deep-sea organisms are less sensitive to high CO2 levels than surface water organisms. Metabolic activity of pelagic animals, including fish and cephalopods, generally decreases with depth. However, it has also been reported that deep-sea animals would experience serious problems in oxygen supply under conditions of increased CO2 concentrations (IPCC, 2005).

With a ‘CO2 lake’ type of storage, immediate large-scale effects are limited. However, it will result in the mortality of most organisms under the lake that are not able to flee and of organisms that wander into the lake. CO2 will dissolve from the lake into the bottom water, and this will disperse around the lake, with effects similar to direct release of CO2 into the overlying water. Depending on the length of exposure, pH reductions expected in the near field are expected to have significant effect on marine biota.

Based on the available information, it can be expected that effects of CO_2 exposure caused by ocean storage, will be mainly local and acute (Figure 7.5). In the far field and long-term scale, the effects are expected to be comparable to the effects of the global rise of CO_2 concentrations, although there is a risk of increasing the problem of ocean acidification.

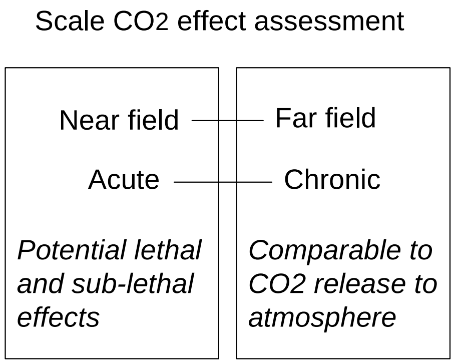

Figure 7.5 Scale CO2 effect assessment (Karman *et al.*, 2006).

The stored CO2 may contain other substances that could have potential health, safety and environmental impacts. Besides CO2, N2, O2 and H2O, it could also contain air pollutants such as SOx, NOx, particulates, HCl, HF, mercury, other metals, and other trace organic and inorganic contaminants (Karman *et al.*, 2006). The types and concentrations of impurities in a CO2 stream captured post combustion will depend on the fuel type, combustion process and type of capture process employed.

A common contaminant in CO2 streams is H2S. Since there are very large sources of H2S naturally occurring in the ocean, ocean ecosystems that have adapted to deal with sulphide and sulphur-oxidizing bacteria are common throughout the world's oceans. However, H2S could have an impact on respiration and performance of higher marine organisms (Karman *et al.*, 2006).

Furthermore, changes of pH in sediments due to CO2 might have effects on metal speciation e.g., mobilising trace metals and other compounds to a higher extent of bioavailability. This may lead to direct toxic effects and/or accumulation in the food chain (Karman *et al.*, 2006).

<u>Semi-quantitative estimation</u>

A semi-quantitative estimation of the impact of CO2 storage on the high seas is presented in Table 18.1.

Conclusions on effects

- Two ecosystem compartments will be affected:
    - the sea floor,
    - the overlying water.
- Main effects are those that result from the increase of CO2 concentration in the ambient water and sediments which causes a decrease of pH;
- The growth, survival and reproductive success of marine animals has been found to decrease at low ambient pH;
- Dissolved CO2 is expected to have significant effect on marine biota in the near field;
- There is a risk of increasing the problem of ocean acidification;
- The effects of elevated CO2 levels cannot be accounted for by only considering the pH;
- The stored CO2 may contain other contaminants, such as H2S.

7.5 Assessment of socio-economic importance

It is predicted that the deployment of CCS systems starts to be significant when carbon dioxide prices begin to reach approximately 25–30 US$/tCO2 and large-scale deployment of CCS systems are foreseen within a few decades from the start of any significant regime for mitigating global warming. Because ocean storage is more expensive compared to geological storage (Table 7.2), it is expected to be a secondary option. Early CCS deployment will be in the industrialized nations, with deployment eventually spreading worldwide (IPCC, 2005).

Table 7.2 Representative cost range for geological and ocean CO2 storage (IPCC, 2005)

Option	Representative cost range (US$/ton CO_2)
Geological	0.1 – 8.0
Ocean	6 - 31

7.6 National activities

Several countries are involved with (research on) CCS. An international consortium involving engineers, oceanographers and ecologists from 15 institutions in the United States, Norway, Japan and Canada proposed the CO2 Ocean Sequestration Field Experiment, located at the deep ocean near Keahole Point on the Kona coast of the Island of Hawaii. This would have been the largest intentional CO2 release into the ocean water column. However, the project met with opposition from environmental organizations and had to be canceled. The group than developed a plan located off the coast of Norway which was also cancelled as the Norwegian Environment ministry did not approve the project (IPCC, 2005).

7.7 Trends

Productivity and economics

Public opinion and public's acceptance or rejection of CCS is likely to affect the large-scale implementation of CO2 storage. For the geological storage of CO2, the current lack in policy, legislation and a proper regulatory framework in most jurisdictions is presently considered as the most significant barrier (Bachu, 2007). It can be expected that developments in this area will affect the economics and financial risk of CO2 geological storage and will accelerate or delay the deployment of this technology for reducing anthropogenic CO2 emissions into the atmosphere (Bachu, 2007).

Scenario studies show that CCS contributes 15–55% to the cumulative mitigation effort worldwide until 2100. In most scenario studies, the role of CCS in mitigation portfolios increases over the course of the century, and the inclusion of CCS in a mitigation portfolio is found to reduce the costs of stabilizing CO2 concentrations by 30% or more (IPCC, 2005). As ocean storage involves higher costs compared to geological storage, it is not expected to reach large scale productivity. However, developments in regulations for areas within the national borders, considering CCS, could lead to more restrictions and therewith relatively less suitable for CO2 storage.

Environmental regulations

Some regulations for operations in the subsurface do exist that may be relevant or, in some cases, directly applicable to geological storage, but few countries have specifically developed legal or regulatory frameworks for long-term CO2 storage (IPCC, 2005). Existing laws and regulations (regarding i.a. mining, oil and gas operations, pollution control, waste disposal, drinking water, treatment of high-pressure gases and subsurface property rights) may be relevant to geological CO2 storage.

There are currently several treaties (notably the London and OSPAR Conventions) that apply to the injection of CO2 into the geological sub-seabed or the ocean. OSPAR has recently developed guidelines for risk assessment and management of storage of CO2 streams in geological formations (OSPAR Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations). The purpose of the Decision is that by application of the OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations, authorities shall ensure that carbon dioxide streams, which are stored in geological formations, are intended to be retained in these formations permanently and will not lead to significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area (OSPAR, 2007).

Besides the developments on a global and regional level, individual countries are working on the legislative conditions for subsea storage of CO_2. Such conditions or guidelines may very well be stricter than those of London Convention and OSPAR (Karman *et al.*, 2006).

7.8 Future developments

CCS for the purpose of reducing atmospheric CO2 levels is a new technology and very few industrial scale projects exist at the moment. There are no projects known to take place on the high seas. Increasing knowledge and experience would reduce uncertainties and thus facilitate decision-making with respect to the deployment of CCS for climate change mitigation.

The IPPC (2005) identified major knowledge gaps concerning the ecological impact of CO2 in the deep ocean. The authors note that these should be filled before the risks and potential for ocean storage can be assessed. Studies are needed of the response of biological systems in the deep sea to added CO2, including studies that are longer in duration and larger in scale than those that have been performed until now. Coupled with this is a need to develop techniques and sensors to detect and monitor CO2 plumes and their biological and geochemical consequences (IPCC, 2005).

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8 Antarctic tourism[40]

8.1 Introduction

In a discussion of the potential conflicts between human activities and biodiversity of the high seas, tourism is not an immediately obvious issue. In the open ocean, at more than 200 nautical miles distance from land, it is hard to imagine tourist activities that could have a significant impact on ecosystems or biodiversity.

Nevertheless, tourism has to be discussed in this report because there is one region where the 'high seas' reaches in fact all the way to the coastline. The Antarctic continent and associated islands south of 60°S have no effective 'national authority' over the usual maritime zones, in particular the 'Exclusive Economic Zone" (EEZ) even if some states with territorial claims like Australia have also claimed an EEZ.

The Antarctic continent and surrounding ocean south of 60°S are governed by the international community as united in the Antarctic Treaty System (ATS). Decisions concerning the area are made by the annual Antarctic Treaty Consultative Meetings (ATCMs). The status of Antarctic Treaty Consultative Party (ATCP), which includes the right to vote, is open to any state party to the Antarctic Treaty that makes a significant and permanent effort in peaceful research in the Area.

Where the Antarctic Treaty area is delimited as the area south of 60°S, the associated Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) uses a wider area definition, which roughly follows the track of the Antarctic Polar Front (APF). Cold Antarctic and warmer northern waters bounce and submerge in the APF, which creates a natural physical and biological boundary separating the Antarctic environment from the temperate zone. The Netherlands has the status of ATCP and is a party to the CCAMLR Convention since 1991 but is not a member of the CCAMLR Commission.

In 1998 the 'Protocol on Environmental Protection to the Antarctic Treaty' (known as the 'Madrid Protocol') entered into force. States parties meet in the 'Committee on Environmental Protection (CEP)'. The Netherlands is also a party to the Madrid Protocol, except for its Annex VI on Liability.

The rate of growth of tourism in the Antarctic justifies the inclusion of this industry as a significant human activity on the high seas that may have impact on ecosystem values and biodiversity. Comparable touristic activities and impacts occur in many coastal areas of high natural value worldwide, but there they occur within the maritime zones of coastal States (including EEZs) where national authority applies. In relation to 'high seas' biodiversity discussions, the impacts of tourism are almost completely linked to the impacts of 'shipping' which are more broadly discussed elsewhere in this report (Chapter 5.4). This tourism chapter focuses on those shipping aspects that are particularly relevant in relation to Antarctic touristic activities. Further impacts from other forms of Antarctic tourism, e.g. visitor disturbance effects onshore on wildlife concentrations or cultural or historic sites are not included in this report.

8.2 Relevant indicators

Antarctic tourism is a fast growing industry largely based on tours with cruise ships. A smaller part of tourist visits is by aerial transport, partly landing and partly just making overflights. Although aerial transports are growing and of serious concern for nature conservation and management, they fall outside the scope of this report.

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[40] Author: J.A. van Franeker

The type of tourist ships visiting Antarctic waters is extremely variable and ranges from small sailing yachts to huge cruise-liners. The largest ships, carrying over 500 passengers, usually make no landings but only cruise in the area. However, also these very large ships navigate along the interesting spots close inshore, manoeuvring in narrow channels and between islands close to dense concentrations of wildlife like penguin breeding colonies.

Compared to the situation elsewhere in the world, tourist operators in Antarctic waters show a high level of coordination and self-regulation. Most operators are members of the International Association of Antarctic Tour Operators (IAATO) which coordinates visits and develops operational regulations beyond what is strictly legally required. IAATO provides public information on tourist activities and communicates with the Council of Managers of National Antarctic Programs (COMNAP) and the ATS meetings.

8.2.1 Measurement of the function

Almost all tourist activity is registered by IAATO, and regularly updated information is provided on their website and in reports to the ATCMs. Since the early 1990's the number of visiting passengers has increased fivefold. Currently about 35000 passengers visit the Antarctic by ship during the Nov-Mar austral summer season (Figure 8.1). Not included here are crew members, which may number more than half of the number of passengers. Most tourist ships make landings at interesting sites. Similar increases can be seen in the number of tourist operators active in the industry and the number of visiting ships and voyages. In the 2006-07 summer, 47 ships made a combined number of 268 voyages to Antarctic waters.

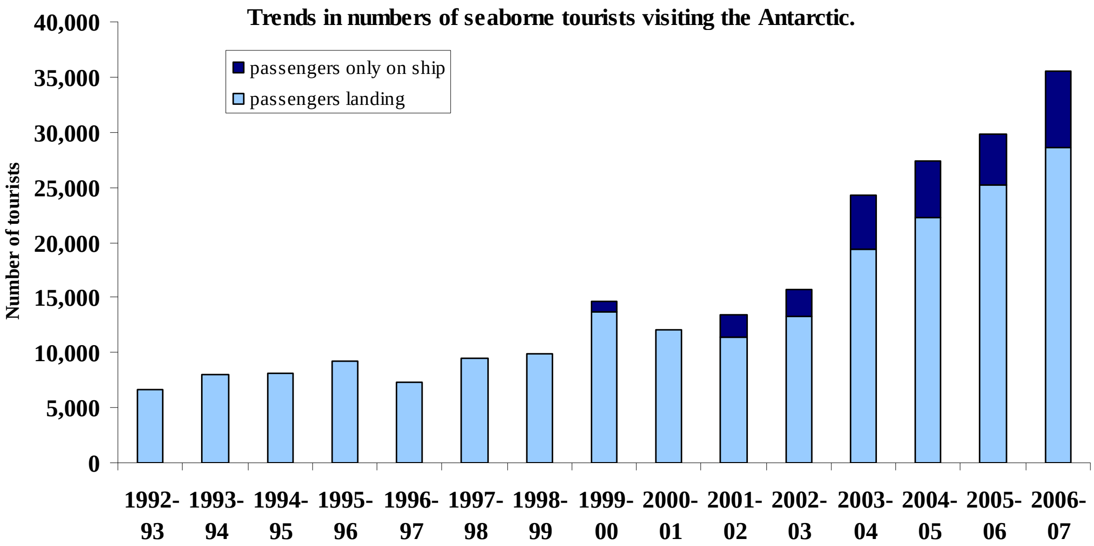

Figure 8.1 Trends in numbers of seaborne tourists visiting the Antarctic *(Source IAATO 2007a: table 1))*

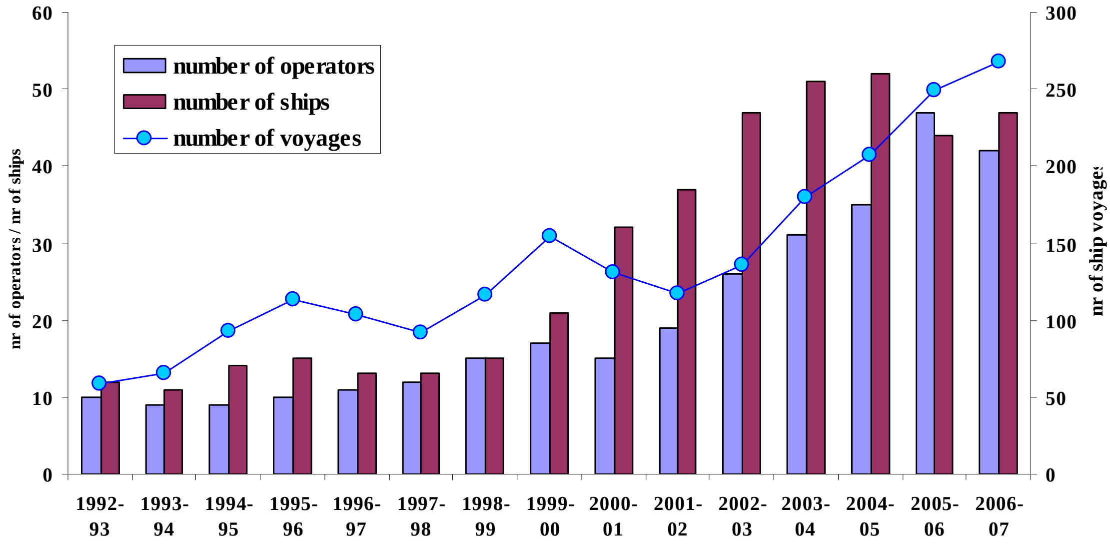

Figure 8.2 Trends in number of operators, ships and voyages involved in Antarctic tourism *(Source IAATO 2007a: Table 1))*

8.2.2 Nationalities involved in the function

The tourists that visit the Antarctic are dominated by visitors from the USA, with considerable numbers also from the UK and Germany (Figure 8.3). Passengers from the Netherlands represent just over 3% of the visitors. The Netherlands are more strongly represented in the operational aspect of Antarctic tourism, being involved in 11% of ships and 18% of visitor numbers (Table 8.1).

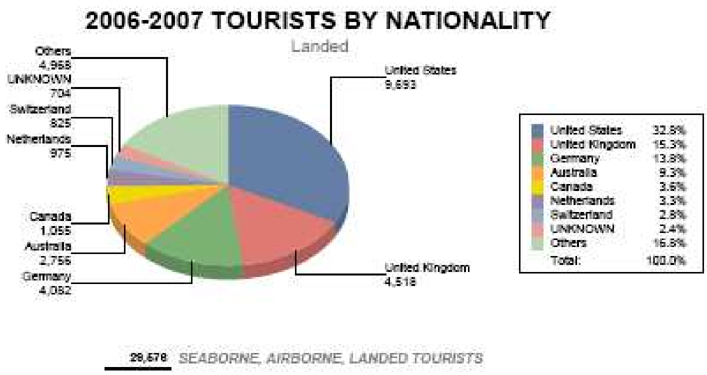

Figure 8.3 Nationalities involved in Antarctic tourism: tourist origins. *(Source: http://www.iaato.org/ http://image.zenn.net/REPLACE/CLIENT/1000037/1000116/application/pdf/touristsbynationality_landed4.pdf)*

Table 8.1 Netherlands involvement in shipbourne tourism in Antarctica, season 2006-07.
(Source: IAATO 2007a: Table 2)

Ship	Registry	National authority	Passenger capacity	Active in Antarctic since
Bark Europa	Netherlands	Netherlands	38	2000
S/V Tooluka	Netherlands	Netherlands	6	2003
Prinsendam	Netherlands	USA	793	2005
Rotterdam	Netherlands	USA	1316	2005
Grigoriy Mikheev	Russia	Netherlands	46	1999
Netherlands involved in 5 of 47 ships 11%			NL Passenger capacity 2199 of 12411 passengers 18%	

Tourist shipping is strongly concentrated in the region of the Antarctic Peninsula, where approximately 90% of visitor numbers go. Only about 5% visits also the more continental locations around the Antarctic, and 5% travels to land locations for activities on land.

8.2.3 Socio economic aspects of Antarctic tourism

Financial turnover of the Antarctic tourist industry may represent over € 300 million Euro annually with an estimated generated direct employment of 1500 man-years. For details, see Chapter 5.1.2.

8.2.4 Future trends

Currently no reduction in the rate of increase of Antarctic tourism is expected, and annual growth with thousands of extra tourists is expected by IAATO. At some stage, the cost-level of Antarctic cruises can be expected to limit tourist activity in the area. It is unlikely that shipping accidents as with the Explorer in the summer of 2007-2008 (see Chapter 8.3.2) would have a longer term effect on tourist numbers.

8.3 Measuring the ecological impacts

Direct quantitative measurement of the ecological consequences of ship-related tourism in the Antarctic is not possible. These will have to be estimated from the number and duration of visiting ships; the number of passengers plus crew; and of course ship type and design and operational measures taken on board to reduce the impacts of the ship on the environment. Crew members represent a significant addition to the number of tourists, increasing the number of persons in the area by more than 50%. Based on average duration of cruises, tourist numbers as given in Figures 8.1 and 8.2 can be calculated to represent over 800.000 ship-based man-days in the Antarctic in the summer of 2006-2007 (See Chapter 5.2.1).

A discussion of the potential impacts of seaborne tourism on the Antarctic marine habitat best starts along the lines of the international convention for the prevention of pollution by ships (MARPOL 73/78) and related conventions. For a general discussion of shipping and biodiversity of the high seas, see Chapter 5.4 of this report. General discussions of impacts from shipping or tourism on marine birds and mammals are given in Chapters 5.4 and 5.5. Discussions here focus on shipping and tourism in the context of Antarctic tourism.

8.3.1 Shipping conventions and Antarctic tourism

Four of the six Annexes of MARPOL 73/78 have relevance in relation to Antarctic tourism. Only the annexes II (transport of liquid chemicals in bulk) and III (packaged dangerous substances) seem of little relevance in relation to Antarctic tourism.

MARPOL 73/78 Annex I: prevention of pollution by oil

The Antarctic Treaty area (south of 60°S) is a 'Special Area' under Annex I, which implies that in no situation whatsoever discharged water (from machinery spaces or tanks) can have a concentration of over 15ppm oil. Special storage tanks and oil-water separators have to be used to achieve this. Under normal conditions, this limit can be considered as environmentally safe. However, in situations where ships concentrate, the total quantity of discharged oils can accumulate even if concentrations are low. In addition, performance of storage systems and oil-water separators is definitely not always perfect, and operation failure is more frequent where the quality of fuel is lower (see Annex VI).

MARPOL 73/78 Annex IV: prevention of pollution by sewage from ships

Annex IV does not allow discharges of "black water" (sewage) within three nautical miles from shore; between 3 and 12 nautical miles only treated sewages may be discharged; but beyond 12 nautical miles untreated sewage may be discharged. For the discharge of "grey" water from shower, kitchen etc., Annex IV gives no regulations at all.

This implies that tourist ships with high numbers of tourists and crew can legally discharge considerable amounts of wastewater and sewage in the direct vicinity of large concentrations of marine wildlife. Most animals will also feed beyond 12 nautical miles from shore.

MARPOL 73/78 Annex V: prevention of pollution by garbage

The Antarctic Treaty area is a Special Area under MARPOL 73/78 Annex V, which implies that only remains of food, grinded to size below 25mm can be discharged at a distance of at least 12 nautical miles from the coast. Outside Special Areas, some other garbage like paper, rags, and glass, may be discharged. Discharges of plastics are nowhere allowed. Garbage may be burned in suitable on-board incinerators. Like in Annex IV, the amount of waste generated will be directly proportional to the number of passengers and staff. Food wastes, so plant and animal remains, can be discharged at distances from shore (12 nautical miles) that are well within the foraging range of the majority of local wildlife.

MARPOL 73/78 Annex VI: prevention of air pollution

This recent MARPOL Annex gives some regulations for fuel quality from the background of air pollution (SOx; NOx emissions) and reduction of ozone affecting gases. Exhaust fume deposits will have some influence on the water near shipping activity, but for this report the main relevance is the relation between poor fuel quality (in general the 'heavy grade fuels') and increased risk of machine failure (loss of navigational control over the ship), problems in fuel residue storage and oil-water separators controlling oil concentrations in discharged water from tanks and machinery spaces. The type and quality of fuel carried is of course also of major importance in case of ship accidents.

Most tourist ships in the Antarctic are reported to use light to medium types of fuel, although some use heavy grade fuel also on part of their journey, thus carrying tanks with more dangerous oils into the area, even if not used in the area itself (ATCM 2005a). In 2004, the ATCM (2004) recommended special guidelines for ships operating in the Antarctic, but these refer to construction standards of the ship that may reduce losses in accidents, rather than to standards on fuel quality/quantity that could reduce risks of accidents occurring and reduce general environmental impact from ship operation.

The practical tendency to avoid the heaviest grade of fuels in Antarctic tourist ships is likely related to operational requirements of complicated ship manoeuvres rather than to environmental considerations. Currently there are no specific regulations on fuel quality for Antarctic ship operations that go beyond the general MARPOL 73/78 regulations.

IMO Ballast water Convention

A new convention was adopted in 2004 on procedures to reduce risks of unintended biological introductions from ballast water discharges by ships. Inside the Antarctic Treaty area, ballast discharges hardly occur (ATCM 2005b), and gradual implementation of the Convention will likely further reduce potential impact. The ATCM (2006b,c) refers to IMO regulations with the addition of a number of 'common sense' guidelines. Further information ballast water can be found in Chapter 5.4 on function *'Shipping'.*

International Convention on the Control of Harmful Anti-fouling Systems on Ships

Leaching of toxic components from anti-fouling paints based on TBT in particular have caused worldwide problems in areas intensively used by ships (harbours, shipping lanes). It is likely that some effects have also occurred at more busy Antarctic shipping locations. However, as of 2008, TBT will be internationally banned and phased out (International Convention on the Control of Harmful Anti-fouling Systems on Ships 2001) and this issue is not expected to present a serious problem in relation to tourism in the Antarctic or elsewhere. However, if no good alternatives are developed, higher fouling of ship hulls imply a potential increased risk of biological introductions to the Antarctic.

Further information on this topic can be found in Chapter 5 on 'Shipping'.

8.3.2 Most relevant impacts from Antarctic tourist shipping

Introduced alien species and diseases

In addition to operational and accidental pollution risks, the issue of introduced species and diseases may be the most important threat to Antarctic marine biodiversity from tourist related shipping. On the one hand, there is a strong awareness of the danger of alien species and diseases in Antarctic operations. Tourist ships as well all ships used for national science programs in the Antarctic have procedures for cleaning clothing, footwear etc of passengers to avoid risks of unintended introductions. Scientific fieldwork in Antarctica is often subjected to strict regulations aimed at reducing risks of biological introductions, e.g. restrictions of bringing poultry based food products into the field. Remains of chickens and eggs are well known for their risk of spreading diseases like Newcastle's disease (Clarke and Kerry 2000) or bird-flu (Wallenstein et al. 2006).

But in strong contrast to such precautionary policies, the same ships are allowed to discharge food-wastes and wastewater under MARPOL 73/78 Annexes IV en V. Such discharges release large quantities of all sorts of potentially dangerous biological material directly into the marine environment including near-shore Antarctic habitats. High concentrations of marine organisms reside in or migrate through those habitats, many of which will eagerly forage on shipwastes. In particular birds like tubenoses and skuas will directly transport ingested materials to the breeding colonies to feed their offspring facilitating the spread of disease in densely populated areas. Introduced diseases have occurred in the Antarctic (e.g. Gardner et al 1997; Clarke and Kerry 2000; Kerry et al 2000; Wallenstein et al. 2006). Compared to the sewage and food discharges, ballast water and fouling of hulls may represent a relatively minor risk, to which considerable attention is given in international policy.

In the light of major efforts made to contain the spread of diseases like bird flu, the permission for ships to discharge food wastes and sewage is a hard to understand paradox in national and international policies. Although this is true worldwide, the rapidly growing number of tourist ships in the Antarctic bring large numbers of people producing large quantities of wastes into close vicinity with the most dense concentrations of wildlife that is least adapted to human influence. From this perspective, Antarctic tourist shipping, representing over 800.000 man-days of generated wastes, can be considered an especially prominent risk for biodiversity

IAATO is advising its members to follow MARPOL 73/78 Special Area waste procedures in the CCAMLR Convention area, extending further north than the Antarctic Treaty area (south of 60°S) and using the natural physical and biological barrier of the Antarctic Polar Front . Although highly recommendable, this does not alter food-waste and sewage discharges in the areas of concern.

Shipping accidents

The growing density of tourist ships operating in shallow coastal waters in the immediate vicinity of major wildlife concentrations represents an extra risk for the environment from accidents. The type of environment, climate and water temperatures further increase the risks as salvage or impact containment are extremely difficult and breakdown of pollutants extremely slow.

A well known example of shipping risks is that of the grounding of the Bahia Paraiso, an Argentinean supply vessel which also carried tourists. The Bahia wrecked near Anvers Island in 1989 which caused considerable pollution and disturbance of surrounding bird colonies (Penhale et al 1997). In spite of a clean-up operation in which the Netherlands was actively involved (Acero et al 1992), evidence for continued oil leakage from the wreck was observed in 2002 (Janiot et al 2003), indicating salvage problems and long impacts in this environment. During tourist season 2006-07, two shipping incidents were reported, both from Deception Island. The vessels *Nordkapp* en *Orlova* had independent incidents and in at least one of these, a considerable quantity of fuel oil leaked out of the vessel. Recently, in the 2007-08 tourist season, things turned even worse. On 24 Nov 2007, the tourist ship *MV Explorer* with over 150 persons on board hit an iceberg near King George Island and sank. Fortunately all passengers and crew were rescued, but the vessel with over 180 tonnes of fuel will undoubtedly represent a long-standing environmental problem. A month after the sinking of *MV Explorer*, another ship, the MS *Fram*, a large cruise-liner carrying over 300 passengers, lost power and drifted against a wall of glacial ice. Fortunately the damage was relatively minor, but might have ended as dramatic as the *Explorer*. Remarkably, an overview of ship accidents (tourist or other) and near-accidents in Antarctic waters seems to be missing. The IAATO secretariat (Crosbie personal information) reports to have little information except for the two 2006-07 incidents reported to ATCM. The COMNAP secretariat has not responded to a similar query. However, events in the 2006-07 and 2007-08 tourist seasons make very clear that increased tourist shipping in difficult near-shore polar situations has high risks. This suggests that in the Antarctic situation, general regulations like MARPOL 73/78, are insufficient, and that there is a 'local' need for upgraded standards on ship construction, maintenance, crew quality, and for example fuel-quality carried.

Disturbance by underwater sound from ships

In addition to general issues from underwater noise produced by ships (See Chapter 5.4 'Shipping'), the tourist sector has an additional problem in that tourist ships tend to search, approach and follow marine mammal concentrations, and spend considerable time in their vicinity. See also Chapter 15.8 on marine mammals. IAATO has provided ATCM (2006a) with an information paper on whales and tourism, but this document only discusses behavioural guidelines to avoid whale disturbance from actively approaching ships, and does not deal with the potential disturbance of marine wildlife from the underwater sound from the ship in general operation. Engine design and ship speed are relevant aspects in sound disturbance and collision risks, but regulation of these in Antarctic waters appears non-existent.

8.4 Positive effects of Antarctic tourism

Eco tourism, also that to the Antarctic has a definite positive role to play in protection and management of nature and the conservation of biodiversity (Lamers & Amelung 2005). The personal experiences from visitors contribute to public, political and policy support for conservation and protection of the Antarctic. Such positive effects are extremely difficult to quantify. But an excellent example is that the status as ATCP of the Netherlands was triggered by political lobbying by the late W. Thomassen after having visited the Antarctic as a tourist (Thomassen 1983).

8.5 Policy options to reduce biodiversity risks

Direct regulation for risk reductions from shipping is possible through ATCM, COMNAP en IAATO, indirectly via MARPOL and related Conventions. Recently, the Antarctic and Southern Ocean Coalition (ASOC) submitted an information paper to the Marine Environment Protection Committee of IMO, signalling problems and giving potential solutions to be considered (MEPC 2008). Area protection and tourist numbers and modes of transport could be regulated through the Antarctic Treaty System (Antarctic Specially Protected Area (ASPA); best broadened with concepts of Marine Protected Areas) and the Madrid Protocol.

8.6 Conclusions

- In relation to *Biodiversity of the High Seas*, tourism is mainly an issue of concern in the Antarctic where no common maritime zones of coastal States exist and thus the 'high seas' include vulnerable coastal waters
- Antarctic tourism is a rapidly growing industry which concentrates in the area around the Antarctic Peninsula, also the richest in animal life
- Biodiversity risks of Antarctic tourism mainly occur through shipping related effects, with specific concerns for:
- Shipping accidents resulting in prolonged sources of pollution close to biodiversity hotspots
- Risks from introduced diseases from (legal) discharges of large quantities of sewage, grey water and food-wastes close to biodiversity hotspots.
- Relevant regulations are largely based on MARPOL 73/78, but in this specific situation a more proactive role of the Antarctic Treaty system might be considered.

8.7 Sources of information

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COMNAP, the Council of Managers of National Antarctic Programs
http://www.comnap.aq/ Council of Managers of National Antarctic Programs

IAATO International Association of Antarctic Tour Operators http://www.iaato.org/

IWC International Whaling Commission http://www.iwcoffice.org/

ACAP Agreement on the Conservation of Albatrosses and Petrels *(onder de Convention on the Conservation of Migratory Species of Wild Animals (CMS)).* http://www.acap.aq/

MARPOL International Convention for the prevention of Marine Pollution from Ships *(aangestuurd via IMO-MEPC International Maritime Organisation – Marine Environment Protection Committee)*
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9 Infrastructure[41]

9.1 Introduction and scope

Infrastructure at the ocean floor consists of pipelines, power transmission cables and cables for data communication (mostly fibre-optic cables). All States have the right to lay submarine cables and pipelines as a freedom of the high seas (UNCLOS art. 87). However, submarine infrastructure in the high seas consists almost entirely of fibre-optic cables, while power cables and pipelines are only laid within the nations EEZs.

Pipelines

Despite long length of some pipelines, off-shore pipelines are also restricted to the nations EEZ's. Intercontinental transport of oil and gas is yet the domain of large tankers. For instance, Russian gas is transported by pipelines over the European mainland and through the Black Sea. A 1200 km pipeline over the bottom of the Baltic Sea is planned to transport gas from Russia to Germany (source: Nord Stream). Also this pipeline will run entirely within areas of national jurisdiction..

Power cables

The longest power transmission cable to date is a Baltic cable (250 km, 130 nautical miles) which runs from Sweden to Germany, within the EEZ of both countries (Andrulwicz *et al.* 2003). Currently, a longer submarine power cable is being laid. This NorNed-cable running from Eemshaven in the Netherlands to Kvinesdal in Norway will measure 580 km (322 nautical miles) (website Nederlands centrum van normalisatie www.nen.nl, 2006). The cable should start to operate from 2008 onwards and will be the world's longest submarine power cable. Also this power cable is laid entirely within the EEZs of the Netherlands, Germany, Denmark and Norway. In order to connect two countries that are separated by high seas, cable length should exceed 400 miles (twice the 200 mile of the EEZ). Considering energy losses related to long-distance (even when using HVDC technology) energy transfer, power cables at the bottom of the high seas are not to be expected in the near future.

Data cables

Since the 1980s, fibre-optic cables capable of carrying huge amounts of data have been laid along the ocean floor. As demand has grown, so has the number of cables on the seabed. To date there are already millions of kilometres of submarine fibre-optic cables and this is rapidly increasing. Considering such growth of human activity in the high seas justifies the question whether this might harm marine ecosystems and biodiversity.

Scope

In this chapter the ecological impact and socio-economic importance of data cables in the high seas are assessed. Power cables and pipelines are addressed briefly, considering possible impact in the future. In order to properly assess ecological impacts related to infrastructure in the high seas, first the materials and technology used and the size and distribution of infrastructure will be described.

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9.2 Materials and technology

9.2.1 Fibre optic cables

An optical fibre is a glass or plastic fibre designed to guide light along its length. It is especially advantageous for long-distance communication, because light propagates through the fibre with little attenuation compared to electrical cables. Additionally, the light signals propagating in the fiber can be modulated at rates as high as 40 Gb/s, and each fiber can carry many independent channels, each by a different wavelength of light (Ramachandran 2001). Although, fibres can be made out of transparent plastic, glass, or a combination of the two, the fibers used in long-distance telecommunication applications -thus submarine cables- are always glass, because of the lower optical attenuation.

Submarine fibre-optic cables typically have only the diameter of a garden hose (i.e., up to 2,5 cm) and in trajectories where extra protection is required up to 6,5 cm. An optical fibre cable intended for submarine use has a central cylindrical strength member over which are laid the optical fibres. These are within a sheath, itself within an aluminum tube, usable to convey electrical power for repeaters. On the outside of this tube we have a layer of high tensile steel wires, surrounded by a layer of low density polyethylene. In a cable for shallower waters where the risk of damage is greater than in deep water the polyethylene layer is surrounded by a layer of armouring wires separated from the polyethylene by bedding material and enclosed by a layer of binding material (United States Patent 4371234).

Cable laying

Submarine fibre-optic cables typically are laid by a large specialized cable-laying ship, spooling the cable out of huge holding tanks. Four different installation techniques may be used for different segments of a cable route (Shorb, 2002).

1. At the shoreline, directional drilling is often used to install cable conduits passing under the beach and any nearshore reef, to minimize impacts on them.
2. When crossing soft bottom areas that are potentially subject to ship anchoring and trawling or other bottom-fishing techniques, the cable typically is buried, to protect the cable from the fishing gear. This is typically done by the cable vessel pulling an underwater plow that continuously cuts a furrow and places the cable into the furrow. Before long, the furrow smoothes out due to natural forces.
3. When crossing hard bottom areas where burial is infeasible and anchoring or bottom-fishing gear is expected, typically “armoured” cable is used. It has a diameter no more than a soft drink can (i.e., up to 6,3 cm). The evidence shows that such cables do not move laterally once placed. Old cables are found encrusted with corals and other sea life.
4. When crossing the deep ocean where no anchoring or bottom-fishing gear is expected, the cable is just laid flat on the ocean bottom.

Cable repair

Cables can be broken by fishing trawlers, anchoring, undersea avalanches and even shark bites. Breaks were common in the early cable laying era due to the use of simple materials and the laying of cables directly on the ocean floor rather than burying the cables in trenches in vulnerable areas. Cables were also sometimes cut by enemy forces in wartime.

To repair cables, the damaged portion is brought to the surface using a grapple. Deep cables must be cut at the seabed and each end separately brought to the surface, whereupon a new section is spliced in. The repaired cable is longer than the original, so the excess is deliberately laid in a 'U' shape on the sea-bed. A submersible can be used to repair cables that are near the surface.

A number of ports near important cable routes became homes to specialised cable repair ships. Halifax, Nova Scotia was home to half a dozen such vessels for most of the 20th century including long-lived vessels such as the CS Cyrus West Field, CS Minia and CS Mackay-Bennett. The latter two were contracted to recover victims from the sinking of the RMS Titanic. The crews of these vessels developed many new techniques to repair and improve cable laying, such as the "plough", a device to bury cables.

9.2.2 Future developments for power cables and pipelines

To date, there are neither high voltage power cables nor pipelines installed in the high seas. There are also no definite publicized plans to do so.

Considering energy losses related to long distance transport with current technology, even when using high voltage direct current (HVDC), power cables at the bottom of the high seas are not to be expected in the near future. However, new technologies may further reduce cable resistance and hence energy losses during transport. It is currently difficult to predict what materials will be used for such cables, but the methods used for cable laying and repair will likely be similar to those used for current cables.

Pipelines are also restricted to onshore areas and the nations EEZ's. Intercontinental transport of oil and gas is yet the domain of large tankers. Constructing pipelines for intercontinental fluid transport would face technical challenges related to the high hydrostatic pressure, equipment that can control lengthy pipelines in turbid sea and maintenance in the deep sea. If these technological challenges are dealt with, pipelines may become a more cost-effective and reliable way to transport oil and gas than tankers.

9.3 Size and distribution of the cable network

Over the last century, millions of kilometres of seafloor submarine cables have been installed for telecommunication purposes. This undersea network interconnects the large urban centres of the world within and between continents (Williams 2000 in Kogan *et al.* 2006). To date, submarine cables link all the world's continents except Antarctica (Figure 9.1).

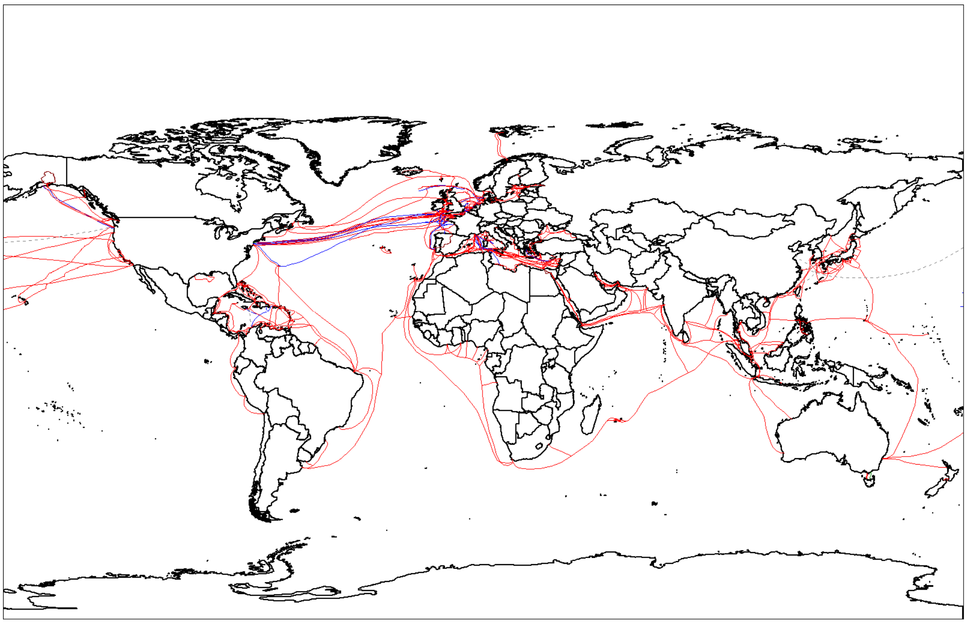

Figure 9.1 Map of submarine cables throughout the world (source: Wikipedia)

9.4 Ecological impacts

9.4.1 Introduction

Several international organizations have expressed their concern about (possible) impact of cables on marine biodiversity. In contrast the North American Submarine Cable Association (NASCA) stated before the United States Commission on Ocean Policy that there are no known adverse effects of fibre-optic cables laid on the ocean floor (Shorb, 2002). According to NASCA, fibre optical cables are environmentally benign. The Federal Communications Commission (FCC) has stated that "Although laying transoceanic cable obviously involves considerable activity over vast distances, the environmental consequences for the ocean, the ocean floor, and the land are negligible."

Possible impact of cables on marine biodiversity includes:

- Disturbance of marine habitats and fauna during cable laying;
- Disturbance during cable repair and maintenance;
- Change of habitat due to the presence of cables;
- Disturbance of animals due to the electrical field surrounding cables;

The benign chemical composition of submarine telecommunications cables, removes any risk of direct chemical contamination (Drabble 2006).

9.4.2 Disturbance during cable and pipeline laying

During cable laying both marine habitats and fauna may be disturbed. Ships and equipment used for the cable and pipeline installation produce noise that can disturb birds and marine mammals in the vicinity. Disturbance by ships is discussed elsewhere in this report. The effects assessed here focus on the disturbance caused by the cable, while being laid.

During cable and pipeline laying, marine sediments are likely to be disturbed when the cable hits the ocean floor. The impact of this disturbance, however, is not long lasting. Between one and eight years after cable installation, the zoobenthenthos community in the vicinity of the cable will be completely recovered (Kogan et. al. 2006; Andrulewicz, 2003; see also next paragraph). Rocky substrates are not likely to be damaged by cables. Sessile fauna growing on the hard substrate will. When cables and pipelines hit fragile habitat structures, such as vents, these might be damaged.

In conclusion, published observations suggest that the impact of cable laying on marine biodiversity is local and not permanent (see also Chapter 9.4.3).

9.4.3 Habitat change due to the physical presence of infrastructure

Cables and pipelines form hard substrates alien to the marine benthic environment. Kogan *et al.* (2006) have conducted a study on the impact of the presence of a coaxal type SD cable on benthic fauna. The cable studied, runs from an air force station in half Moon bay California towards a seamount 95 km offshore. Maximum depth reached by the cable is approximately 2000 m. During an 8 year period of observations few changes were detectable from video observations (epifaunal) and sediment core analysis (in fauna). Of 17 megafaunal groups and 19 infaunal groups, no tests evaluating the overall effect of the cable, were statistically significant. While these results indicate, that the impact of the cable on benthic fauna is minor at most, three faunal groups exhibited cable related changes. Actinarians (sea anemones) colonized the cable when it was exposed on the seafloor (Figure 9.2), and were therefore generally more abundant on the cable than in surrounding sediment dominated sea floor habitats. Some fishes were also more abundant near the cable, apparently due to the higher habitat complexity provided by the cable.

Similar results were found in a study observing macrozoobenthos in the vicinity of a high voltage cable in the Baltic Sea, between Sweden and Poland (Andrulewicz, 2003). After one year of installation no significant changes in macrozoobenthos species, composition, abundance or biomass were observed in the sediment floor. However, in the direct vicinity of cable parts on less dynamic deeper sediments, the number of individuals per m^2 increased, while biomass decreased after cable installation. This suggests that after disturbance during cable laying, the macrozoobenthos is recolonizing the impacted area surrounding the cable.

Figure 9.2 Photograph showing three *Metridium farcimen* positioned directly on the cable in 134m of water (from Kogan et al. 2006).

A submarine pipeline, constructed in 1997-1998 to provide water to Redang Island, Malaysia traverses an area covered with corals. Biological studies were conducted before and following pipeline construction to monitor the changes in the biota at selected sites. The results of these studies suggest only short-term impacts and recovery of the benthic community (Renzai et al., 1999).

While the local effects of cables on marine biodiversity are small, so is the total area covered by cables. Even tough, millions of kilometres of cables have been laid on the seafloor, the diameter of the cables varies only between 3 cm if unarmoured and 6 cm if armoured. This means that the surface area of all submarine cables is in the order of magnitude of 100 km^2, a negligible small percentage (order of 10^{-5} %) of the total 361 milion km^2 of ocean floor in the world. The percentage of the floor of the high seas covered by cables is even smaller, cable density being higher within the nations EEZ's than beyond (Figure 9.1). Similarly, the physical presence of power cables and pipelines will also not significantly affect biodiversity of benthic communities in the high seas.

9.4.4 Impact of electric-magnetic radiation on marine animals

Since repeaters in fibre-optic cables need electricity to amplify the light pulses, there may be electro-magnetic waves around fibre-optic cables too. The potential impact of electromagnetic radiation has been frequently assessed for power cables, but rarely for fibre optical cables.

The current in power cables produces electro-magnetic waves. It has been suggested that this could disturb marine animals that use electrical fields for prey detection or magnetic field for navigation. Potential impact of cables on marine animals depends on:

- electrical and magnetic fields surrounding cables;
- the sensitivity of marine animals to electrical and magnetic fields;
- the relevance of this sensitivity for prey detection and navigation.

The first point is a matter of physical measurements and calculations, but the latter two points are still a matter of scientific debate.

Magnetic and electrical field affected by cables

Both theoretical calculations (Andrulewicz *et al.*, 2003) and measurements with an underwater magnetometer (Kerridge, 2002), show that the area affected by cables is relatively small. Beyond 20 m of a HVSC transmission line there is no measurable difference in inclination compared to the natural inclination of the earth magnetic field (Andrulewicz *et al.*, 2003). Directly above a 150 KV AC submarine power line the change in magnetic field is calculated to be 4,5 μT, but this is rapidly decreasing with distance. At a distance of 10 m from the power line, the change in magnetic field is hardly measurable (Grontmij 2006). As cables are directly laid on the ocean bottom, much of the water column is unaffected.

Data on the electrical and magnetic field around fibre optical cables are not readily available in the literature, but is certainly orders of magnitude lower than in high voltage cables for electrical power transport.

Sensitivity to electrical and magnetic fields in marine organisms

A considerable amount of research has been undertaken to elucidate the mechanisms of electro sensory ability of marine animals and the use of this ability for navigation and prey detection. This research has demonstrated that electrical sensitivity is common, but also that only few species, including sharks and rays, have the ability to differentiate features of weak electrical fields from background noise in any useful way (Kalmijn, 2000). Sensitivity to steady magnetic fields appears to much more common. In contrast to the weak electromagnetic fields present in the ocean, the relative strength of the earth magnetic field (20-70 μT) does appear to be important for orientation of marine animals.

Sensitivity to weak electrical fields

It is widely accepted that at least some sharks, skates and rays (elasmobranchs) have well developed abilities to perceive and interpret weak electric fields using a specific organ called the ampullae of Lorenzini Their sensitivity is developed enough to allow them to notice and orient to the bioelectric field of prey organisms. Sharks and rays are able to detect the movement of hidden prey animals whose electrical field is as low as 10^{-8} V/m, and their electric pattern recognition is tuned to field frequencies caused by movement of a gill or beating of a hard in prey (Kalmijn, 1966). Many shark species were attracted to electrical fields in the range of 10^{-5} to 10^{-3} V/m in experimental tests, but avoided stronger electrical fields (CMACS, 2003 and references therein). Most other fish species are not capable of detecting weak electrical fields, except probably chimaeras and some eel species.

In September 1985, AT&T installed the world's first deep-sea fibre optic communications cable. The cable linked two of the Canary Islands, Gran Canaria and Tenerife. In October of the same year, system monitors indicated that power transmission in the cable had shorted out about 10 kilometres from Tenerife at a depth of about 1.000 metres. Similar faults occurred elsewhere along the cable in January 1986, March 1986, and April 1987. Examination of the damaged cables indicated that in all cases, shark bite had caused the failures. Scores of shark teeth and tooth fragments were removed from the recovered cable segments. Two were apparently from an open ocean carcharhinid, probably the oceanic whitetip (*Carcharhinus longimanus*), a few were tentatively identified as having belonged to goblin sharks (*Mitsukurina owstoni*), but the vast majority — a total of over 50 teeth and fragments — were identified as having come from a rare and little-known species: the crocodile shark. As to why the sharks were biting AT&T's cable, it was presumed that their electric field simulated that of prey and elicited the attacks. Unfortunately, laboratory experiments using chain dogfish (*Scyliorhinus retifer*) and Lemon Sharks (*Negaprion brevirostris*) produced inconclusive results (ReefQuest Centre for Shark Research, 2007).

Sensitivity to magnetic field

The detection threshold for magnetic intensity gradients (changes in magnetic field levels with distant) is postulated to be 1,2 nT in sharks and 50 nT (0,1 % of the earth magnetic field) in whales and turtles. This sensitivity for magnetic fields has been shown for direct current and low frequency magnetic fields, but has not been shown for high frequency magnetic fields, such as the magnetic field of 50 to 60 Hz AC power lines. Statistical studies have shown a high correlation between strandings of dolphins and whales with magnetic minima (Kirchvink *et. al* 1986).

The abibility to orient to earth magnetic field has been shown in sharks, rays (Kalmijn 2000), whales and turtles (Kirchvink, 1997) and has been suggested in dolphins (Zoeger et. al, 1981). The ability of marine mammals to orient to magnetic fields suggests the possibility of navigation, but does not necessarily proof it, because navigation also requires the development of a cognitive map (Paulin, 1995). A clear link between magnetic sensory ability and navigation has not yet been demonstrated in marine organisms (Klimley, 1993).

One argument against the reliance of marine organisms on magnetic orientation is the fact that any small natural abnormality or magnetic storm (from solar flares, for example) could circumvent directional movement. A more plausible argument is that marine animals can incorporate any changes in the magnetic landscape in their cognitive map. Under water cables would not appear to be capable of interfering with the navigation of marine mammals because of the limited area over which they can be detected.

Conclusions

- Marine animals sensitive to weak electrical fields, swimming close to fibre-optical cables may be attracted to the electrical field emitted by the cable. Sharks may occasionally attack these cables, confusing them with prey. However, this is unlikely to be detrimental to the animal (more likely to the cable) and will not affect the dynamics of shark populations.
- At present, there is no definite answer to the question, whether high voltage power cables have an effect on migrating fish and marine mammals. This is not (yet) an issue in the high seas, simply because all submarine high voltage power cables are laid within the nations EEZ's only.

9.4.5 Possible Impact of oil and gas spills from pipelines

Oil spills can be ecological disasters, killing many birds and marine mammals. It can take many years before habitats are clean and recovered. In the year 2000, 300.000 gallons of marine fuel spewed out of a broken pipeline into Guanabara Bay in Brazil, polluting beaches and intertidal habitats and endangering plant and animal life (Michel, 2000). In 2006, over 1000 barrels of oil were spilled from a leakage in a pipeline on the seafloor near Alaska. There are other examples of pipeline ruptures with smaller amounts of oil spilled. However, there are many more examples of ecological disasters in the marine environment following accidents with oil tankers. The ecological impact of oil spills has been addressed in Chapter 5 (shipping). Since at present there are no oil pipelines in submarine areas beyond national jurisdiction, this issue will not futher be elaborated here.

A semi-quantitative estimation of the impact of infrastructure on the high seas is presented in Table 18.1.

9.5 Socio-economic indicators

9.5.1 Economic importance of the submarine cable network

Optical fibers have played a key role in making possible the extraordinary growth in world-wide communications that has occurred in the last 25 years, and are vital in enabling the proliferating use of the

Internet. The network of fibre-optic cables is currently the backbone of the world's information infrastructure. The increased demand for bandwidth driven by the Internet, as well as the continuing international trend of privatization of national telecommunications industries, has outstripped by far the resources offered by satellite transmission of voice and data. Instead, the fraction of transoceanic voice and data transmitted over undersea cables has grown from 2 percent in 1988 to as high as 80 percent in 2000 (Mandell, 2000).

Total worldwide investment in undersea fiber optic cable systems, 1987-2007 was $46 billion (source: Terabit Consulting Undersea Cable Undersea Cable Report 2008).

9.5.2 Regional distribution

This investment includes sumarine cables within and beyond the EEZ. Figure 9.3 shows the regional distribution in cable investments in the period 2006-2008. Investments in the regions European regional, Carribbean, Australia, South America and East Asian regional are largely within the nations' EEZ, whereas over 90% of transatlantic and transpacific cables are laid beyond the EEZ. Hence, roughly 40% ($ 10.5 billion) of investments in undersea cable in the period 2000-2008 are cables laid in the high seas. From 2006 onwards there has been a shift in investment towards Souts Asia and Transpacific cables and away from transatlantic cables (source Terabitconsulting).

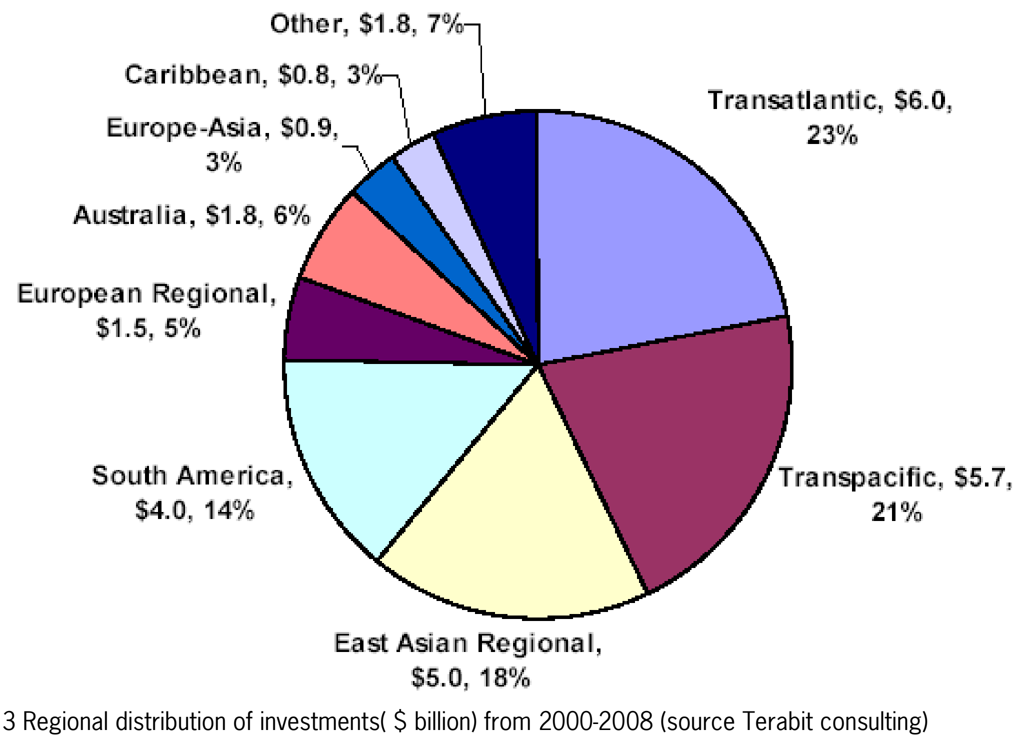

Figure 9.3 Regional distribution of investments($ billion) from 2000-2008 (source Terabit consulting)

9.5.3 Countries and organisations involved

Suppliers

The supliers market of submarine cable systems is currently dominated by only three companies/consortia Alcatel-Lucent/ Pirelli, Tyco and NEC, with a combined marketshare of 91% (Table 9.1).

Table 9.1 Suppliers' market share of submarine cable systems ($ billions of primary contracts, source Terabit consulting)

	2006	2007	2008	Total	Share
Alcatel-Lucent/Pirelli	$487	$85	$675	$1,247	39%
Tyco	$162	$125	$800	$1,087	34%
NEC	$75	$60	$455	$590	18%
Nexans	$20	$90		$110	3%
NSW/General Cable/Siemens/Corning Cable	$56	$41		$97	3%
Ericsson		$78		$78	2%
KDDI-SCS				$0	0%
Fujitsu				$0	0%
Other				$0	0%

Cable-laying ships

There are approximately 12 companies owning cable-laying ships in the world. These companies are based primarily in the western world and new Asian economies (Table 9.2).

Table 9.2 Owners and operators of cable-laying ships and their country of origin (source wikipedia, websites of cable companies)

Company	Country
TYCO	US
NSW	Germany
France Telecom Marine	France
Global Marine Systems Limited	UK
NTT World Engineering Marine Corporation (NTT-WEM)[	Japan
S. B. Submarine Systems	China
E-MARINE	United Arab Emirates
IT International Telecom Inc	Canada
Subsea	UK, Africa, Asia Pacific, Brazil, Gulf of Mexico, Norway and The Netherlands.
Alcatel Submarine Networks Marine	Denmark, US
Elettra	Italy
YIT Primatel Ltd.	Finland

9.6 Conclusions

- To date there are no high voltage power transmission cables or pipelines that have been laid in the high seas.
- Over the last century, millions of kilometres of seafloor submarine cables have been installed for telecommunication purposes. This undersea network interconnects all the world's continents except Antarctica and is currently the backbone of intercontinental data and voice transmission. The frac-tion of transoceanic voice and data transmitted over undersea cables has grown from 2 percent in 1988 to as high as 80 percent in 2000.
- Submarine fibre optical cables are therefore of high economic importance. Total worldwide in-vestment in undersea fibre optical cable systems, 1987-2007 was $46 billion.
- Submarine fibre-optic cables typically have only the diameter of a garden hose (i.e., up to 2,5 cm) and in trajectories where extra protection is required up to 6,5 cm.
- The ecological impacts of data cables are limited in extend, severity and recovery. Installation of these cables causes some disturbance of animals and habitats, but these effects are local and temporal. Electormagnetic radiation emitted by data cables is very low compared to the radiation emitted by power cables. Marine animals sensitive to weak electrical fields, swimming close to fibre-optical cables may be attracted to the electrical field emitted by the cable. However, there is no indication that submarine datacables disturb the orientation or navigation of marine animals.

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10 Bioprospecting and marine scientific research[42]

10.1 Introduction and scope

For decades, the depths of the oceans have fascinated researchers. The discovery of strange creatures perfectly adapted to eternal darkness, high pressure, and other unusual conditions has raised enormous interest in how life emerged on Earth and how it flourishes in such extreme environments. This abundance of life has also lured researchers and biotech companies to the oceans in the hope of finding unknown genes, proteins, and other compounds that could be exploited commercially (Figure 10.1). Despite the enormous costs that still pose a considerable barrier to deep-sea research and exploitation, some now worry about the negative side effects of deep-sea bioprospecting (Ruth 2006).

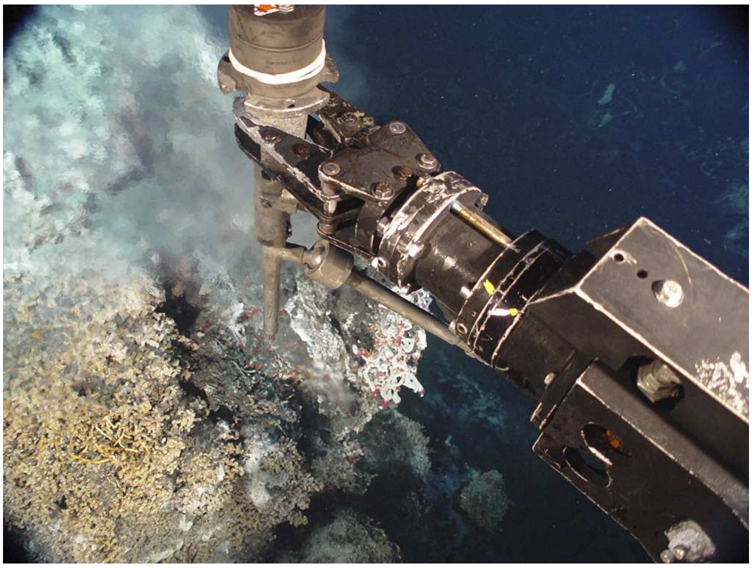

Figure 10.1 Remotely Operated Platform samples vent fluids from the Northeast Pacific Ocean (Photo: NOAA, http://oceanexplorer.noaa.gov)

Definitions and scope

There is no internationally agreed definition of bioprospecting (Arico & Salpin, 2005). While definitions of bioprospecting still diverge as to whether bioprospecting covers the subsequent stages of the search and sampling, application and development, a survey undertaken by Arico and Salpin (2005) shows that there is an emerging common understanding that the term "bioprospecting" involves research for commercial purposes. Possible elements of a definition of bioprospecting include:

- systematic search, collection, gathering or sampling of biological resources for purposes of commercial or industrial exploitation;
- screening, isolation, characterisation of commercially useful compounds;
- testing and trials; and

42 Author: A.M. Mouissie

• further application and development of the isolated compounds for commercial purposes, including large-scale collection, development of mass culture techniques, and conduct of trials for approval for commercial sale.

As with the term "bioprospecting", there is no internationally-agreed definition of "marine scientific research." While UNCLOS provides for a regime for marine scientific research (MSR), it does not define what MSR is. With regard to the right of coastal States to withhold consent to MSR projects proposed by other States or international organisations in their Exclusive Economic Zone (EEZ) or on their continental shelf, UNCLOS draws a distinction between MSR intended to increase scientific

knowledge for the benefit of all humankind, and MSR "of direct significance for the exploration and exploitation of natural resources." (Art.246(5), UNCLOS.). The distinction between those two types of research, which equate to pure scientific research for the former and applied research for the latter, is not made with regard to MSR undertaken in the high seas (Arico & Salpin, 2005).

In practice bioprospecting and marine scientific research are interrelated. There is no substantiated evidence that any company has mounted its own dive to the deep sea - or any marine area beyond national jurisdiction - to collect samples for the purpose of research and development in relation to biotechnology derived from deep sea genetic resources (Vierros *et al.,* 2007). The involvement of commercial organisations in sample extraction from the deep sea is limited to funding scientific expeditions and collaborations in laboratories once samples have been collected. Samples of microbes from the highs seas are also sold via national culture collections, where samples are deposited by research organisations.

In this chapter both bioprospecting and marine scientific research are assessed, often without making a clear distinction. The assessment of ecological impact focuses on microorganisms, macroorganisms and marine benthic habitats. Research involving fishing or whale hunting is not included in this chapter as fishing is discussed extensively elsewhere in this report.

10.2 Technology, equipment and materials

Reaching deep seabed extreme environments and maintaining sampled organisms intact and alive, as well as culturing them, requires sophisticated and expensive technologies. Typically, the technology associated with research on deep seabed genetic resources involves: manned or unmanned submersible vehicles (the latter are normally referred to as Remote Operation Vehicles or ROV); in situ sampling tools; technology related to culture methods, including pressurized aquaria to maintain sampled organisms at original pressure conditions; molecular biology technology and techniques; and the technology associated with the different steps of the commercialisation process of derivates of deep seabed genetic resources. Formerly, scientific dredging was widely used to obtain samples from deeper water environments.

10.3 Distribution and frequency of site visits

The deep sea is of increasing interest to science and industry. Until recently most bioprospecting in the oceans had been confined to shallower waters of the coastal waters and near coastal zones. A lack of knowledge of the biodiversity in the deep sea, together with logistical difficulties of working in environments of high pressure and total darkness associated with the deep sea, meant that bioprospecting in the deep-sea was unknown. To date a range of biological communities and habitats in the deep-sea including hydrothermal vents, deep-sea sediments and methane seeps have been visited. Even the deepest point in the ocean, the Marina Trench at a depth of more than 11.000 m has been visited by research vessels. Several research institutions are currently exploring microbial communities at hundreds of meters below the see bed, referred to as the "deep biosphere" (Leary, 2007). For instance see the European funded program 'DeepBug, the Deep Biosphere work of the Ocean Drilling Program and the Research Program for Deep-Subsurface extremophiles of the Japanese marine research institution JAMSTEC.

Hydrothermal vent research and bioprospecting

Hydrothermal vents are present in all of the world's oceans in areas associated tectonic and/ or volcanic activity. Hydrothermal vents are most abundant in the vicinity of deep sea-spreading centres, areas where the plates are moving apart and new sea-floor is being formed. Hydrothermal vents are home to highly specialised microbes and animals not found elsewhere on the planet. Because of their adaptation to extreme temperatures and chemical composition of vent fluids, these organisms are often referred to as extremophiles or thermophiles. Deep-sea hydrothermal vents were discovered in the 1970's and scientists have only begun to unravel the potential of scientific discovery of these remote environments. It is believed that the potential for continuing fundamental discoveries of biotechnological and perhaps medical importance is still high. Furthermore the study of hydrothermal vents contributes to our understanding of deep-sea ecology, the limits of life and perhaps even the origin of life (Devey, 2006).

Active vent sites are distributed very patchily along oceanic spreading centres. Distances between active vent sites can be as little as a few tens of metres, but sites are often separated by more than 100 km. The organisms living on vent sites are apparently well adapted to long-distance dispersal, as communities found on different vent sites within a spreading range show a high level of homogeneity. However, vent communities in the Pacific are very different from those in the Atlantic or Indian Ocean. Based on the level of similarity between vent communities scientist have described six biogeographic provinces spread around the Pacific, Atlantic and Indian Ocean's. New provinces of hydrothermal vent communities are likely to be discovered, for instance in the Artic Ocean.

Among the few hundred hydrothermal vents discovered so far, only a few are visited once a year, and others once every few years. It is likely that some deep seabed sites may become the subject of systematic observations under various monitoring programmes. The most studied sites are located in the Pacific Rise, the Juan the Fuca Ridge, Gorda Rich and Explorer Ridges in the eastern Pacific and the Mid Atlantic Ridge in the north central Atlantic (Van Dover, 2000). Given that the mid Ocean Ridges are known to circle the globe for some 75.000 km it is expected that many more, probably thousands of hydrothermal vent sites exist (Leary, 2004). .

The InterRidge MOR & BAB Cruise Database contains 432 records corresponding to the period 1992-2003. This database provides a proxy for identifying the sites that are most subject to scientific research. An analysis of the information contained in this database showed that the most visited sites were the Juan de Fuca Ridge in the Northeast Pacific (72 cruises) and the Mid-Atlantic Ridge located between 20°N and 40°N (61 cruises). These are followed by the Northern East-Pacific Ridge (42 cruises) and the Mid-Atlantic Ridge comprised between 0°N and 20°N (24 cruises), as well as the Manus & Woodlark Basins in the Pacific Ocean (21 cruises). The only site extensively studied in the Indian Ocean is the Southwest Indian Ridge (17 cruises). In the Arctic, the most researched site is the Kolbeinsey visited 6 times. Overall, the sites in the Pacific Ocean lead with a number of 218 cruises, followed by Atlantic Ocean sites (129 cruises), Indian Ocean sites (40 cruises) and the Arctic Ocean (16 cruises) (Figure 10.2).

According to the InterRidge databases, in the case of the above-mentioned most researched sites, out of the 21 sites located in the Juan de Fuca Ridge, 12 fall under Canadian jurisdiction while nine are located in the Area. Sites comprised between 20°N and 40°N in the Mid- Atlantic Ridge are located in the Area, except for the Menez Gwen and Lucky Strike sites, which fall under Portugal's jurisdiction. The sites of the Kolbeinsey Ridge (Northern Atlantic) all fall within Iceland's jurisdiction. Ascertaining the jurisdiction of sites comprised between 0°N and 20°N in the Mid-Atlantic Ridge was difficult. Regarding the 50 vent sites recorded in the Northern East-Pacific Ridge, the jurisdictions of Canada (the 12 sites mentioned above), the US (six sites) and Mexico (seven sites) have been identified. 11 sites fall outside national jurisdiction and, for some vents, it is unclear whether these fall within or beyond national jurisdiction. The 12 sites recorded in the Indian Ridge fall either in the Area or it is unclear whether they are located within or beyond national jurisdiction. Out of the 12 sites listed for the South-East Pacific, Chile is thought to have jurisdiction over two to four sites, while the others seem to be located in the Area. Of the 35 sites in the South-West Pacific, nine fall under Papua New Guinea's jurisdiction (including six sites in the Manus & Woodlark Basins), one under the Solomon Islands' jurisdiction, five under Fiji's (Figures 10.2).

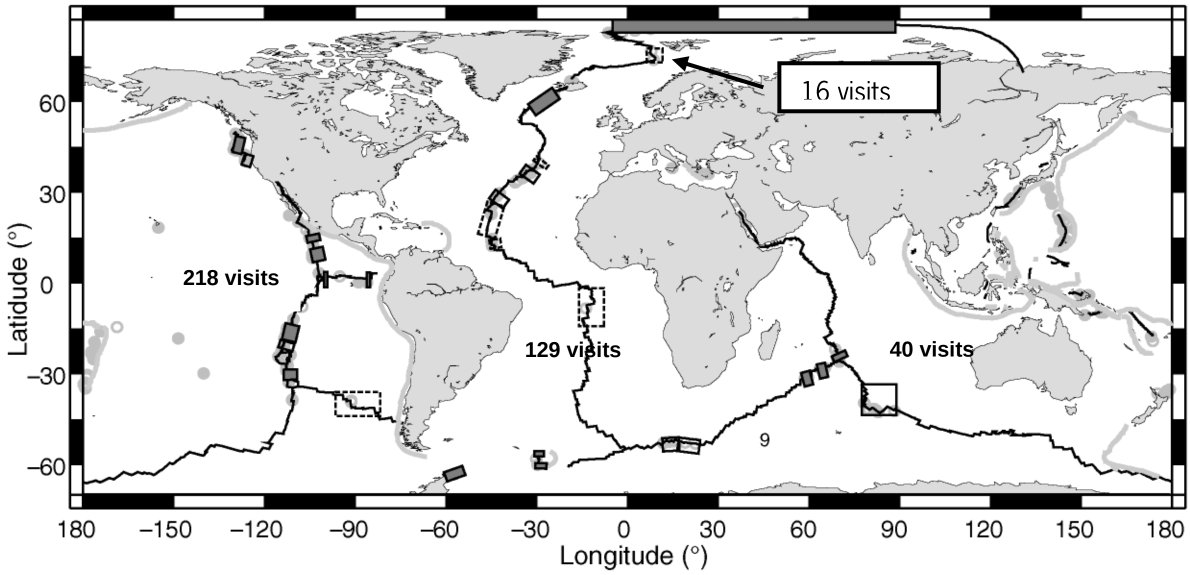

Figure 10.2 Vent site distribution overlain with boxes indicating intensity of research along oceanic spreading ridges: densely surveyed (solid boxes), moderately well surveyed (open boxes), or sparsely surveyed (dotted line boxes) (Map from Baker & German, 2004). The number of visits per Ocean in the period 1992-2003 is indicated based on records from the interridge database.

Seamounts and cold water corals

A literature research has not revealed direct evidence of marine scientific research or bioprospecting in sea mounts located in the high seas. There are also no known products or patents from organisms sampled on sea mounts in the high seas (personal communication Marjo Vierros).

The modal distance between the centroid of seamounts and cold-water coral reefs is 50 km. Modes with higher distances are likely associated with smaller seamounts. This suggests that outside of EEZs, cold-water corals are exposed to the same threats as oceanic seamounts (Cheung et al. 2005).

10.4 Future developments

Bioprospecting and marine science are strongly driven by technological development. Innovations and improvements to existing deep-sea expedition technology may help to lower the cost of deep-sea research in the near future, enable exploration at greater depths, cover larger areas of the sea bottom, or improve the sampling possibilities.

Various new deep-sea research platforms are being developed to augment the existing fleet Forty years after their first-generation Alvin submarine, the Woods Hole Oceanographic Institution (WHOI) next-generation submersible is hoped to be available in 2008 and will be able to reach 6,500 m, similar to the Japanese Shinkai submersible. China is also building its first submersible, able to reach 6,500 m, which reflects the country's interest in becoming an international player in deep-sea research (Ruth 2006).

Another area under development is the use of remotely operated vehicles (ROVs) to explore large depths without risking the lives of scientists on board. By using ROVs and satellite transmissions to send live video, audio and scientific data to geologists, chemists, biologists, as well as educators and the public. WHOI hope to send a hybrid ROV to the Marianas Trench, the deepest part of the ocean with a depth of approximately 11,000 m, in 2008.

The sampling tools on board the submersibles are also evolving. WHOI and NOAA are developing a mass spectrometer that samples water at a depth of 2,000 m and 200 Atmospheres pressure. Similarly, DNA microarrays, coupled with 'lab-on-a-chip' technology, are another potential real-time analytical device that could analyse biological samples directly on board a submarine. However, the physical conditions at such depths pose a considerable engineering challenge.

Alliances between the biotechnology and pharmaceutical sector with other industries, such as the oil and shipwreck salvaging businesses, might become fruitful avenues in the future.

10.5 Ecological impacts

10.5.1 Introduction

NGO's including Greenpeace (2005) and WWF, as well as intergovernmental organisations (Convention on biological diversity, UNESCO) and Scientists (Arico & Salpin, 2005). have expressed their concern about possible ecological impacts of bioprospecting in the high seas. InterRidge, the organisation for marine scientist involved in hydrothermal vent research, stated that:

"The potential for significant impact of scientific activities on a single vent site [..] pales in comparison to potential for volcanic/tectonic events or industrial mining/harvesting activities. Nonetheless, we recognize that some scientific activities could adversely affect individual sites or impact communities more than is necessary if the activities are not carefully planned and executed (Devey, 2007)."

So far, however, little effort has been done to actually measure the effects of bioprospecting (Nichols, 2007), but see Sarrazin *et al*. (1997) and Tunnicliffe (1990). Inevitably, the assessment of ecological impacts in this paragraph has a largely theoretical character.

When evaluating possible ecological impacts of bioprospecting it is important to differentiate between the phases:

- exploration, sampling, experimenting,
- on shore isolation and testing; of genes and substances,
- exploitation including large scale harvesting of organisms.

For each of these phases, possible effects on biodiversity and marine habitats that have been suggested in the literature, are assessed.

10.5.2 Exploration, sampling and experimenting.

A diverse range of biological communities and habitats in the high seas, including hydrothermal vents, methane seeps and deep sea sediments have been sampled in the course of scientific research. The ability of organisms to deal with extreme temperatures, high pressure, toxic chemical and absence of light found in deep sea habitats, mean that many of these life forms exhibit unique properties with potential for developments in biotechnology. Research interest in marine habitats in the high seas, however, is wider than finding bioactive compounds. Many articles (more than 400) deal with the biological and ecological properties of extreme environments in the deep sea, the metabolic properties of inhabitant species, adaptation strategies and evolutionary aspects (Vierros, 2007).

The main focus of bioprosecting activities in deep sea areas within and beyond national jurisdiction has focused on microbial communities associated with hydrothermal vents, but also eukaryotic species including deep sea sponges, tube worms and sea hares have been sampled. During the exploration phase samples are typically very small. So is the risk of overexploitation of marine organisms. Possible effects (Sarrazin *et al*. 1997) occurring while conducting research in the Area include:

- damage to underwater structures induced by submersibles;
- disturbance caused by light, noise;
- pollution from research vessels;
- unintended introductions of organisms from other sites.

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Damage of underwater structures due to submersibles

There is evidence that contact with submersibles can locally destroy parts of fragile habitat structures such as chimneys in hydrothermal vent sites. However it is expected that human-induced perturbations are relatively small compared to natural perturbations at least at the Juan the Fuca Ridge (Sarazin et al. 1997, see also paragraph 10.5.7).

Disturbance by light and noise

The exploration of deep-sea hydrothermal vents has depended on the use of manned submersibles, which are invariably equipped with high-intensity floodlights. But the eyes of many deep-sea crustaceans, which are exquisitely adapted for the dim conditions at such depths, can suffer permanent retinal damage as a result. There is some evidence that the use of floodlights has irretrievably damaged the eyes of many of the decapod shrimps (family Bresiliidae) that dominate the fauna at vents on the Mid-Atlantic Ridge (Herring et al., 1999).

Research vessels and scientific equipment installed to carry out long term experiments may also negatively impact the deep seabed environment. Alteration of environmental conditions is likely to impact on the organisms living in those areas. Alterations can occur for example in the context of in situ experiments aimed at clarifying the reproductive biology of some organisms, bringing changes in water temperature. Introducing light and noise in an environment that is naturally deprived of the former, and in which characteristic patterns of noise are very different from those induced by human activities, is also likely to cause alterations (Arico & Salpin, 2005).

Pollution

Marine scientific research may entail pollution in the form of debris or biological contamination due to disposal of biological material in areas different from the sampling area. Upon discovery of a hydrothermal vent or other habitat in the deep sea, bioprospecting is the first encounter of the local organisms with mankind.

Unintended introductions

It is suggested that new species may be unintentionally introduced by research vessels into deep sea habitat, which might change the local ecological community (eg Arico and Salpin, 2005;). These effects should be analogous to the effects seen from unintended introductions via the ballast water or exteriors of ships involved in intercontinental transportation (see chapter on shipping elsewhere in this report). To date there is no evidence that such introductions take place by research vessels. Here the odds of such occurrence are evaluated.

Scientific expeditions to study sites in the high seas differ from the transport that has lead to the introductions from intercontinental shipping, in the distance covered during a single trip. Research sites in the high seas visited on the same research cruise are unlikely to be much further apart than the natural dispersal range of the species living in these sites.

For instance, hydrothermal vent communities within the same biogeographic province, but over hundreds of kilometres apart, show high similarities in species composition (Devey, 2006). Introduction of species from one of these vent sites to another are unlikely to become invasive and disrupt the community. Cross contamination of species from vent sites in different biogeographical provinces will not occur within one research cruise as these distances are too large. Between expeditions the submersibles are brought to surface, where the vent organisms should have to survive conditions totally different from where they normally live. Even when the next expedition takes place in another ocean, it is unlikely that there are still organisms attached to the submersible from the previous visit, let alone living organisms.

Also genetic distance in marine viral communities appears to be related to geographic distance (Figure 10.3, Angly 2006). This shows that exchange of genetic material between marine sites that are geographically close is relatively high. Hence, it is unlikely that submersibles that visit two near sites introduce species that would not be able to reach the site by natural means.

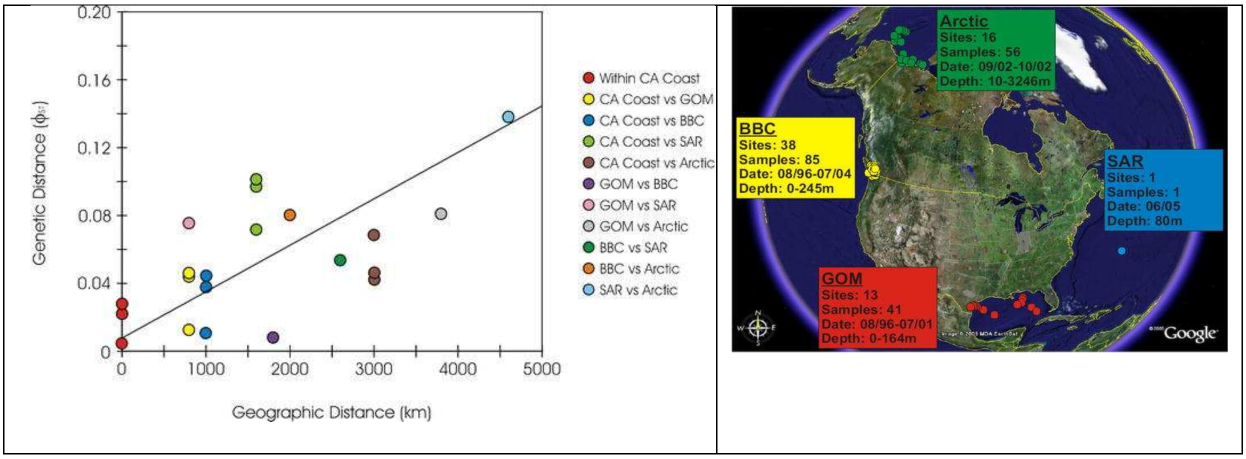

Figure 10.3 Relationship between Geographic and Genetic Distances of Marine Viral Assemblages (left panel) and sampling location (right panel) (from Angly *et al.*, 2006).

Positive effects

Besides negative effects, marine scientific research and bioprospecting also have positive effects on the preservation of marine biodiversity in the high seas. Knowledge of the deep sea biology might help preserve ecosystems in the Area and biodiversity in general. Specifically research in extreme environments such as those near hydrothermal vents provides insight in the evolution of life on earth. In the UN resolution A/RES/59/24 (Oceans and the Law of the Sea) the UN, therefore, urges its member states to enhance our knowledge of biodiversity in the high seas through intensifying their research activities.

10.5.3 On shore isolation and testing

During off shore research involving marine organisms no direct damage will be done to the biodiversity of the high seas. If compounds can be synthetically reproduced, further harvesting of marine organisms will be avoided.

Exploitation

Marine organisms that have yielded bioactive compounds with actual or potential commercial applications comprise a diverse group of algae, fungi, bacteria, tunicates, nudibranchs, sponges, bryozoans and fish (Kitagawa &Kobayashi, 1989; Vierros *et al.* 2007; Smit and Wheeler, 2006; Roch *et al.* ,2004). In addition, venomous fishes represent an untapped resource of natural products. Most sources, however, do not specify whether these organisms are collected in areas within or beyond national jurisdiction. Sampling of organisms in the deep sea and hence also in the high seas is targeted at microbial organisms living in extreme environments, such as hydrothermal vents.

Most samples originate from easily accessible sea parts within nations EEZ's rather than from the high seas.

Water depth in the high seas for most part at least exceeds the depth of the continental shelf which is about 700 m deep.

Only a limited number of scientific articles deal specifically with the properties of bioactive substances isolated from deep-sea organisms.

If compounds derived from biological resources can be produced synthetically no further collection of these organisms is needed. However, if synthesising these compounds is not possible, large scale harvesting of these organisms is not unlikely to take place. Some critics fear that industrial exploitation may create environmental problems similar to overfishing and mining of marine areas (Ruth 2006). Amounts of original material to be collected are often an order of magnitude larger than the quantity of useful material yielded (Table 10.1). This table highlights the possible risk of overexploitation.

Table 10.1 Quantities of original material required to yield relative quantities of lead material collected within EEZs (Garson 1994).

Original material	**Quantity yielded**
450 kg acorn worms	1 mg cephalostatin
1 600 kg sea hares	10 mg dolastatin
2 400 kg sponge marine sponge *Hyrtios erecta*	<1 mg spongistatin
847 kg moray eel livers	.35 mg ciguatoxin

10.5.4 Impact on fish

So far fish have not been a primary target for bioprospecting. Fishes, however, with thousands of venoms, represent an untapped resource of natural products (Smit and Wheeler, 2006). To date, most venom bioprospecting has focused on snakes, resulting in six stroke and cancer treatment drugs that are nearing U.S. Food and Drug Administration review. The potential pharmaceutical benefits of fish venom may be larger. Venomous fish are distributed over diverse habitats across the globe including oceanic midwater (Nelson 1994). Venomous fish living in the open seas are a potential source of drugs.

Deep sea fishes are often bioluminescent. Genes or proteins of such fish might have applications in biotechnology, similar to luminescent proteins from the jellyfish *Aequorea victoria*. In 1961, Green Fluorescent Protein was discovered in the jellyfish *Aequorea victoria* by scientists studying bioluminescence. This protein has since become one of the most useful tools in biology (Pieribone & Gruber, 2006).

Proteins of Antarctic fish are used as antifreeze agent in food preservation and medical crysurgery (Meliane, 2003).

Compared to commercial fishing the impact of bioprospecting and scientific research on fish populations are small. To date there are no fish species that are harvested on a large scale for commercial purposes other than human consumption. The impact of fishing is evaluated elsewhere in this report.

10.5.5 Impact on marine mammals and birds

Bioprospecting in the high seas does not have a direct impact on marine birds, except perhaps effects related to disturbance caused by the research vessels. Bioprospecting, sealing and whaling has had in the past in some cases a dramatic impact on marine mammals (Reijnders *et al.* 2008). Present bioprospecting still affects some stocks of several species through commercial, aboriginal subsistence, and scientific whaling. For example in the 2007/2008 seasons, besides some 10,000-20,000 small cetaceans, at least 1945 large whales (incl. minke, humpback, sei, Bryde's, sperm, bowhead and gray whale) have been killed (Figure 15.2). Some hunt, particularly under the aboriginal subsistence whaling, is exerted in stocks recovering from earlier overexploitation and therefore growth of the stocks in question is impacted. Whaling as such is not further discussed here, but in Chapter 15 on marine mammals.

The impact of shipping is discussed elsewhere in this report (Chapter 5). Also indirect effects through the food chain are not to be expected. Current scale of bioprospecting and marine research is not such that it could significantly impact the global productivity of ecosystems in the high seas.

10.5.6 Impact on marine benthic fauna

Many marine benthic fauna species, including sea sponges, gorgonians, cone snails, sea hares and sea cucumbers have known or potential applications in biotechnology (Vierros *et al.,* 2007). So far most of these applications originate from shallow waters within territorial boundaries of nations. Applications from deep-sea samples are usually bacterial in nature. However, there are also potential applications of tube worms for artificial blood production. In the future also deep-sea sponges, corals and other benthic fauna may be a target for bioprospecting.

Whether these applications of marine benthic fauna will have a negative influence on the targeted species will strongly depend on the question whether the bioactive compounds can be synthetically reproduced. If this is not the case large scale harvesting could lead to similar effects as overfishing. Sampling during the exploration phase only has local effects at the decimetre scale. Once harvested, it may take many years before sessile organisms have recolonised the site (Sarazin *et al.* 1997).

10.5.7 Impact on specific habitat types

Hydrothermal vents

Bioprospecting cruises are often targeted at hydrothermal vent sites. Some sites are so frequently visited that the disturbance by research vessels is a cause of concern. Marine scientific research may entail physical disruption, e.g. by removal of parts of the vent physical infrastructure. Sarrazin and colleagues have monitored biological and hydrological dynamics at the Juan de Fuca Ridge hydrothermal observatory during 4 years (Sarrazin *et al*. 1997). This site is among the most intensely studied hydrothermal vents. It has been designated by the US RIDGE program as the primary site for seafloor observatory studies of the interaction of the hydrothermal and biological processes.

Major perturbations caused by submersibles during the study period were limited to one summit where effects on local faunal composition and flow characteristics were substantial. Sampling of sessile organisms such as tube worms lead to local (decimetre scale) extinction for at least four years, while mobile organisms were re-colonising other areas after disturbance. On the other hand several major redirections of fluid flow were observed and resultant faunal changes that are best explained by processes occurring within the sulphide structure itself. The importance of minor, decimetre-scale contact between submersibles and sulphide surfaces is difficult to quantify, although Sarazin and colleagues (1997) suspect it to be negligible compared to natural disturbances. This suspicion is in concurrence with the highly dynamic nature of fluid flow, volcanic activity and venting activity observed in hydrothermal vent sites. Individual vents can form and then cease to be active on time scales of years (Devey, 2006).

Cold seeps

Cold seeps are subject of substantial scientific research. Like in hydrothermal vents, during visits, habitat structures and sessile organisms may be disturbed or destroyed by submersibles. While in hydrothermal vents the disturbance caused by research activities is likely to be small compared to natural disturbances from tectonic or volcanic activity, this may not be the case in cold seeps.

At seeps, geological processes causing fluid and gas seepage can last hundreds to millions of years, whereas hydrothermal vents often have a lifespan in the order of decades. Also the reproduction rate and regeneration time of organisms living in cold seeps is much slower than in vent sites. Seep tubeworms (vestimentiferans) are usually thinner, have slower growth rates, and have greater longevity than their vent relatives (Fisher *et al.,* 1997). For example, a 2-m-long *Lamellibrachia luymesi* individual is estimated to be more than 200 years old and hence represents probably the longest-lived animal on earth (Berquist *et al*. 2000). Recovery of habitat structures and marine communities will also take much longer than at hydrothermal vents.

At the current scale of bioprospecting and marine scientific research there does not seem to be a problem for the biodiversity of cold seeps.

Sea Mounts and cold coral reefs

Currently, bioprospecting and marine scientific research in sea mounts and cold water coral reefs does not appear to take place at a scale that it could significantly impact these marine habitats.

The local impact depends largely on the sampling equipment used. If sampling gear which is dragged along the bottom or on the coral reefs is used, then the impact is relatively high. However, nowadays, ROVs and manned submersibles are used for sampling in order to retrieve uncontaminated and unharmed organisms, and the use of such high-technology equipment reduces the impact on the environment considerably (Freiwald *et al*., 2004).

10.5.8 Semi-quantitative estimation

A semi-quantitative estimation of the impact of bioprospecting en scientific research on the high seas is presented in Table 18.1.

10.5.9 Conclusions

- The exploration phase of bioprospecting and marine scientific research involve very small samples.
- There are only local (dm scale) effects on benthic fauna and habitats caused by sampling and submersibles. No effects are expected during on shore isolation and testing.
- When compounds can not be synthetically reproduced, harvesting marine organisms may overexploit targeted organisms.
- There are no signs of overexploitation, except perhaps of some sponges locally, but exploitation of marine organisms in the high seas poses a potential threat to targeted species in the future.

10.6 Socio-economic importance

10.6.1 Applications

Sampling marine organisms is expensive compared to sampling terrestrial organisms. The high potential of some marine organisms makes them commercially interesting regardless. For instance, the US cancer institute estimates that 0,01 % of terrestrial samples show anti- tumor potential versus 1% of marine samples. In general biodiversity has a strong track record as origin for drugs. Over 60% of the 877 new chemical entities that reached the market over the last 20 years have origins in nature. Besides drug compounds extracted from marine organisms have applications in chemical technology, biotechnology, laboratory technology in the life sciences, cosmetics, the food industry and agriculture.

At least 14 biotechnology companies have so far been involved in research and product development, and/or collaboration with research institutions in relation to derivatives of deep-sea genetic resources. Six of these companies already market products derived from deep-sea genetic resources sourced both within and beyond national jurisdiction. Products developed from hydrothermal vents and other deep-sea genetic resources are already on the market. A brief search in European and US patent databases by researchers from the United Nations University (Arico & Salpin 2005) revealed that at least 37 patents have been granted with respect to products derived from deep-sea genetic resources in Europe and North America. Most of these patents however appear to be based on genetic resources collected in areas within national jurisdiction. The only patents which could be verified to originate from the high seas are based on samples collected in the South Ocean close to Antarctica.

In the future more patents are expected from samples collected in the Area in the water column of the high seas. Scientific and commercial interest in biodiversity of the high seas include:

- Development of novel enzymes for use in a range of industrial and manufacturing processes
    - thermostabile enzymes from vents for use in chemical and industrial processes involving high temperatures;
    - several processes in the presence of enzymes derived from *Candida antarctica*
- Thermostable DNA polymerases from deep-sea vent bacteria (*Thermococcus litoralis*) used in PCR technology for life sciences research and diagnostics;
- Pharmaceutical and therapeutic applications including:
    - A possible anti cancer drug based on lasonolides derived from deep-sea sponges (US NOAA);
    - the use of exo-polysaccharides as a new bone-healing material which may be of significant benefit in treating several bone diseases or as an aid to bone regeneration. Microbial exo-polysaccharides isolated from deep-sea hydrothermal vents are also under investigation for potential use in tissue regeneration and treatment of cardiovascular diseases;
    - novel antifungal and antibiotic compounds;
    - development of artificial blood from the haemoglobin found in the blood of tubeworms;
    - the production of a substance that bares a chemical resemblance to heparin, an anti-coagulant that delays the onset of blood clotting;
    - chemicals with anti HIV activity from cyanobacteria, sea weeds, sponge metabolites and marine fungi (equisetin, phomasetin and integrid acid (Tziveleka, *et al.,* 2003)).
- The development of ingredients for cosmetics, including anti-aging creams;
- Possible uses in novel biotechnological processes including oil, coal and waste-gas desulphurisation as well as in the treatment of industrial effluents;
- Copper tolerant yeast;
- New mining techniques such as bio-mining and bio-leaching.

10.6.2 Sales profits

This study did not reveal any evidence of current sales profits made on products derived from marine organisms from the high seas. However, marine biotechnology is a growing industry. Global sales of marine biotechnology products are estimated at US$2.4 billion (BCC, 2003). Although the contribution of deep sea products is relatively small, this is a growing area, with more than 37 patents registered in the USA and Europe. Annual profits from a compound derived from a sea sponge to treat herpes are US$50 million to US$100 million. Value of anti-cancer agents from marine organisms: US$1 billion a year. One UK biotechnology company, Aquaoharm, estimates that currently 10% of their source material originates from the deep sea. Globally this percentage is probably higher, since the UK is currently lagging behind the USA and Europe in terms of bioprospecting in the deep sea. The Natural Environment Council has invested £ 6.9 million in 'blue technology' and estimates the economic benefit to the UK could reach £ 1 billion in the next 25 years, assuming appropriate research and investment

Between 1998 and 2003 profits in the biotechnology sector have risen 100% worldwide. Profits are divided as follows 77% for the US, 16% for Europe, 4% for Canada and 3% for Asia (Ernst & Young, 2004).

10.6.3 Employment

Worldwide 200.000 people were working in the biotechnology sector in 2003 (Ernst & Young, 2004). It is not precisely known how many of these workers are dedicated to bioprospecting marine biodiversity in the high seas. All major pharmaceutical firms, including Merck, Lilly, Pfizer, Hoffman-Laroche and Bristol-Myers Squibb, have marine biology departments. A rough estimate based on the relative part of marine products in the total biotechnology sales (2.4 billion US$, (BCC 2003), compared to 46.6 billion (Ernst & Young, 2004)) and the proportion of hydrothermal vents located in the Area would amount to some 5 thousand employees worldwide.

10.6.4 Costs, investments and grants

A 30-day expedition cruise costs roughly US$ 1 million, with an average daily operating cost of about US$ 30,000. Diversa, which collaborates with Deep Ocean Expeditions, estimate its annual costs to be approximately US$ 5–6.5 million to operate the RV Akademik Keldysh vessel, owned and operated by the PP Shirshov Institute of Oceanology in Moscow, Russia. These high costs usually require academic and commercial partnerships—academic institutions have the equipment and the knowledge, and the commercial partners provide funds and other useful capabilities (Ruth, 2006). The InterRidge MOR & BAB Cruise Database contains 432 records corresponding to the period 1992-2003, approximately half of these cruises visited sites in the high seas. Hence, total spending roughly amounts to US$ 200 million. This figure does not include costs of on shore analysis, culturing, isolation, drug testing etc.

Some of the Harbor Branch Oceanographic Institution's deep sea missions, which include benthic and/or mid-water observations, photo/video documentation, and collection of organisms, are funded or co-funded by the US National Science Foundation and the National Oceanic and Atmospheric Administration.

10.6.5 Countries and institutions involved

Most of the technology necessary for accessing the deep seabed and studying and isolating organisms from the deep seabed is owned by research institutions or by the navy. To date, only very few countries have access to these technologies. The US, Japan, France and Russia have submersibles that can dive deeper than 6.000 m. China is currently building a vehicle that can also reach 6000 m below sea level. The US are building a ROV that can reach even greater depths. Germany, Canada and Portugal own submersibles that can go down to 1000 m (Arico & Salpin, 2005). An overview is provided in Table 10.2.

Table 10.2 Some institutions involved in Marine Scientific Research and Bioprospecting in the high seas.

Country	Institution	Domain	Activities/ products
Japan	Agency for Marine Earth Science and Technology (formerly known as JAMSTEC)	Public	
Australia	Commonwealth Scientific Industrial and Research Organisation (CSIRO)	Public	
France	Insitut français de recherché (IFREMER)	Public	
Korea	Korean Ocean Research and Development Insitute	Public	
US	Woods Whole Oceanographic Institute	Public	
New Zealand	NZ Institute of Geographical and Nuclear Sciences		
	Diversa Corporation and (50/50) joint venture Innovase LLC	private	Isolation of enzymes from extremophiles and product development particularly additives for animal and human food and high performance chemicals, eg Pyrolase™ 160
	Invitrogen Corporation	private	commercialisation thermostabile DNA modifying enzymes from Diversa Company
	New England Biolbs Inc.	private	Isolation of enzymes from extremophiles *(Thermococcus litoralis*) and product development for PCR technology eg Vent® DNA Polymerase
Iceland	Prokaria ehf	private	development of products for biotechnology eg DNA polymerases and ligases from vent bacteria.
	Genecor International Inc.	private	Enzymes for applications such as detergents, producing ethanol and additives in animal feed
	Montana Biotech Corportation & Mycologics Inc.	private	Discovery and isolation of antifungal compounds in extremophiles
	Biopolymer Engineering Inc.	private	Research in relation to polysaccharides for use in consumer paper products. Studied evolution of chtin in the exoskeleton of a hydrothermal vent crab.

According to the InterRidge database, since 1992, deep seabed expeditions have been led by scientists from the US (196 cruises), followed by France and Japan (67 cruises each), Germany (34 cruises), Canada (27 cruises), Russia (13 cruises) and Portugal (11 cruises). This information from the InterRidge database may underestimate the scale of international collaboration, since researchers from certain countries participate in other countries' research expeditions.

10.7 Conclusions

- Bioprospecting and marine scientific research are interrelated. Research vessels for deep sea research are generally owned by public organisations. The involvement of commercial organisations in sample extraction from the deep sea is limited to funding scientific expeditions and collaborations in laboratories once samples have been collected.
- At least 14 biotechnology companies have so far been involved in research and product development, and/or collaboration with research institutions in relation to derivatives of deep-sea genetic resources.
- Bioprospecting and marine scientific research in the high seas is targeted at benthic habitats, usually at great depths. To date a range of biological communities and habitats in the deep-sea including hydrothermal vents, deep-sea sediments and methane seeps have been visited.

- Only very few countries have access to technologies needed to explore the deep sea. The US, Japan, France and Russia have submersibles that can dive deeper than 6.000 m. Germany, Canada and Portugal own submersibles that can go down to 1000 m
- There is no evidence of commercial applications derived from genetic resources collected in the high seas. However, the economic potential for these resources is high.
- Possible applications include:
    - novel (thermostabile) enzymes for use in a range of industrial and manufacturing processes and in life sciences
    - drugs against cancer, cardiovascular diseases, aids;
    - novel antifungal and antibiotic compounds;
    - development of artificial blood from the haemoglobin found in the blood of tubeworms;
    - cosmetics, including anti-aging creams;
    - copper tolerant yeast.
- The exploration phase of bioprospecting and marine scientific research involves very small samples. Only local (dm scale) effects to benthic fauna and habitats caused by sampling and submersibles takes place. No effects are expected during on shore isolation and testing. When compounds can not be synthetically reproduced, harvesting marine organisms may overexploit targeted organisms. Currently, there are no signs of overexploitation, but exploitation of marine organisms in the high seas poses a potential threat to targeted species in the future.

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11 Diffuse sources[43]

11.1 Introduction

In 1990, the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) described the state of the marine environment (GESAMP, 1990). They made a very rough estimate of the relative contribution of all potential pollutions from various human activities entering the seas and found that 44% was contributed by run-off and land based discharges and 33% by atmospheric discharge. The remaining 13% was contributed by offshore production (1%), maritime transportation (12%) and dumping (10%). Although these are rough estimates of nearly twenty years ago, it shows that land-based sources and the atmosphere are main sources of marine pollution.

This report focuses on the impact of seaborne activities on the high seas. However, since land-based sources and the atmosphere are considered main sources of marine pollution, the impact of these sources on the high seas should be considered. This chapter describes potential impacts on the high seas from land-based sources (pollution and litter), the atmosphere (air pollution and acidification) and climate change.

11.2 Land-based sources

Pollution

Marine pollution from land-based activities ("point" and "diffuse" sources from rivers, estuaries and coasts) is thought to represent as much as 90% of all marine pollution inputs world wide (Greenpeace, 1998). However, river-borne inputs to coastal regions mostly remain in the estuary and shallow water and little reaches beyond the edge of the continental shelf (GESAMP, 1990). This is probably related to the adsorption of substances to particulate matter that, through the process of sedimentation, will remain within coastal areas.

Recent model simulations (Giraud *et al.*, 2008) suggest that global ocean biogeochemistry can be affected by the supply of nutrients from the coasts. When excess nutrients in the coastal ocean are not limiting production locally, they will not be used locally but will be advected and enhance biological activity offshore. The study of Giraud *et al.* (2008) shows that changes in the supply of nutrients can have a direct impact on global CO_2 fluxes.

Conclusions

- Land-based activities are thought to represent 90% of all marine pollution inputs world wide
- Little input reaches beyond the edge of the continental shelf
- Global ocean biogeochemistry can be affected by the supply of nutrients from the coasts

Litter

The main sources of marine litter are land based. The estimate that land-based sources are responsible for up to 80% of marine debris and the remainder was due to sea-based activities is commonly used in literature (GESAMP, 1990; Greenpeace, (2006); Sheavly & Register, 2007). Land-based sources of litter are (UNEP, 2005):

- Municipal landfills (waste dumps) located on the coast;
- Riverine transport of waste from landfills, etc., along rivers and other inland waterways;
- Discharges of untreated municipal sewage and storm water (including occasional overflows);

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- Industrial facilities (solid waste from landfills, and untreated waste water);
- Tourism (recreational visitors to the coast).

Threats to wildlife and the environment from marine litter are described in Chapter 5 (shipping), and include: entanglement, ingestion, smothering of the seabed, a source of accumulation of toxic substances in the marine environment, and environmental changes due to the transfer and introduction of invasive species. Given the durability of plastics and the disposable nature of many plastic items, this type of contamination is likely to increase (UNEP, 2005).

Conclusions

- Land-based sources are responsible for up to 80% of marine debris and is likely to increase
- Marine litter can cause various physical and toxic effects, and introduce invasive species

11.3 Atmospheric deposition

Air pollution

Globally, air pollution is as important, or sometimes even more important, as rivers in contaminating the open ocean with metals and organic compounds (GESAMP, 2001a). Once emitted, many of these compounds stay in the air for weeks or more, being the major route to reach the open oceans. Substances with long atmospheric residence times will be widely distributed on regional, or even global, scales. Because contaminant sources are mainly in the mid-latitudes in the northern hemisphere, materials tend to move from west to east. In general, North America contributes to the North Atlantic Ocean and the Asian continent influences the North Pacific and Arctic oceans.

Substances of greatest concern include mercury and lead, among the inorganic chemicals, and a range of organic substances. Of particular concern are the semi-volatile and persistent substances such as the polychlorinated biphenyls (PCBs), a number of pesticides and some inadvertent byproducts of combustion, such as polychlorinated dibenzop-dioxins and dibenzo furans. These have all been included in a group of compounds categorized as “persistent organic pollutants” (POPs) (GESAMP, 2001b). A study of Jurado *et al.* (2004), shows that the surface ocean is enriched in the lower chlorinated PCBs, which are not effectively removed by the settling of biogenic particulate matter. However, the deeper ocean may contain a much greater inventory of PCBs. Although there are no estimated amounts known for the deeper ocean, oceanic deep water can be considered as a sink for PCBs, since they will not move back to the atmosphere and cycle through the biogeosphere.

Once in the sea the substances may be taken up by the air again and despatched to the polar regions by a process of global distillation, which boils the chemicals off the ocean in hotter areas, and allows them to condense out of the air again in colder ones (GESAMP, 2001a). For example, the global mercury deposition (Figure 51.1) shows an elevated deposition at the arctic region. There are also local sources of industrial metals in the Arctic, but emissions of metals transported through the air from industry in Europe and Asia are, however, the largest sources (UNEP, 2007).

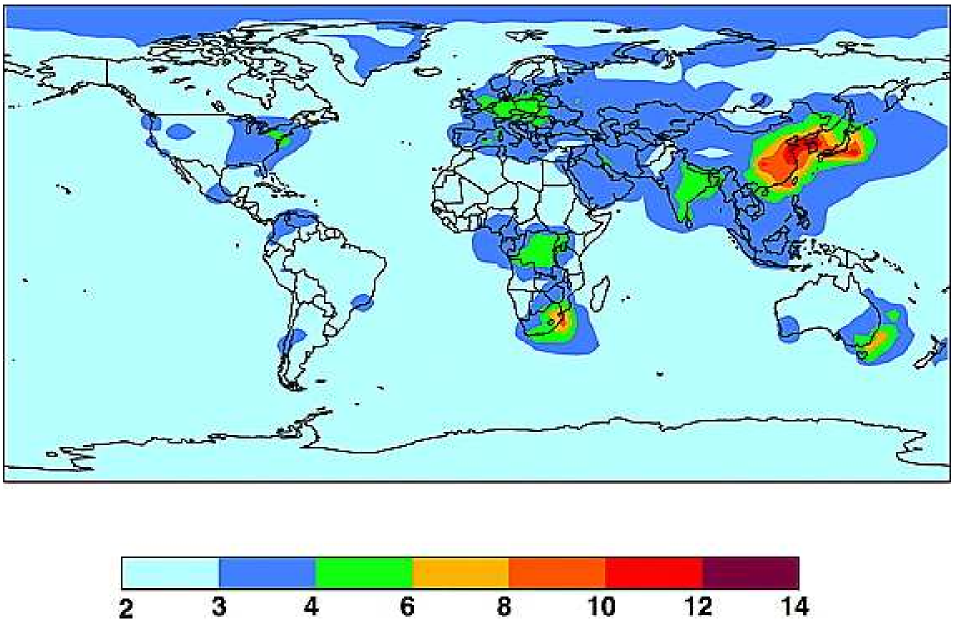

Figure 51.1 Enrichment factor of present-day relative to preindustrial mercury deposition (Selin *et al.*, 2008).

Conclusions

- Air pollution is the major route by which metals and organic compounds reach the open oceans.
- More volatile substances are among those of greatest concern, i.e. mercury, lead, organic substances (PCBs, POPs).
- The surface ocean is enriched in the lower chlorinated PCBs and oceanic deep water can be considered as a sink for these substances.
- Some substances can be distributed on global scales.
- Materials tend to move from west to east.
- Many toxic chemicals are transported to the Polar Regions.

Acidification

Elevated carbon dioxide concentrations in the atmosphere cause not only climate change, but also causes acidification of the oceans, which is already measurable today. Carbon dioxide dissolves directly in seawater. CO2 infusion reduces the pH, the carbonate ion concentrations and hence the saturation levels of calcium carbonate in sea water (Schmittner *et al.,* 2008). Ocean acidification is rapidly changing the carbonate system of the world oceans. Simulations show that the Southern Ocean surface waters might begin to become undersaturated by the year 2050 (Orr *et al.*, 2005). By 2100, this undersaturation could extend throughout the entire Southern Ocean and into the subarctic Pacific Ocean. It presents particular threats to calcifying marine organisms, such as corals, that have a key function in marine food webs and global biogeochemical cycles. Aragonite shells of live pteropods (pelagic snails) showed notable dissolution when exposed to the predicted level of undersaturation (Orr *et al.*, 2005). Potential changes in species distributions and abundances could propagate through multiple trophic levels of marine food webs, though research into the long-term ecosystem impacts of ocean acidification is in its infancy (Guinotte & Fabry, 2008). Ocean acidification has the potential to reduce the rain ratio in the future and would counteract the effect of increased calcium carbonate production in warmer water.

As also mentioned in the chapter on shipping, it is calculated that annual emissions from the world's merchant fleet have already reached 1.12 billion tonnes of CO2, or nearly 4.5% of all global emissions of the main greenhouse gas (source: the Guardian of Wednesday February 13, 2008, at

http://www.guardian.co.uk/environment/2008/feb/13/climatechange.pollution). This means that the main source of CO2 that causes ocean acidification is not related to sea borne activities.

Conclusions

- Sea borne activities contribute <5% to greenhouse gas emissions.
- Ocean acidification presents particular threats to calcifying marine organisms, such as corals, that have a key function in marine food webs and global biogeochemical cycles.
- Acidification of the oceans is already measurable today and could affect calcifying marine organisms within decades.

11.4 Climate change

The world's oceans are the primary regulator of global climate, and an important sink for greenhouse gases (UNEP, 2007). Climate change will inevitably alter the magnitude and distribution of global ocean net air–sea CO2 exchange, fishery yields, and dominant basin-scale biological regimes. The equatorial zone of the Pacific is the major oceanic CO2 source area, the Atlantic (north of 50°S) is the most important CO2 sink.

Climate change, induced by elevated CO2 levels in the atmosphere, is mainly caused by land-based activities.

At continental, regional and ocean basin scales, the water cycle is being affected by long-term changes in climate (UNEP, 2007). These changes are affecting Arctic temperatures, sea- and land ice, including mountain glaciers. They also affect ocean salinity and acidification, sea levels, precipitation patterns, extreme weather events and possibly the ocean's circulatory regime. This circulation is of enormous significance to the world, carrying carbon dioxide (CO2) to the deep ocean, distributing heat and dissolved matter, and strongly influencing climate regimes and the availability of nutrients to marine life. Schmittner *et al.* (2008) predicts changes in the biological pump are unimportant until 2600, but subsequently strengthen to account for most of the ocean component of the climate–carbon cycle feedback at year 4000.

At the global scale, ocean temperatures and sea levels continue their rising trends. Observations since 1961 show that the average temperature of the global ocean has increased at depths of at least 3 000 metres, and that the ocean has been absorbing more than 80 per cent of the heat added to the climate system (UNEP, 2007). Increasing temperatures lead to faster recycling rates in the marine ecosystem. Warmer ocean temperatures lead to lower solubility of oxygen. Acceleration of biological cycling in the upper ocean also leads to accelerated water column denitrification and increased $CaCO_3$ production and hence a strongly increased alkalinity gradient (Schmittner *et al.*, 2008).

Oceanic phytoplankton contributes roughly half of the biosphere's net primary production (NPP). Several studies suggest climate change affects marine (primary) production, with decreased export production in the low latitudes but increased export production the high latitudes (Bopp *et al.,* 2001; Schmittner *et al.*, 2008). Changes in marine production will impact biogeochemical cycles such as dimethylsulfide (DMS) and carbon, which in turn will feedback on climate. Changes in marine production will impact higher trophic levels.

Conclusions

- Climate change, induced by elevated CO2 levels in the atmosphere, is mainly caused by land-based activities.
- Climate change will alter the global ocean net air–sea CO2 exchange, biological regimes, ocean temperature, salinity and acidification, sea levels, precipitation patterns, extreme weather events and possibly the ocean's circulatory regime.
- Climate change affects marine production which will impact higher trophic levels.

11.5 Summary and conclusions

This report focuses on the impact of seaborne activities on the high seas. However, since land-based sources and the atmosphere are considered main sources of marine pollution, the impact of these sources on the high seas is briefly described.

Land-based activities are thought to represent 90% of all marine pollution inputs world wide but the input hardly reaches beyond the edge of the continental shelf. Air pollution is the major route by which metals and organic compounds reach the open oceans.

Land-based sources are responsible for up to 80% of marine litter, causing various physical and toxic effects, and introduce invasive species.

Climate change and ocean acidification are caused by elevated CO2 levels. The main cause of the rise in atmospheric CO2 concentration is emissions from land-based activities. World wide shipping contributes approximately 4.5% to the global CO2 emission.

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12 Fish[44]

12.1 Introduction

The open sea can be subdivided into different habitats, namely the epipelagic, the mesopelagic, bathypelagic, abyssalpelagic and hadalpelagic zone (Table 12.1). These zones are distinguished from each other by their depth and their ecology.

Table 12.1 Depth zones in the open sea (Nybakken, 2001; UNEP, 2007; Wikipedia, 2008[45])

Pelagic zone	Light	Depth range (m)	Habitat
Epipelagic	Present (photic)	0-200	Sunlit open sea
Mesopelagic	Present (diphotic)	200-1000	Midwater zone
Bathypelagic	Absent (aphotic)	1000-4000	Deep-sea
Abyssalpelagic	Absent (aphotic)	4000-6000	Deep-sea
Hadalpelagic	Absent (aphotic)	6000-10000	Deep-sea

The high sea is home to a great many species, some of which have still to be discovered. The fish species in the high sea can be subdivided into a smaller set of ecotypes. "An ecotype is a distinct entity of animal, plant or other organism that is closely linked (in its characteristics) to the ecological surroundings in habitats" (Wikipedia, 2008). Fish species in the high sea can be subdivided according to their position in the water column into the following ecotypes:

- Epipelagic species
- Mesopelagic species
- Deep ocean pelagic species
- Deep ocean demersal species

In this overview different ecotypes are described according to habitat. A distinction is drawn between epipelagic species, mesopelagic species and deep-sea species (pelagic and demersal). Though mesopelagic species are often referred to as deep-sea species, they are discussed separately.

12.2 Adaptation to the deep-sea environment

The deep sea is often referred to as the area below the epipelagic zone. In this review a distinction is drawn between the species inhabiting the deep sea where very little light is present (mesopelagic zone) and waters where no light is present at all (deep ocean). The organisms inhabiting deep-sea waters show a number of adaptations correlated with the environmental conditions.

First of all, the organisms show adaptations to life under low or no light intensity. A well-known phenomenon is bioluminescence, i.e. the production and emission of light by living organisms. At least 90% of deep-sea life is capable of producing light (Robison, 2004). However, it has been shown that light emissions are highest at a depth of 300-500 metres and decrease with depth (Heger *et al.*, 2008). The light produced by bioluminescence can be used for various purposes: as predator deterrence, defensive mechanism, visual mechanism and to attract prey (Robison, 2004). Large eyes are another adaptation to a life under low light intensity. This enables the organisms to capture as much light as possible. However, in the deeper regions

44 Authors: H.M.J. van Overzee and H.J.L. Heessen

45 Information is from Wikipedia (2008): http://www.wikipedia.org

where no light is available at all, a different adaptation has evolved. Many of these organisms either have small eyes or no eyes at all (Nybakken, 2001).

Additionally, deep-sea fish may have adapted their colour in such a way that they are invisible to their predators and/or prey. In the mesopelagic zone this often results in fish with black or silvery-grey colour. Organisms living in deeper abyssal and bathyal zones are often colourless or white. In contrast with mesopelagic species, this is not to attract or detract other fish but simply because the fish lack pigments (Nybakken, 2001).

In addition, most deep-sea organisms have relatively large mouths. As food is scarce in the deep sea, this enables them to feed on a wider range of food (Cocker, 1978). Some fish can even open their mouth wider than their own body, allowing them to eat prey that is larger than themselves. For example, the anglerfish can swallow a prey three times larger than itself (Helfman *et al.*, 1997). Many deep-sea fish have large teeth to prevent the prey from escaping.

Moreover, it is known that deep-sea organisms have a low metabolism and are generally slow-moving (Nybakken, 2001). This is due to the high pressure the species are exposed to; pressure increases by 1 atmosphere every 10 metres. Hence, the pressure at a depth of 1,000 metres is 100 times higher than near the surface.

12.3 High-seas fish species

Epipelagic species

The epipelagic zone is the top zone of the ocean. As light is available for photosynthesis within this zone, the epipelagic zone is highly productive. Its lower boundary (100-200m) is determined by the limit of the light penetration through the water. Tuna, sharks and billfish[46] are usually encountered in this zone (Haedrich, 1997; Brill *et al.*, 1993). These are predatory fish and belong to the top predators in food chains. Their main diet consists of fish, squid, crustaceans and mollusks (Springer & Gold, 1989).

The richness of the tuna and billfish species appears to be highest at the intermediate latitudes and decreases towards polar and equatorial regions (Figure 12.1). Sharks, on the other hand, are most common in tropical and subtropical waters (Springer & Gold, 1989). While the high sea is home to tuna and billfish species, only 5% of all shark species live there (Helfman *et al.*, 1997).

In general, epipelagic species are thought to be K-strategists, i.e. species with a long life span, large body and a low reproductive rate (see also Box 1). There does appear to be some variation in this characteristic between epipelagic species. But as epipelagic species generally have a long life span and a low reproductive rate, they are slow in recovery and can easily be depleted. These species are therefore vulnerable to high exploitation rates. Tuna and billfish species are commonly targeted by the pelagic longline fishery. Sharks are typically caught as bycatch in this fishery.

Epipelagic species are known to be rapid and highly migratory swimmers (e.g. Hsu *et al.*, 2007; Block *et al.*, 2005). For example, tuna is known to make extensive migrations within the tropical zone but can also move into temperate waters during the warmer season (Nybakken, 2001). Due to their migratory nature it is extremely difficult to protect these species. The FAO Code of Conduct for Responsible Fisheries mentions that the management of such highly migratory species is primarily a task of Regional Fisheries Management Organisations.

[46] Billfish are species that can be characterized by their large size and long, sword-like bill. They include swordfish, marlin and sailfish (Wikipedia, 2008).

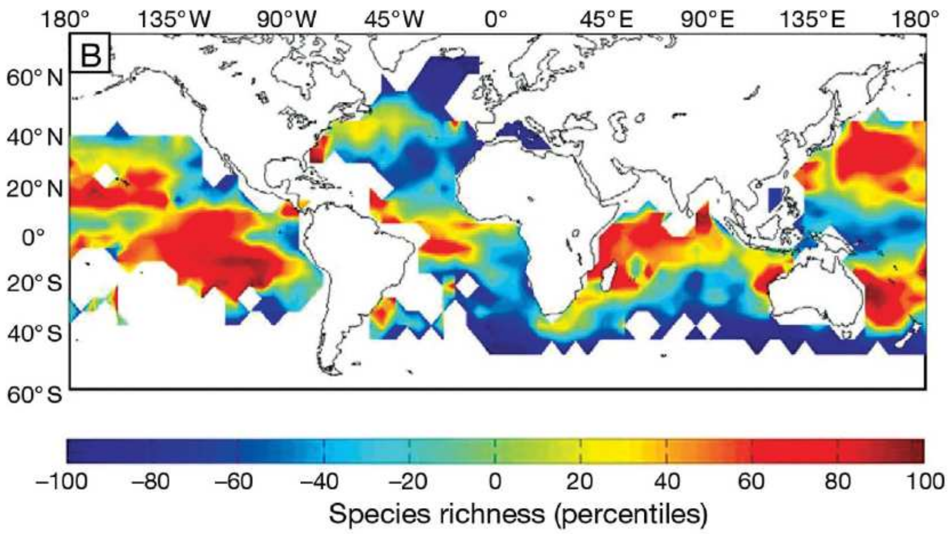

Figure 12.1 Percentiles of rare tuna and billfish species richness derived from Japanese longlining data for the period 1990-1999 (Boyce *et al.*, 2008).

Mesopelagic species

The mesopelagic zone can generally be found at depths between 200 and 1,000 metres (Table 12.1). The thermocline[47] is located within this zone, causing immense variation in temperature. Even though light can penetrate into this (diphotic) zone, the intensity is insufficient for photosynthesis. Most mesopelagic fish species are small, have a short life span of one or a few years and have a higher reproductive rate than long-lived epipelagic species (Salvanes & Kristoffersen, 2001).

Around 750 species can be found in the mesopelagic zone (Helfman *et al.*, 1997). Lanternfish (Myctophidae), silver hatchetfishes and gonostomatids (Sternoptychidae, Gonostomatidae), viperfish (Chauliodontidae) and predatory stomiatoids (Stomiatoidei) are generally found at mesopelagic depths (Haedrich, 1997). The highly commercial blue whiting[48], which is restricted to the Atlantic Ocean, can also be found in the mesopelagic zone.

A large number of mesopelagic species (including blue whiting) migrate towards the water surface during the night (Sassa *et al.*, 2002; Stensholt *et al.*, 2002). Presumably, they migrate to the water surface to feed on plankton (Nybakken, 2001). What is more, mesopelagic species represent a major food source for other marine organisms (e.g. Watwood *et al.*, 2006; Hussain, 1992). For example, it has been shown that sperm whales dive into the mesopelagic zone to depths of 400-1,200 metres to search for food (Watwood *et al.*, 2006). High exploitation rates of mesopelagic species could thus affect interactions in the food chain.

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[47] The thermocline is the transition layer between the mixed layer at the surface and the deep water layer. Below the mixed layer the temperature drops rapidly. The thermocline varies with the season. throughout the year the thermocline is strong in the tropics where no mixing occurs between the two layers, variable in the temperate climates and weak to non-existent in the polar region (source: Wikipedia, 2008).

[48] For 2008 an allowable catch limitation of 181,748 tonnes for blue whiting in waters beyond the areas under national fisheries' jurisdiction for all European countries except Russia was established to reduce the exploitation rate of this species in the high seas (source: http://www.neafc.org).

Deep-sea species

The deep-sea habitat can be divided into pelagic and benthic habitats. The fish fauna that lives in these two habitats is quite different (Haedrich, 1997). Deep-sea habitats frequently show high levels of endemism[49] (e.g. Brandt *et al.*, 2007). However, little is known about the organisms living in the deeper, darker and colder waters, as this part of the ocean is extremely difficult and costly to sample.

Many deep-sea pelagic fish species are widespread (Haedrich, 1997). In the deeper, bathypelagic regions, deep-sea anglers (Ceratioidei), whalefish (Barbourisidae and relatives) and gulper eels (Saccopharyngidae) are found (Haedrich *et al.*, 1997). The fish species that freely move over the bottom are considered to be deep-sea demersal species.

Species originating from deeper water generally exhibit K-selected life history characteristics: extreme longevity, late age of maturity, slow growth and low fecundity (Koslow *et al.*, 2000). These characteristics make the species extremely vulnerable (Jennings *et al.*, 1998) and they may therefore be easily depleted.

Box 1: Life history characteristics of K- and r-strategists
Life history characteristics refer to the life cycle of an organism and can therefore vary between species. Since different organisms have different life history traits, they will react differently to pressure. A trade-off between different characteristics enables an organism to survive optimally in a specific environment. Two main strategies are identified: K-strategists and r-strategists (see Table below). K-strategists are slow-growing, late-maturing, long-living organisms that live in stable environments, while r-strategists are fast-growing, early-maturing, short-living organisms that live in variable environments (Nybakken, 2001). K-strategists and r-strategists stand at opposite ends of the spectrum. All species lie somewhere between the two extremes. Organisms that are resilient – opportunistic species – have a better chance of recovery from extra mortality due to fishing than slow-reproducing long-living species.

Features	K-strategist	r-strategist
Reproduction periods	Few per year	Many per year
Development	Slow	Rapid
Death rate	Low	High
Recruitment	Low	High
Colonizing time	Late	Early
Adult size	Generally large	Generally small
Mobility	High	Low

12.4 Biodiversity hotspots

The human impact on marine biodiversity in the high seas is causing concern (Dulvey *et al.*, 2003). In order to maintain biodiversity it is essential to ascertain the locations of marine biodiversity hotspots. Myers (1988) defines hotspots as areas with extremely high concentrations of species with exceptional levels of endemism and which face an exceptionally high probability of being destroyed. Even though hotspots may be static areas, they can attract migrating species that are able to actively search for such highly productive sites. Several types of hotspots can be distinguished in the high seas namely, seamounts, cold-water corals and hydrothermal and cold vents.

[49] Endemic species are unique to a specific place.

High species richness of exploited marine fish in the high seas is particularly observable in the tropics (Figure 12.2). In addition, localized richness is found in temperate regions. These hot spots are mainly associated with seamounts. Seamounts may create currents leading to upwelling of nutrients into the photosynthetic zone which will support primary production (for further details see chapter on food webs). In addition, their complex topography may lead to a variety of living conditions. Accordingly, seamounts provide a habitat for a highly diverse species assemblage and may therefore function as hotspots in the open ocean, attracting fish species such as whales, sharks, tuna or rays (UNEP, 2007; Holland & Grubbs, 2007). Richer de Forges *et al.* (2000) discovered more than 850 species around seamounts in the Tasman Sea and the south-east Coral Sea. Even though the number of seamount fish species represents a relatively low fraction of the total number of fish species in the sea, most of them do not appear to be closely genetically related to each other. This results in a high genetic diversity (Froese & Sampang, 2004).

The fish stocks around seamounts are being targeted by bottom trawl and longline fisheries (Table 12.2). Seamount fish species have a higher intrinsic vulnerability than other fish due to an often low productivity, great longevity and late maturation (Morato *et al.*, 2006). Seamount fisheries can only be sustainable at very low level of fishing effort (Clark, 2001).

Cold-water corals and hydrothermal vents are biodiversity hotspots that may also be reflected in the fish community (UNEP, 2007). In the deep coral banks off the south-eastern United States 99 fish species were identified (Ross & Quattrini, 2007). Fish inhabiting hydrothermal vents are adapted to the unique environment. For example, zoardic *Thermarces ceberus* and the deep-sea anguillid *Symenchelis parasitica* are endemic to hydrothermal vent environments (Weber *et al.*, 2003). Similar communities of organisms are found around cold seeps, also called cold vents.

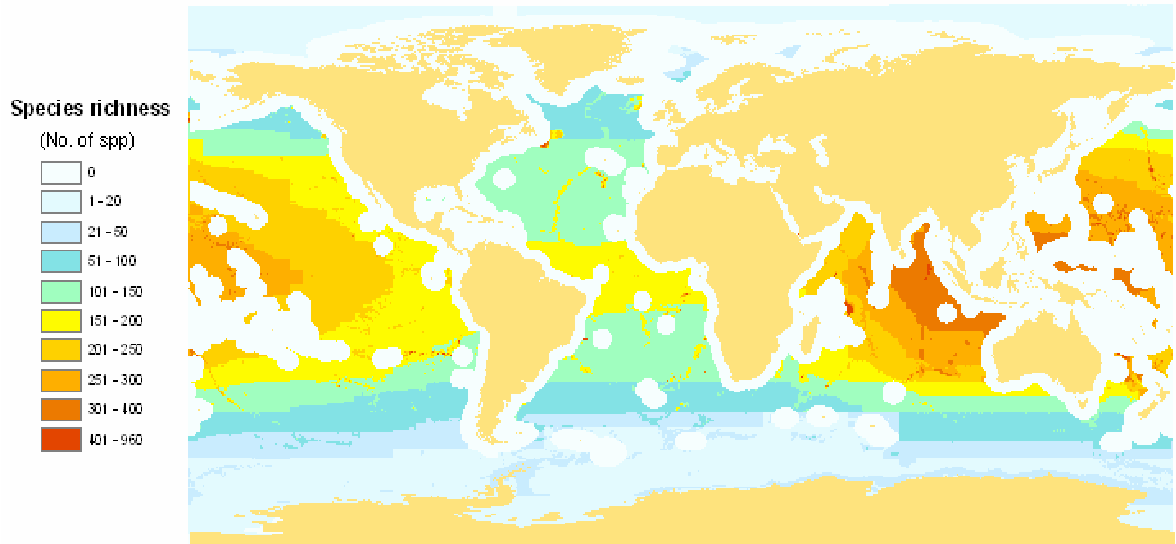

Figure 12.2 Map of species richness of exploited marine fish in the high seas based on 463 species distributions and 189 additional ranges representing 1,942 species (UNEP, 2005).

Table 12.2 Commercial species from seamounts targeted by fishing (Table 6.3 from Clark *et al.*, 2006)

Common name	Scientific name	Main fishery years
Alfonsino	*Beryx* spp.	1978-present
Cardinalfish	Epigonidae	1978-present
Rubyfish	*Plagiogeneion macrolepis*	1995-present
Blue ling	*Molva dypterygia*	1979-1980
Black scabbardfish	*Aphanopus carbo*	1973-2002
Sablefish	*Anoplopoma fimbria*	1995-present
Pink maomao	*Caprodon longimanus*	1972-1976
Southern boarfish	*Pseudopentaceros richardsoni*	1982-present
Pelagic armourhead	*Pseudopentaceros richardsoni*	1968-1982
Orange roughy	*Hoplostethus atlanticus*	1978-present
Oreos	*Allocyttus* spp.	1970-present
Bluenose	*Hyperoglyphe antarctica*	1990-present
Redfish	*Sebastes* spp.	1996-present
Roundnose grenadier	*Coryphaenoides rupestris*	1974-present
Toothfish	*Dissostichus eleginoides*	1990-present
Notothenid cods	Nototheneiidae	1974-1991

12.5 Anthropogenic impacts

Fishing will be the dominant anthropogenic activity that will impact fish populations. Fishing remove a part of the biomass, reduces the size and age structure of the population and is the exploitation level is too high may reduce the level of recruitment. Many deep sea fish species are particularly vulnerable for fishing and therefore can only sustain low levels of fishing mortality. Fishing may also indirectly affect fish populations through its effect on fish habitats or on the size and species composition of the fish community. Fishing activities will be concentrated in areas of high fish biomass, which correspond to areas of increased productivity and probably of a high biodiversity. Also, bio-prospecting will likely be concentrated in biodiversity hotspots.

Other anthropogenic activities affecting habitat quality and quantity will impact fish populations. Although pollution may affect the survival and growth of fish, this impact is considered to be negligible in the High Seas. There is no information that fish will be affected by noise. In contrast to fishing and bio-prospecting, other anthropogenic activities are unrelated to areas of high biodiversity and are therefore less likely to overlap.

12.6 Conclusions

- Fish species in the high sea can be subdivided according to their position in the water column into different ecotypes, namely epipelagic, mesopelagic and deep-ocean species.
- Epipelagic fish inhabit the top zone of the ocean. Tuna, sharks and billfish are encountered in this zone. These species generally have a long life span, large body and a low reproductive rate (K-strategists).
- The deep sea is referred to as the area below the epipelagic zone and is home to organisms that show a number of adaptations to the environment.
- Mesopelagic fish inhabit the mesopelagic zone and form an important connection in the food chain. They are generally small, short living species with a high reproductive rate (r-strategists)

- Species originating from deeper waters generally exhibit K-selected life history characteristics making them extremely vulnerable to exploitation.
- In the high seas several hotspots can be distinguished, namely seamounts, cold-water corals and hydrothermal and cold vents.

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13 Benthos and benthic habitats[50]

13.1 Introduction

Most of the seas outside of the EEZ's are deepseas, and the major part of it has a soft sediment bottom. The sea bottom between 200 (shelf-slope break) and 4000 m (transition from the slope to the abyssal plane) is often indicated as the bathyal zone, while the area deeper than 4000 is called the abyssal plain. This last one the abyss is the largest marine benthic habitat on earth, covering 53% of the global seabed. So the high seas fall almost completely in the bathyal and abyssal area. Therefore this chapter restricts itself to the benthos of the bathyal and abyssal seas.

13.2 History of biodiversity research.

At the beginning of the deep sea research in the early 19th century the deep sea was believed to be azoic, without live. The famous Challenger expedition (1872-1876) sampled the deep seas around the world and found a rich deep sea live everywhere. Now we know living animals are even found at the deepest point on earth. In the Challenger Deep (11.034 m) situated in the MarianaTrough single celled Foraminifera were found in the bottom ooze. Even more surprising was that so many (432) species were found. Also macrobenthic animals can live in very deep water. They also have a high biodiversity in the deepsea. This fact was quite unexpected for the food-poor and cold deep-sea soft sediments, but is now well documented. However, explaining this proved to be not easy. Many theoretical explanations have been put forward, each of which does not seem to be satisfactory on it own. We will give here a short and popular review of the main theories:

Stability-Time hypothesis

This is one of the first theories (Sanders 1968) and is based on data from a transect off the coast of the eastern United States. It argues that an area with a lot of changes in environmental factors within the live span of the animals (e.g. currents, temperature, salinity, sedimentation) will harbor fewer animals than an area with hardly any changes. This is caused by the stress the environment exerts on the species. As in the deepsea most environmental parameters are very stable it has allowed an extreme adaptional specialization of species, so that competitive interactions between species are minimized. In other words, each species has its own very narrow food source, which means that a lot of different species can live next to each other without competing for the same food. In modern studies in shallow water biodiversity is also used as a valid measure for disturbance (fisheries, eutrophication). The higher the species richness, the more pristine the area is.

Large distribution hypothesis

Circumstances in the deepsea are almost the same over large areas without barriers. This could mean that most deep-sea animals have a vast (ocean) wide distribution. The chances of a complete extinction of one of these species would than be extremely small. In the geological time scale this would lead to a large number of rare species, which contribute much to the local species richness (Abele & Walters, 1979; Osman & Whitlach 1978).

Habitat heterogeneity

There seems to be a close and positive relationship between the complexity of the habitats and the species richness of an area. For example rain forests and coral reefs form a complex 3D-structure and also are seen has hotspots for biodiversity. At first it is not expected that in the deepsea, with its soft sediment bottom that looks everywhere the same, there would be a large variety in habitats. However, if zoomed in to

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the sphere of influence of the individual animals, we can discover small-scale biogenic features as animal tubes, burrows, tracks and food falls. In the deepsea, with its normally much lower physical disturbance and low rates of biological activity, these features persist long enough to provide lots of distinct microhabitats, and thereby leading to higher species diversity (Menge & Sutherland, 1976).

Biological disturbance

This theory argues that there is widespread disturbance by large predators (omnivorous fish) or large vacuum cleaning seacucumbers in the deepsea that crop the macro- and meiobenthic fauna (Dayton & Hessler, 1972). This disturbance will depress abundances and thereby also depress the competition for food. The ecosystem will never reach equilibrium. This minimizes competitive interactions and so allows the co-existence of species sharing the same resources. A modification of this theory includes the slow recolonization of disturbed places. A short while after disturbance the species richness will be still low as time is needed for the repopulation of the micro area. As a next disturbance at this same place will take on average a long time in the deepsea, the diversity can increase as more time is available for immigration and larval colonization from the surroundings. However, as the interval between disturbances increases further, the place becomes so well populated that competitive interactions and exclusions will take place (Connell, 1978). Than of course species diversity declines again. This could be an explanation for the maximum of biodiversity at medium ocean depths.

All of these theories have some positive as well as negative points to explain the high diversity in the deep sea (Gage & Tyler, 1991). The big draw back is that we still have limited biodiversity data for the deepsea. This is not only because sampling the high seas requires expensive ship time and special gear, but the sorting of samples is very laborious and even more important the knowledge for the identification of the fauna up to species level is almost non existent. The few generalists are dying out and the new generation of scientists is pushed to publish and not to “waste” their time behind a microscope. Specialists at natural history museums often focus on a small group, and are mostly not willing or able to do routine identifications. Professional sorting labs could be a solution for this general problem that is certainly not restricted to the deepsea environment. Another hope is in the identification of animals by genetic methods. This is still in development and certainly can help, but will not completely replace the conventional ways. One example is that the number of specimens will have to be counted too to get a good picture of biodiversity.

In conclusion it can be stated that diversity-depth trends still remain incompletely understood, but it seems likely that they are shaped by a complex of interacting factors that operate at different scales of time and space (Levin et al, 2001; Stuart et al, 2003).

13.3 Estimates of total species richness of the high seas

Several estimates regarding the possible number of species of macrobenthic fauna in the oceans (deep-sea) have been made on the basis of different assumptions. As there will be always debate about the validity of the different assumptions, and because the different estimates differ (sometimes one order of magnitude) there will be a high uncertainty in the given values. Based on the expert judgment of taxonomic specialists Snelgrove et al. (1997) estimated the number of marine macrofauna species at 10 million. Grassle & Maciolek (1992) came at a similar number for the deep-sea, but they extrapolated it from the rate at which species were added with increased area sampled. For this they used the actual data of 233 boxcores on a 176 km long transect at a depth of 1500-2500 m off the coast of the eastern United States. Their analysis suggested that for every square km of deepsea 1 new species would be found. This would mean a total figure of macrofauna of 300 million species. The authors trimmed their estimate severely down to correct for the less species rich oligotrophic areas of the oceans. May (1992) comes to a much lower estimate, although he used the same data set as the previous authors. He looked at the number of undescribed species in the samples. This proved to be about 50%. As up to now the number of described marine species is about 250,000 he came to the figure of 500,000. But Snelgrove & Grassle (2001) noted that in the Pacific only 1 out of 20 species is described. If May’s approach is used this would mean that the total number of deep-sea species would increase to about 5 million. Poore & Wilson (1993) came to a similar estimate of about 6 million. These figures put the species richness of the deepsea at the same level as those of tropical coral reefs and tropical rainforests (Erwin, 1982). But if meiofauna (<0.5 mm) is included, especially the group of Nematoda which is exceptionally abundant and biodiverse in the deepsea, the estimates can run to over 100 million (Snelgrove & Grassle, 2001).

13.4 Distribution of biodiversity

The distribution of the benthic biodiversity over the oceans and thus over "high-seas" area is still not very well known and attempts to publish world wide maps of biodiversity are restricted to those of Cheung et al. (2005). But on the basis of the limited number of sorted deep-sea samples a few preliminary generalities have been drawn. There can be substantial differences in the distribution of biodiversity from north to south, between oceans and ocean basins, and between depths. In the North Atlantic there is a reduction in the deep-sea macrobenthic diversity from the equator to the North Pole (Herring, 2002). In contrast the smaller fauna (meiofauna) increases here towards the pole (Lambshead et al., 2000). In the southern hemisphere a reduction of the biodiversity with increasing latitude is not so clear (Rex et al, 1993). The reduction of the number of species towards the poles is known as the Rapoport rule, which was originally proposed for terrestrial species. A proposed explanation for the higher biodiversity in the deep-sea around the equator, is that here the fauna is adapted to the much more constant conditions (compared to those around the poles), and that therefore the ranges of the animals are much more restricted. Unfortunately, as indicated above, this rule does certainly not count in the deep-sea for all oceans or all animal groups. Next to latitude the biodiversity is also influenced by depth. In general, it increases from the shelf to a mid-slope depth (2000 m), before declining again towards the abyssal plain (Rex et al, 1993, Weaver et al, 2004). The last author compiled a lot of the available deep-sea data and produced Figure 13.1 on which this optimum is clearly shown.

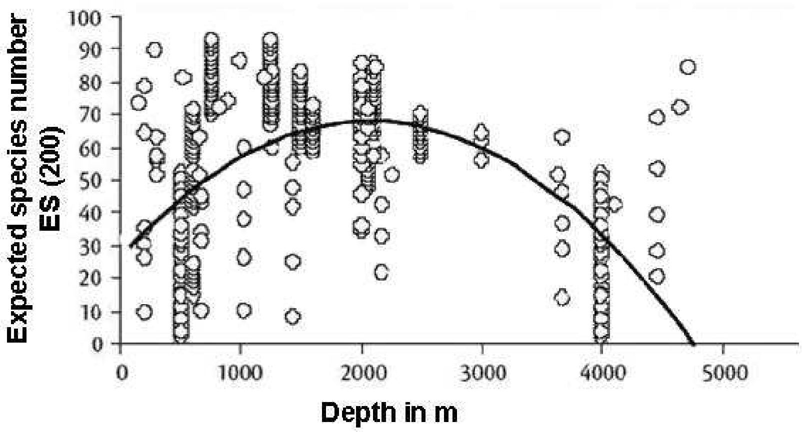

Figure 13.1 Distribution of marine benthic biodiversity in relation to water depth (after Weaver et al., 2004). The optimum of biodiversity values is around 2000 m depths.

Cheung et al. (2005) attempted to make worldwide maps for the biodiversity of the area outside of the EEZs on the basis of published maps of species or from depth and latitudinal range data. On the assumption that there is a clear relation between diversity and longitude / latitude, he made range polygons that were used into a GIS system to design distribution maps. Specifically his assumptions were that species numbers increase from poles towards the tropics, and that the area centered around Indonesia had the highest diversity declining eastward and westward with a minimum in the Atlantic. As there are not enough data for the small non-commercial invertebrate fauna Cheung et al (2005) only included exploited marine invertebrates in their analyses. They used the FAO fisheries statistics, and extracted from these 276 species and 34 genera of invertebrates, together representing 557 species. Of course this is only a fraction of the total species in the deep-sea (see Chapter 13.3). Another drawback is that the different animal groups are very unevenly represented, with crustaceans accounting for 33%. Though groups as Mollusca (excluding Cephalopoda) and Echinoderms are clearly benthic, it is unclear if and how many pelagic species are included. Their conclusion from their analysis was that hotspots for deepsea diversity lie mostly in the Indo-Pacific in the inter-tropical belt. The Atlantic only had few hotspots. Of course this is not surprising as it agrees with their super imposed assumptions. More interesting are their other conclusions, that these hotspots are associated with concentrations of seamounts.

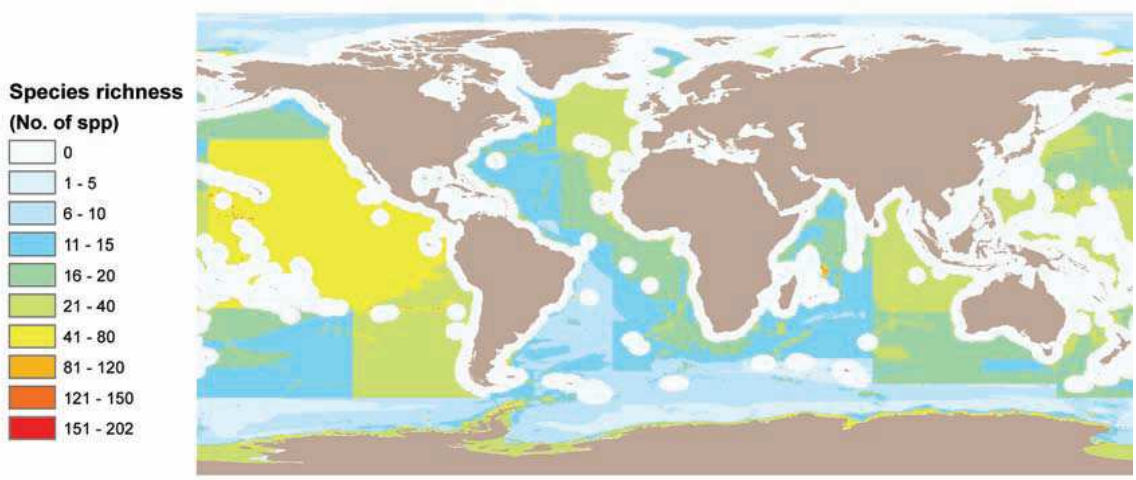

Figure 13.2 Map of the species richness of exploited marine invertebrates in the high seas. The block like distribution is caused by the assumptions (see text) and the borders of the FAO distribution blocks (after Cheung et al, 2005)

13.5 Biomass distribution of benthos

Quantitative sampling in the deepsea only started during the Galathea deep-sea expedition around the world in 1950 (Spärck, 1956). At the same time Soviet scientists also started quantitative research with the use of an OKEAN grab (Zenkevitch, 1961). The last ones produced the first world wide map of the benthic biomass covering all oceans. (Figure 13.3). Later the boxcorer became the standard quantitative sampling gear for sampling the macrobenthos of the deepsea. And although some areas were studied in more detail, a complete overview of the benthos was not updated up to now. But we have to remember that the total area sampled so far in the deepsea is incredibly small. It is estimated that so far only 2 km2 has been sampled for the macrofauna and only 5 m2 for the meiofauna, while the total surface of the deepsea 3.25 x 108 km2 (Snelgrove & Grassle, 2001). From the map it is obvious that the Pacific Ocean is especially poor over a large area. In the Atlantic and Indian Ocean the central parts, far from the continents, also belong to the poorest areas. The biomass in these areas can be as low as -0.05 g/m2. The explanation for this is quite simple as firstly there is no transport of nutrients from the continents (e.g. outflow of rivers) to these areas and secondly the open oceans also have a low primary production which will reach the seafloor in a much degraded form because of the depth of the sea. In summary benthic biomass decreases with depth and distance from shore. Thus, in conclusion we can say that the high sea area has in general a very low benthic biomass in comparison to most EEZ areas. This also means that it cannot support a high biomass of demersal fish. Exceptions within the EEZ are the Mediterranean and part of the Gulf of Mexico, which both have a low benthic biomass.

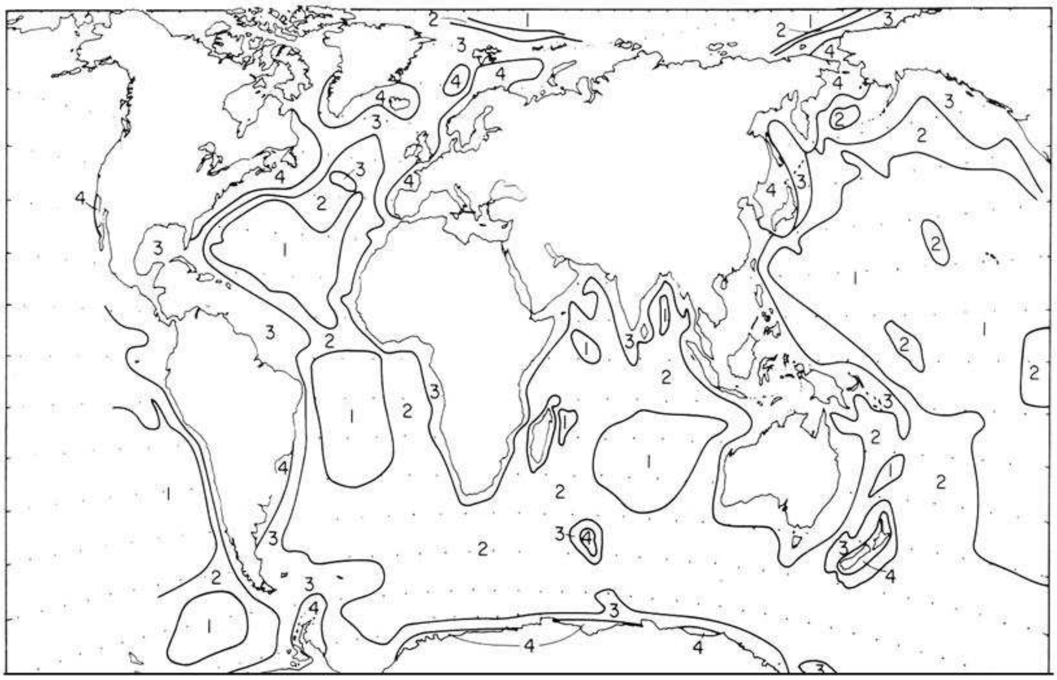

Figure 13.3 Worldwide wet weight biomass distribution of the macrobenthos (1 < 0.1 g/m2, 2 = 0.1 -1 g/m2, 3 = 1-50 g/m2, 4 = > 50 g/m2). After: Rowe, 1983.

13.6 Special benthic habitats

13.6.1 Distribution of coldwater coral reefs outside the EEZs

Surprisingly corals also thrive in the deeper waters of all oceans. A few coldwater corals even form coral reefs just like tropical corals do. As these reef-forming corals live at a depth between 100 and 1000m at temperatures of 4–13°C, they do not possess symbiotic algae like their tropical counterparts, but instead live by feeding mainly on suspended particulate organic matter (Freiwald et al., 2004). Cold-water corals are most commonly found on topographic reliefs like slopes, canyons, seamounts and carbonate mounds. The most common and best studied species is *Lophelia pertusa*. It abounds especially in the Northeast Atlantic, where it is mainly distributed from northern Norway to Mauritania. The largest individual reef discovered so far (Røst reef off the coast of Norway) measures 40 kilometers in length and 2–3 kilometers in width. Growth rates of corals are quite slow at a rate of 1 cm a year, and although we still know little about their reproduction and recruitment this seems to be low too. This makes these corals extremely vulnerable to mechanical impacts like trawling. Therefore recovery rates are estimated too be low. With the destruction of the corals a whole ecosystem will be destroyed too, as cold-water coral reefs are among the richest biodiversity hotspots of deep-sea ecosystems, providing shelter and food for hundreds of associated species, including commercial fish and shellfish. This makes cold-water corals, like seamounts, attractive for fisheries. Cold-water coral reefs are also threatened by the indirect impacts of climate change. With increasing CO2 emissions in the atmosphere, large amounts of CO2 are absorbed by the oceans, which results in a decrease in pH ("ocean acidification"). This inhibits or weakens the ability of marine organisms to build their carbonate skeletons and shells. Therefore scientists predict that, due to this phenomenon, by 2100 around 70 per cent of all cold-water corals will live in waters under-saturated in carbonate, especially in the higher latitudes (Guinotte et al., 2006).

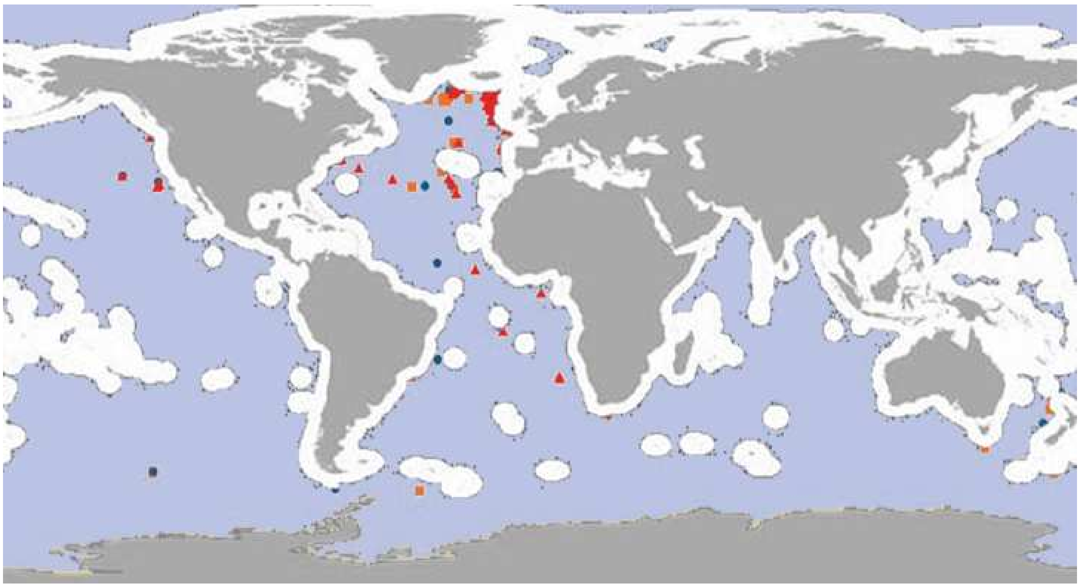

Figure 13.4 Distribution of Cold Water Coral reefs (3 species) outside the EEZs (changed after Freiwald et al 2004, Cheung et al 2005). Red triangles = *Lophelia pertusa*, blue dots = *Madrepora oculata*, Orange squares = *Solenosmilia variabilis*.

13.6.2 Distribution of large seamounts outside the EEZs

Seamounts are underwater mountains of tectonic or volcanic origin, and therefore often found along the edges of tectonic plates and mid-ocean ridges. The number of very large seamounts (with summit heights of more than 1000 meters above the surrounding area) is estimated at 14,000. But if smaller mounts with a height a few hundred meters are included the total increases to above 100,000. Because of their topography, often made more complex by terraces, pinnacles, ridges, crevices and craters, they influence the currents over and around them. By complicated physical processes the particle supply and thereby also the food supply to the seamounts is often enhanced. This leads to special possibilities for the benthic and demersal fish fauna at and around seamounts. Of the estimated 100,000 seamounts (Fig. B) less than 250 have been biologicaly sampled (Stocks 2005). Most of the current knowledge is a by-product of fisheries studies. As a consequence very few data on invertebrates are available. Therefore the reported number of seamount species must be a gross underestimate of the total. Studies that provide lists of species are incomplete and have a lot of unidentified species (e.g. Wilson & Kaufmann, 1987). But the few detailed studies suggest that they host a high number of endemic species (de Forges et al., 2000). A world wide overview of the benthos of seamounts is therefore impossible. However, some areas in the SW Pacific have been studied recently in more detail and are reviewed by Samadi et al. (2007).

13.6.3 Distribution of hot vents and cold seeps

In 1977 completely unexpected hot vents with their spectacular fauna were discovered at 2500 m depth near the Galapagos Islands in the Pacific Ocean. Later more hot vents were discovered at seafloor spreading centers in the Atlantic, Pacific, and Indian Oceans at 850 to 2 800 meters and deeper (Santos et al., 2003). They are commonly found in volcanically active areas of the seafloor (e.g. mid-ocean ridges, tectonic plate margins, above magma hotspots in the Earth's crust), where geothermal heated gases and water plumes rich in minerals and chemical energy are released from the seafloor. It is suspected that many other sites have yet to be explored. The superheated water of up to 400°C full of minerals escapes from the seafloor, and in mixing with the cold deep-sea water these minerals precipitate, forming the so called "smoking chimneys". These chimneys can grow up to 30 centimeters a day and reach heights of up to 60 meters) and polymetallic (copper, iron, zinc, silver) sulphide deposits. Commonly the hot water also has high levels of hydrogen sulphide (H2S), and therefore low levels of oxygen. These circumstances are normally highly toxic to animals. The fauna discovered around these hot vents exists of a relatively low number of species that have adapted to these normally toxic conditions. They are mostly restricted to a small zone around the vent where the temperature is between 8-23°C because of mixing with the cold deepsea water. This fauna is so spectacular because of their abundance in the otherwise poorly populated deepsea and because the mostly endemic animals give it a science fiction image. Especially the red tube-worms *Riftia* sp. (Vestimentifera), which are up to 1.5 m long, 3.7 cm thick, with a tube length of up to 3 m and a density of up to 170 m2 they are responsible for spectacular pictures. But also the large vesicomyid clams can give the scene something special with their white shells. The biomass of the fauna found around hydrothermal vents can be 500 to 1 000 times that of the surrounding deep sea, rivaling values of some of the most productive marine ecosystems. Hydrothermal vent communities are not diverse in comparison with that in the surrounding deep-sea sediments (Tunnicliffe et al., 2003). Over 500 vent species have so far been identified (ChEss, 2007). The studies so far have found that 95% of specimens recovered from hot vents are endemic (MBARI, 2007). These studies also triggered the research of Archaea, a group of evolutionary old and simple bacteria-like cells, that possibly can give us more insight in the very first existence of life on earth. The rich fauna can survive and abound because they use hydrogen sulphide as the primary energy source. The multicellular animals often live in symbiosis with bacteria that are capable of chemosynthesis. Instead of oxygen these bacteria use sulfide as oxidizer, and therefore can convert H2S into organic material: H2S + CO2 + O2 + H2O = CH2O + H2SO4. This turn fuels the whole hot vent ecosystem. These ecosystems are thus independent from the sun as an original source for energy.

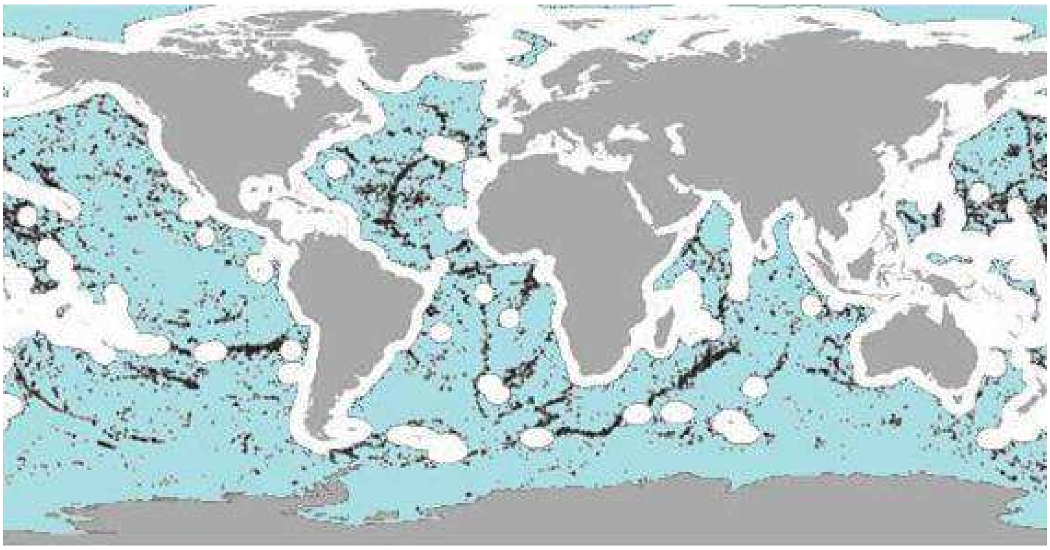

Figure 13.5 Distribution of large seamounts outside the EEZs (changed after Kitchingman & Lai 2004, Cheung et al 2005)

Cold seeps were discovered in 1984 at the base of the Florida Escarpment at 3270 m depth. Here water and/or mud with gases like hydrogen sulphide and methane seep or leak out of the sea-floor through the sediments and cracks by gravitational forces and/or overpressures in often gas-rich subsurface zones. Cold seeps can form a variety of large to small-scale features on the seafloor, including mud volcanoes, pockmarks, gas chimneys, brine pools and hydrocarbon seeps. In contrast to the hot vents the temperature does not differ much from the surrounding cold water, but the species composition is very similar to that of hot vents: namely with a high number of endemic species, a low diversity and a high biomass. Here the exceptionally rich ecosystems also thrive on the basis of microbial chemosynthesis. The fauna living around cold seeps often displays a spatial variability, depending on the distance to the seep. Communities of microbes oxidizing methane thrive around these cold seeps, despite the extreme conditions of pressure and toxicity (Boetius et al., 2000; Niemann et al., 2006). Research recently showed the relevance of such microbes and their genetic makeup in controlling greenhouse gases (GHG) such as methane, which is a much more potent GHG than CO2. Thus, cold seeps could be prime potential targets for bioprospecting (Arico and Salpin, 2005). Cold seeps are often associated with gas hydrates, naturally occurring solids (ice) composed of frozen water molecules surrounding a gas molecule, mainly methane. The methane trapped in gas hydrates represents a huge energy reservoir. It is estimated that gas hydrates contain over half of the organic carbon on Earth in the form of methane carbon, and twice as much as all fossil fuels (coal, oil and natural gas) combined (Kenvolden, 1998). However, the utilization of gas hydrates as energy sources has not started yet as it poses great technological challenges and bears severe risks and geohazards.

Especially for hot vents, but also for cold seeps, it counts that these environments only exist for a geological short time. For hot vents this can be even in the order of several years, and many have longevity of a few decades only. The activity of individual vents might also vary over time. The temporary reduction or stop of the water flow, will also affect the supply of hydrogen sulphide on which the organisms depend. If the flow stops altogether, all non-mobile animals living in the surrounding of the particular chimney will starve and eventually die. The animals therefore require not only special adaptation to the abnormal food source, but also need to have a fast growth, an early maturation, a high number of offspring. As these special habitats are also often separated by tens to hundreds of kilometers of cold water with no exploitable source of energy, and of a small size (25-60 m in diameter) the dispersal of larvae to settle new habitats seems to be a major problem. Large food falls, like dead rotting whales, are possibly temporal stepping stones for some animals between the sites.

The mineral deposits around hydrothermal vents are of potential interest for commercial mining operations, whereas the special fauna of hydrothermal vent ecosystems might become a source of organic compounds for industrial and medical applications (WHOI, 2007).

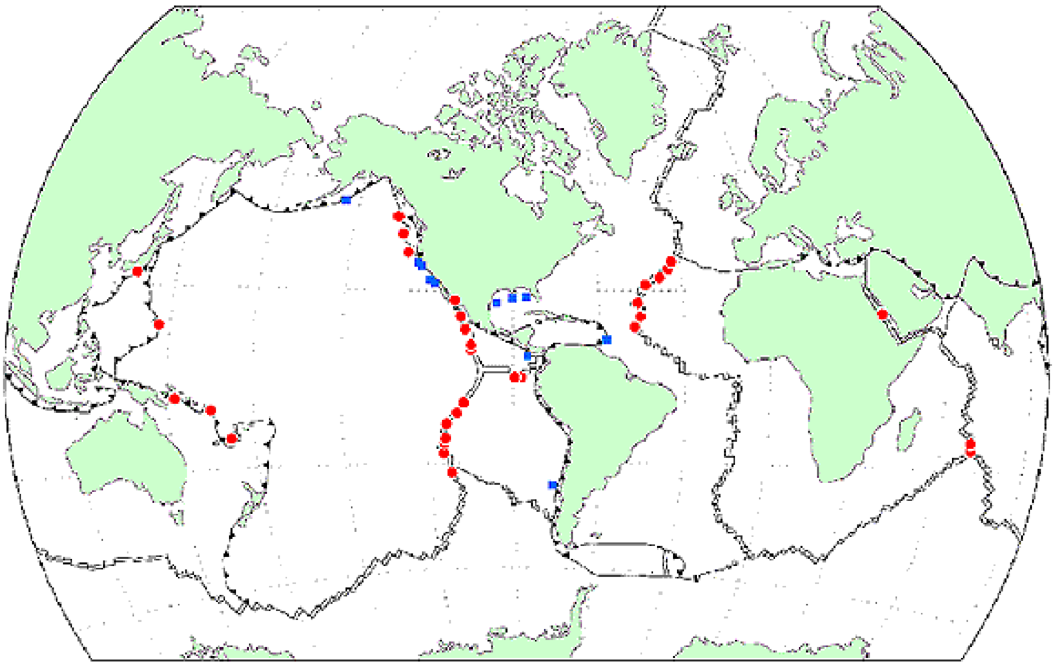

Figure 13.6 Distribution of hot vents (changed after MBARI, 2007)

13.6.4 Distribution of manganese nodules

One of the most commercially desirable deposits in the deep-sea are the ferromanganese nodules. These are found on the abyssal plain in all oceans (Figure 13.7). These nodules have rich concentrations of cobalt, nickel and manganese next to other metals. These nodules can have a diameter of more than 5 cm, are restricted to the oligotrophic parts of the ocean where there is a very low sedimentation rate (less than 1 cm in 1000 years). In these parts, especially in the central North Pacific, they can cover large areas, where the actual surface cover can be larger than 20% (Heezen & Hollister, 1971). Apart from biogenic material (e.g. shark teeth), human waste (charcoals from steamship), dropstones from icebergs and the rare rocky outcrops there is not a lot of hard substrate in the deepsea. The sediment exists of very fine clay-like ooze. Manganese nodules form a very important substrate for sessil animals. Therefore they are mentioned here as a special benthic habitat in the deep-sea. Mining of the nodules of course means the removal of the hard substrate and thus also of the attached animals. As nodules grow very slowly, in the order of a few millimeters per million years (Ross Heath, 1979), this kind of hard substrate will be replaced by new growth. Several studies have been devoted to the impact of mining on the benthic fauna. In general, it is concluded that it will have a detrimental effect on the fauna because of the direct impact (removal of nodules and the upper centimeters of the sediment surface) and because of the resuspension and subsequent deposition of sediment blanketing a much larger area with a thick layer of sediment to which the fauna is not adapted (Knecht, 1982). Recolonization in the deep-sea is a very slow process (Gage & Tyler, 1991). A large-scale experiment, DISCOL (Disturbance and recolonisation experiment in a manganese nodule area of the deep South Pacific) was conducted to evaluate potential impacts from mining on the deep-sea bed (Thiel et al., 2001). It started in 1989 with the large scale disturbance of a manganese nodule field in the Peru Basin, eastern South Pacific. After seven years significant differences in the assemblage composition of the Harpacticoid meiofauna was found in the directly disturbed portions of the experimental area and in the secondarily disturbed areas in between (Ahnert & Schriever, 2001). In the initial post impact phase, abundances of the total macrofauna and those of Polychaeta, Tanaidacea, Isopoda, and Bivalvia were heavily reduced at the disturbed sites, while Cumacea, Gastropoda, and Scaphopoda were lacking entirely. However, the macrofauna had been recovered for the larger part 7 years after the experimental disturbance (Borowski, 2001). Nevertheless, the experimental impact by far did not reach industrial mining impact dimensions and interpretation of the results with regard to commercial mining requires caution.

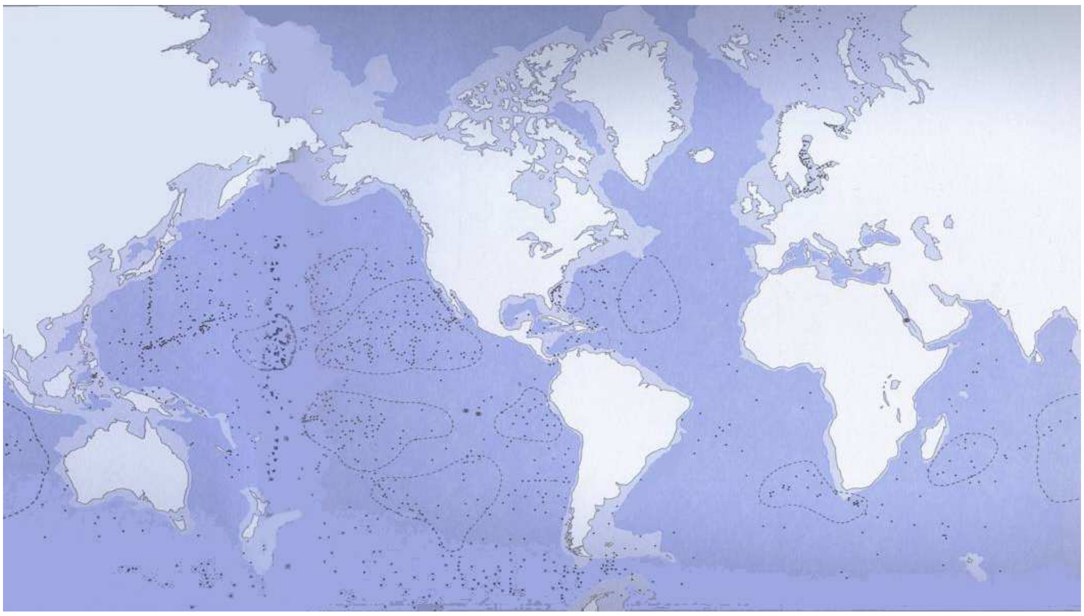

Figure 13.7 Distribution of manganese nodules (changed after Bramwell 1977).

13.6.5 Conclusions Special benthic habitats

- Most cold water coral reefs are within the EEZ's. Reefs outside the EEZ's are concentrated in the North Atlantic. Corals grow slowly, have presumably a low reproduction rate and can easily be destroyed by physical contact (like bottom trawling). Recovery rates will therefore be very low

- The majority of seamounts are situated outside the EEZ's. Though there is a high number of seamounts distributed over all oceans, the endemic fauna is threatened, as seamounts are a particular target for fisheries. The mounts have often concentrations of fish near their summit. These fish e.g. orange roughy have longeivity of up to 100 years, reproduce only at a relative old age, and therefore recovery rates of these populations will be slow. The bottom fauna is often destroyed in the process of fishing. This includes very old soft and stony coral species.
- Hot vents are quite rare and always situated at or near seafloor spreading centers. The problem for the associated fauna does not seem to be the influence of mankind, but more the rapid changes in the volcanic activity. Even the research of biologist does not seem a threat (Tyler et al., 2005)
- Manganese nodule fields are always situated in the deep sea and therefore outside the EEZ's. The highest concentrations are in the Pacific. Though these minerals are commercial attractive, the cost of collecting these from the deepsea floor still poses a problem. But because the growth rate of manganese nodules is incredible slow it is worthwhile to think about protection of a part of these fields.
- Other deep sea special habitats are: sponge reefs, mud volcanoes, soft coral forests.

13.7 Anthropogenic impacts

13.7.1 General considerations

Most likely fewer than 1% of species in marine sediments are presently known. The relative inaccessibility of the deep water habitats put a challenge to our understanding but also put a treat on how properly to address and estimate the real influence of anthropogenic activity on the biodiversity of deep sea habitats.

As stated above a disturbance of the sea bed will allow recolonisation, but in these deep waters only at a slow speed illustrating the sensitivity of the area. Depending on the interval between disturbances it can be expected that with increasing disturbance, recovery can take very long. In their analysis of human impact on marine ecosystems Halpern et al. (2008) demonstrated that even deep sea ecosystems have few to no areas with very low impact.

Some habitats will be more vulnerable to impacts from human activities than others, partly because of their life cycle dynamics, partly because of their recoverability and as a result of the severity and type of human activity.

Cold water corals and deep water sponges grow very slowly. Cold water coral reefs and sponge fields add a three-dimensional structure to the seafloor, thus increasing habitat complexity resulting in shelter and nursery grounds. Such areas are "hot spots" in biodiversity for which a physical disturbance will impact their ecosystems function. Cold water coral reefs have attracted attention from fisheries as they shelter species of commercial interest. Without sustainable management fish stocks from these sites can be depleted within a few years. Once the exploitation of polymetallic nodule (manganese nodules) starts it will have severe consequences as colonisation and recovery are expected to be extremely low (Smith, 1999). The communities forming the ecosystems of hydrothermal vents and cold-water seeps have other life strategies growing relatively faster and having a high number of offspring. Recovery of such habitats might be faster.

Sea bed disturbance, and certainly when conducted at large scales such as necessary for most deep sea mining operations, will have severe consequences to the benthic communities and severely impact biodiversity (Smith, 1999). The effects of such operations affect not only the prospected area but also its surroundings. The occurrence of endemic species would seriously limit the options for conservation in one area to compensate for biodiversity loss in another. Further research would be necessary to assess the scale factor relative to the size and vulnerability of deep-sea ecosystems and biodiversity hotspots.

Next to vulnerability to human threats the importance of the habitat function of an area needs to be considered as well in assessing the importance of the effects of anthropogenic activities. Some areas play a key function as a critical ecosystem link between different trophic levels. Hydrothermal vent, cold seep, seamount, and cold-water coral and sponge reef ecosystems were identified by the Conference of the Parties, as important for their value as genetic resources of great interest for their biodiversity value and for scientific research as well as for present and future sustainable development and commercial applications (UNEP 2008). These habitats are regarded also important for their: (i) high level of endemism, (ii) high diversity, (iii) potential to facilitate the understanding of evolution and global climate change, and (iv) vulnerability.

Although widely spread (see Figure 13.6 of the distribution of hot vents and others) cold water coral reefs, hydrothermal vents and sea mounts represent often relative local sites of increased diversity. Spatial variability and its importance to the overall spatial ecosystem structure is getting more interest as the result of increased deep sea investigations. In some way the identification and characterization of deep sea benthos habitats and their spatial importance to the ecosystem functioning of the high seas will be needed in order to prioritize habitats as a start in the management of the high seas. However, information on the distribution of the benthic biodiversity over the oceans is still scarce and regularly causes surprises. Their spatial importance on the large scale or even the meso-scale ecosystem functioning is still unknown.

13.7.2 Conclusion

Fisheries: The impact of deep sea fisheries on benthic habitats will be related to bottom trawling and to a lesser extend, longlining. Bottom trawling will destroy the tree-dimensional habitat structure, potentially affecting all species of that habitat. Long lines will cause less damage. Nevertheless, bottom long lines can entangle pieces of coral or tear off parts of the bottom structure, negatively affecting benthic habitats.

Deep sea mining for polymetallic nodules: The impacts of deep seabed mining are related to the physical damage in the area of operation. The polymetallic nodules are removed, and with that the hard substrate and its associated organisms, leading to a loss of a special habiat that occurs in the abyssal plains that mostly consist of fine sediments. The mining process itself will further effect the area and the surrounding habitats due to increased sedimentation and plume generation. Due to the scale of the operations the effects on the benthic communities could be large.

Research and Bioprospecting: The most immediate impact of research and bioprospecting activities are related to repeated sampling resulting in the removal of parts of the vent physical infrastructure and/or the associated fauna, placement of observation instruments which may cause temporal changes at individual sites (Glowka 2003; CBD 2005a; Arico and Salpin 2005). Especially hydrothermal vents are impacted by these activities. Research vessels and scientific equipment for long-term measurements may also create a negative impact on the deep seabed physical environment. In-situ experiments may cause alterations in temperature, light, and noise. Pollution in the form of debris or biological contamination can occur due to disposal of biological material from other areas (Arico and Salpin 2005; Leary 2007). Significant loss of habitat, and population oversampling due to bioprospecting, along with mining of polymetallic sulphide deposits associated with vent systems, and high-end tourism may cause future damage to vent ecosystems (CBD 2005a; Arico and Salpin 2005; Leary 2007).

Other activities: Additionally, damage may occur from hydrocarbon drilling and seabed mining, ocean acidification, placement of pipelines and cables, pollution, research activities with destructive impacts, and dumping (UNEP n.d.).

Climate change: Benthic habitats and species distribution are related to temperature and it is likely that sedimentary faunal shifts have occurred, or will occur, as a result of global warming. Ultimately, global warming will compress, enlarge or eliminate habitats as shifts in fauna do occur. As a result of global warming ocean circulation may change (Manabe *et al.* 1994), affecting productivity, larval and sediment transport, and ultimately the benthos community. Also ultraviolet radiation increases associated with ozone depletion could have direct impacts on shallow-water fauna and on the eggs and microplankton of organisms living in deeper water.

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14 Seabirds[51]

14.1 Introduction

Seabirds occur in all seas and oceans and although their densities are much higher over continental shelves, some 250 wide-ranging (or "pelagic") species use the high seas either as their principal habitat or commute over the high seas on long-range feeding trips or during migration. Several different types of seabirds use the high seas. Tubenoses (albatrosses, petrels, prions, shearwaters, storm-petrels and diving petrels) comprise the largest group and probably the most oceanic. Most are strong flyers that are able to spend prolonged periods on the wing, covering large distances looking for sparsely available and often unpredictable food sources. Some species however, use particularly rich feeding zones such as upwelling areas or oceanic frontal systems. Such rich feeding patches are comparatively rare and the birds involved may have to cross entire oceans to reach them. Most tubenoses have evolved to become highly efficient, long distance flyers. Most of their food is pelagic, or found near the surface and tubenose typically have limited diving capacities although some can dive to over 50 m deep.

A second large group of ocean-going seabirds are the skuas, gulls and terns. The four species of northern hemisphere skuas move south for wintering and become oceanic. Many gulls are tied to coasts or shelf seas, but several (mostly northern) species also wander widely in the non-breeding season. Different terns exploit the high seas in different manners. Some tropical species use the vast expanse of the open Indian and Pacific Oceans in similar ways as some of the tubenoses, spending much time in flight, searching for rare and highly dispersed prey items. Others only winter in oceanic waters, usually far away from their summer haunts. Several northern species of tern migrate across half the globe between their breeding and wintering sites (species like common tern and arctic tern). As terns feed on the wing, they can feed on migration and may range widely when not tied to breeding sites, so some species may be found very far from land during the non-breeding season.

The different lifestyles briefly mentioned so far are also used by a variety of other seabirds that utilise the High Seas for different reasons and to a different extent, including tropicbirds, gannets and boobies, frigatebirds, phalaropes and some auks. Two rather special groups of birds utilising the high seas are birds of the Mediterranean and birds living around Antarctica. Their high seas lifestyle is to some extent a matter of definition. Parts of the Mediterranean are beyond the EEZ of the states bordering this sea and all birds that venture across this "mini ocean" are thus using the high seas. The same applies to Antarctica that does not have an EEZ and this group thus includes several penguins and cormorants that might not wander that far from shore (compared to the true ocean-wandering tubenoses for instance, many of which never even enter an EEZ). On the other hand, one does not have to wander too far offshore from the Antarctic coastline, to find oneself in a very harsh, oceanic environment.

The full list of seabirds using the high seas is given in Appendix 14.1. This list has been compiled from distribution maps in Harrison (1983) and Del Hoyo *et al.* (I, II and III, 1992, 1994 and 1996) for all seabirds, Brooke (2004) and Onley & Scofield (2007) for the tubenoses, Olsen & Larsson (2004) for the northern hemisphere gulls and Gaston & Jones (1998) for the auks. Conservation status of each species, and specific threats if known, were taken from the BirdLife International Factsheets (available at: http://www.birdlife.org) and from the IUCN Red List (http://www.iucnredlist.org/).

General threats to the seabirds of the high seas

Since fishing fleets tend to exploit the same highly productive areas that are seabirds hotspots, new food sources in these parts of the oceans are fisheries waste and fisheries bait (used in longlining). These are available in large quantities, at the surface, and often in more or less predictable places. Ocean-going fishing fleets thus attract large numbers of pelagic seabirds, that find a rich bounty of food brought up to the surface (discards, bycatch) or thrown into the sea (longlining bait) around large ships that are visible from long distances and remain at fishing grounds for long periods of time. Observations from the fishing vessels themselves, e.g. from observers programmes (Glass *et al.* 2000; Cuthbert *et al.* 2005) have shown that large numbers of seabirds congregate

51 Author: M.F. Leopold

around fishing fleets. Increasing numbers of seabirds have been fitted with satellite-operated positional equipment, such as GPS loggers and this work has clearly demonstrated that birds from far-away, remote breeding islands repeatedly travel many thousands of miles to go feeding around certain fishing fleets (BirdLife International 2004).

A second interaction between pelagic seabirds and mankind involves the birds ingesting man-made objects, floating at the ocean's surface. Many pelagic seabirds are scavengers (feeding on dead animals floating at the surface) or are planktivorous. Any object floating at the surface is seen as potential food and anything of the right size may be tried for food. Seabird stomachs the world over have been found to contain foreign objects such as plastics and pelagic seabirds, living mostly in areas far away from the industrialised countries are no exception.

A third interaction involves surface pollutants, such as oil slicks. Oil slicks are a well-known hazard to seabirds in coastal seas and the incidence of oil slicks occurring in the high seas is probably comparatively low, but any oil slick is a hazard to the birds that come in contact with it. Particularly in Arctic and Antarctic waters oil slicks are an increasing risk factor. Shipping intensity in these parts has increased in recent decades, due to shrinking ice cover and developing tourist industries. Particularly the prospects of the opening of new Arctic passages for merchant shipping comprise a considerable threat for Arctic seabirds. Several accidents with tourist vessels in the Antarctic, sometimes close to major seabird colonies, have already happened. Oil only dissipates slowly in cold environments, seabirds are particularly concentrated in some parts of high latitudes seas and any substance that is discharged at sea and that floats at the surface may impact the birds' feathers or be seen as food and be eaten.

The fourth interaction is linked to long-term, man-made changes of the oceanic ecosystems, particularly the large scale removal of other warm-blooded top-predators, such as pinnipeds and cetaceans. Consumption rates of these (large and formerly abundant) animals have thus been greatly reduced and competition with seabirds relaxed. On the other hand, seabird numbers in many species have also been reduced directly by man, through hunting/gathering actions in major breeding colonies, introduction of predators to remote breeding colonies and in some birds, by directional catches at sea. Over the centuries, both marine mammal and seabird faunas have been impoverished and this would suggest that the remaining seabirds today would have ample food to sustain them. However, also their food base has been impacted by man, e.g. by overfishing.

At present, probably the greatest threat to the birds of the high oceans occurs on land, on remote islands used for breeding. Such islands have long been free of disturbance, mammalian predators and browsers, and man-induced habitat degradation. However, many such islands have now been touched by man, often with devastating consequences for the birds breeding there, that have not evolved to cope with mammalian contact. Although strictly speaking such threats do not occur at the high seas themselves, they often occur on islands situated far from mainland coasts, and away from the major EEZs.

14.2 Direct Mortality

Bycatch: Longlining

'Albatrosses have survived in the harshest marine environments for 50 million years; more than 100 times longer than our own species. However, these magnificent birds are unable to cope with man-made threats, such as longline fishing.'

Sir David Attenborough
(taken from http://www.savethealbatross.net/the_problem.asp)

Hundreds of thousands of seabirds are bycaught and accidentally killed each year on longline hooks set in the world's oceans in various commercial longline fisheries. Many of the impacted species are long-lived and reproduce slowly. This additional mortality impacts several species on the population level (Alexander et al., 1997; Croxall, 1998; Gales, 1998; Brothers 1999; Inchausti & Weimerskirch 2002; Furness 2003). Important longline fisheries in which incidental catch of seabirds are known to occur are squid and Patagonian toothfish in the Southern Ocean; rockfish, halibut, Greenland halibut, black cod, Pacific cod, cod, haddock, tusk and ling in the northern oceans (Pacific and Atlantic) and tuna, swordfish billfish around the world. The species of seabirds most frequently taken are albatrosses and petrels in the Southern Ocean, northern fulmars in the North Atlantic and albatrosses, gulls and fulmars in the North Pacific fisheries.

Longlining is a type of fishery that uses one or more long (hence the name) lines to which many branch lines are attached. Each branch line has a baited hook at its end. The fishery targets large, high quality, high value fish that hook themselves by taking the bait. Lines are retrieved after a certain soaking time. When in place, few birds are probably bycaught, but during setting the baited hooks need to go down from the ship into the water and are temporarily available to birds scavenging around the vessel. In the 1980s, longlining became an increasingly popular method of fishing, partly in response to the increasing demand for high-quality, high-value fish for upmarket restaurants, but also following the global ban on drift nets. Some longliners set lines of over 100km. Attached to it are literally thousands of baited hooks. An estimated 1 billion hooks are set annually by the world's longline fleets (http://www.birdlife.org/action/science/species/seabirds/longlining.html).

Seabird bycatch during longline fishing thus mainly occurs when birds are attracted to fishing vessels and grab baited hooks during the setting of the longline. Hooked birds are subsequently pulled under the water by the weight of the line and drown. The impact of longline fishing activities on seabirds is regarded as a serious threat, causing widespread declines in populations across the world at a rate of 100,000 albatrosses and unknown, but probably larger numbers of other procellariidae per annum.

Hooked birds have little opportunity to escape drowning and the impact on individual birds is clear: death. Impact on populations depends on three factors: the size of the take, the population size involved and the reproductive potential. Longlining at the high seas mainly impacts slowly reproducing procellariiformes (albatrosses, petrels, shearwaters) but birds with highly different populations sizes are impacted. Obviously, species with very large population sizes will suffer high absolute losses but these may be relatively insignificant at the population level. Examples of frequently bycaught species with population sizes in the millions are: White-chinned Petrel *Procellaria aequinoctialis*; Great Shearwater *Puffinus gravis* and Northern Fulmar *Fulmarus glacialis*. Most worries have been expressed about species that are also frequently bycaught, but that have much smaller population sizes. There has been much focus on one of the most charismatic of all seabirds, the Wandering Albatross *Diomedea exulans*. This “species” has long been thought to be monotypic or at best to have several “races” but it has become clear that several different species exist, some of which with very small population sizes (Robertson & Nunn 1998). Moreover, *D. exulans (sensu strictu)* has breeding colonies dispersed over the Southern Ocean and birds from different islands tend to use different feeding grounds. Local fisheries impact thus concerns relatively small and unique parts of a larger metapopulation, or even small populations of entire species. Highly vulnerable in this respect are the Amsterdam albatross *Diomedea amsterdamensis* (population size only some 130 birds); the Tristan Albatross *Diomedea dabbenena* (9000-15000 breeding pairs and decreasing); the Great or Wandering Albatross (28000 pairs and decreasing) and the Waved Albatross *Phoebastria irrorata* (less than 35,000 pairs and declining (BirdLife International; internet factsheets: http://www.birdlife.org). Impacted birds with population of intermediate size include the Black-browed Albatross *Thalassarche melanophris* (500,000 pairs; Furness 2003) the Flesh-footed Shearwater (220 000 pairs; Baker & Wise 2005) and the Cory's Shearwater (50-80,000 pairs in the Mediterranean; Cooper *et al.* 2003). Some countries have legislation to have observers on board fishing vessels operating in their waters (USA, Canada, New Zealand, Australia) but many countries do not and fishing vessels operating at the high seas will largely produce bycatches that remain unrecorded.

Bycatch: Driftnets

Drifting gill nets are operated both at the high seas and closer inshore. Inshore fishing may be very detrimental to locally breeding seabirds or to migratory seabirds that move over great distances into shelf seas to feed in the non-breeding season (Furness 2003). If bycaught birds would have dispersed over the high seas at other times of year, such bycatches in nearshore waters, if significant, may also affect avian biodiversity of the oceans. Offshore gillnetting has killed millions of seabirds at the high seas themselves. One of the main impacts involved the North Pacific high seas salmon and squid fishery that was estimated to have killed 500,000 birds per annum, until these fisheries were closed in 1992 (DeGange *et al.* 1993; Uhlmann 2003). High seas fisheries in the North Atlantic occur around the Grand Banks and catch unknown (but presumably much smaller) numbers of shearwaters (Uhlmann 2003).

Bycatch: Bottom-setnets

Bottom set-nets are another major source of man-induced seabird mortality (Furness 2003), but because these nets can only be deployed in relatively shallow (<200 m) waters, very few will be used at the high seas. Some offshore usage, e.g. around seamounts cannot be excluded.

Hunting, gathering

Sailors have probably always used offshore islands for provisioning and even remote seabird colonies have been exploited (eggs, chicks, adults) since the early days of sail. It is feasible that modern seabird faunas still reflect the colony raids of times gone by. Modern distribution patterns are likely to be the result of this long-term influence, with seabirds breeding primarily on remote islands, hilltops on islands, inaccessible cliffs, etc. North-Atlantic seabird faunas are thought to be impoverished by the arrival of man at the shores. Seabird colonies are very vulnerable to human raids and birds breeding in accessible places have long been exterminated. The Northeast Atlantic, for instance, once had breeding *Pterodroma feae* around Scotland that today are very rare globally and confined to breeding on a mountain top in Madeira. Archaeological finds strongly suggest that these birds were once much more widespread and that they disappeared with the increase and spread of human populations (Serjeantson 2005).

Seabirds have also been harvested to be used as bait in longline or crabfisheries, but these activities were mainly restricted to nearshore waters. Seabirds, particularly great albatrosses have been caught on towed lines and shot for fun (or "sport") from passenger ships heading from the UK and the Netherlands to Australia and New Zealand in the nineteenth century (see Medway 1998 for a vivid description of these practices).

Oil slicks

Seabirds that come in contact with an oil slick have a low survival probability. Oil slicks are a rather common phenomenon in shelf seas, where shipping intensity is high and where most of the at-sea production takes place. Oceanic oil production, outside the EEZs is yet not possible, but exploration under e.g. the North Pole ice sheet shows that it is being contemplated. Deliberate oil discharges from ships (tanker-cleaning or operational discharges of bilges) are probably common across the world oceans, but these waters are not patrolled by pollution control units (although satellite-radar observations would make this technically possible). In terms of geography, oceanic oil slicks are probably rare, given the low densities of ships and the vastness of the oceans. Bird densities at the high seas are generally low, and impacts of oil slicks on oceanic seabirds are probably small. Some major incidents with tankers have occurred outside EEZs (Table 14.1): the Bahía Paraiso near Palmer Station, Antarctica (1989); the Castillo de Bellver (1983), the Apollo (1994) and the Treasure (2000) off South Africa (the latter two impacting large numbers of African Penguins *Spheniscus demersus*). Major oil incidents with fuel tankers typically occur inshore however, far from the high seas. Some governments, e.g. those of France (Erika, 1999) and Spain (Prestige 2002) have attempted to move stranded and leaking oil tankers out to the open ocean, with disastrous results in both cases (Camphuysen &Leopold 2003; Camphuysen *et al*. 2003).

Chemical waste

Oil incidents often draw a lot of (media) attention but many more substances are discharged at sea, often to clean tankers before the ship takes on a new load. Many substances are poisonous or corrosive (see e.g. Camphuysen *et al*. 1999). Comparatively little is known about the incidence of such discharges, particularly at the high seas, and virtually nothing about impacts on birds.

Introduced predators

Introduced predators are believed to be a major threat to any seabird breeding on remote, once predator-free islands. Rats, cats, mongoose and mink are the most notorious species, but small mammals (mice) have also taken large tolls. The effects of introduced predators are highly detrimental to any seabird (with the probable exception of some very aggressive species), but current effects are probably largest in combination with other reasons of concern, such as a restricted breeding range or a very small (remnant) population size.

Introduced diseases

Introduced pathogens such as Avian Cholera into formally pristine oceanic islands are threatening some species of seabirds, like the Indian Yellow-nosed Albatross *Thalassarche carteri* and the very rare Amsterdam albatross on Amsterdam Island (Weimerskirch 2004).

Table 14.1 Major oil spills since 1967. The biggest 20 are listed plus the well known Exxon Valdez case, that was only the 35th in spill size but still had a large impact on the environment. Also added is the major oil incident in Antarctica. Incidents on the high seas are highlighted. Many of these are unfamiliar to the general public, as the happened far away from any coast and **presumably** caused little or no environmental damage. Note however, that no impact assessments were ever made for such spills. (http://www.itopf.com/information-services/data-and-statistics/statistics/#major).

Nr	Shipname	Year	Location	Spill size (tonnes)
1	Atlantic Empress	1979	Off Tobago, West Indies	287,000
2	ABT Summer	1991	700 nautical miles off Angola	260,000
3	Castillo de Bellver	1983	Off Saldanha Bay, South Africa	252,000
4	Amoco Cadiz	1978	Off Brittany, France	223,000
5	Haven	1991	Genoa, Italy	144,000
6	Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132,000
7	Torrey Canyon	1967	Scilly Isles, UK	119,000
8	Sea Star	1972	Gulf of Oman	115,000
9	Irenes Serenade	1980	Navarino Bay, Greece	100,000
10	Urquiola	1976	La Coruna, Spain	100,000
11	Hawaiian Patriot	1977	300 nautical miles off Honolulu	95,000
12	Independenta	1979	Bosphorus, Turkey	95,000
13	Jakob Maersk	1975	Oporto, Portugal	88,000
14	Braer	1993	Shetland Islands, UK	85,000
15	Khark 5	1989	120 nautical miles off Atlantic coast of Morocco	80,000
16	Aegean Sea	1992	La Coruna, Spain	74,000
17	Sea Empress	1996	Milford Haven, UK	72,000
18	Katina P	1992	Off Maputo, Mozambique	72,000
19	Nova	1985	Off Kharg Island, Gulf of Iran	70,000
20	Prestige	2002	Off Galicia, Spain	63,000
35	Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000
?	Bahía Paraiso	1989	Near Palmer Station, Antarctica	600

14.3 Indirect mortality or sub-lethal detrimental effects

Ingestion of plastics

Scavenging and planktivorous seabirds of the open oceans, where available food is scarce, will try to eat anything that even vaguely resembles food. If ingested objects turn out to be indigestible, they may remain in the stomach for a considerable period of time, until they are small enough (through wear and tear in the stomach) to pass through the gut or until they are regurgitated, often to be passed on to food-receiving chicks. Plastics, being neutrally buoyant and coming in many different shapes and colours, have become very wide-spread in the world's oceans. Such material includes plastic pellets (industrial granules that are an intermediate product for further usage and that are transported, and discharged, in bulk) to all sorts of end products. Plastic pellets may mimic fish eggs and are readily eaten by procellariidae; larger objects, including toothbrushes, cigarette lighters, plastic bags and foils, etc. are also often eaten. Being inert (apart from certain toxic ingredients such as weakeners) they may remain in a bird stomachs for months, interfering with food uptake and eventually they may be passed on to chicks that have not even seen the sea. Birds on the remotest islands have been shown to contain plastics, but the true impact on populations remains to be demonstrated (Van Franeker & Bell 1988; Ainley *et al*. 1990; Day *et al*. 1990; Moser & Lee 1992; Blight & Burger 1997; van Franeker *et al*. 2005).

Ingestion of other chemicals

Some discharged chemicals such as palm oil, or other fatty substances may be mistaken by birds for food, and be eaten. Detrimental effects, if any, are hardly known.

Breeding habitat degradation

Many once pristine oceanic islands, that are remote and rare breeding sites for oceanic seabirds have been visited by man and in some cases, occupied by man. This has had various effects on the local seabirds that were usually highly detrimental. In some cases human settlements or airstrips have been built on the rare flat patches of (ice-free) land that had seabird colonies for the same reasons of accessibility. Human settlements have been accompanied with light pollution that has resulted in disorientation of both breeding adults and fledging young; birds have been crashing into buildings, particularly lighthouses and lines holding up man-made structures, etc. Introduced pets (cats, dogs) have run havoc amongst local seabirds, but also seemingly more benign introduced animals such as pigs, goats or sheep have made breeding habitats become unsuitable. One such example are the cows that were once introduced on Amsterdam island, and that are now considered a rare race worth conserving, are threatening the breeding habitat of the very rare Amsterdam Albatross (Micol & Jouventin 1995). There is one case of an introduced insect that is eating away the vegetation on an oceanic island, threatening the local seabirds (Newell's Shearwaters, *Puffinus newelli*, of Hawaii).

14.4 Restricted breeding ranges and small populations

Quite a few seabirds now have very restricted breeding ranges that make them very vulnerable for (further) human interference or natural events such as floods (tsunamis) or hurricanes. On top of that, some of these species have very small population sizes of only hundreds or even dozens of breeding pairs. Combined with small clutches, low breeding success and a high vulnerability for e.g. introduced predators, or susceptibility for enhanced mortality from e.g. longlining, some of these species are close to extinction.

14.5 Changed ecosystems and climate conditions

The vast majority of commercially exploited fish stocks today are “fully exploited”, overexploited, or have crashed (Pauly 2007; this report, Section 2.3 (fisheries) and Figures 2.3 and 2.4). The high seas comprise one of the last ecosystems to be impacted by fisheries but their exploitation is now well under way. Bulk fisheries, that directly compete with seabirds for the same resources are rather a-typical for the open oceans, rather large, predatory fish are targeted here. Such fish compete for food with seabirds that in the end may have profited from the removal of stocks of predatory fishes. Even more, the once very abundant large whales, as well as many species of pinnipeds (seals, fur seals) have been brought to near-extinction by whalers and sealers, long before modern fisheries started to impact the oceans. Seals and fur seals most likely interact with seabirds in shelf seas (Kaschner & Pauly 2004); whales (also) at the high seas. Fur seals in particular, compete with Southern Ocean seabirds for breeding space and with their present come-back, have started to push seabird colonies back.

There are some indications that El Nino events are becoming more severe, that hurricanes are becoming more frequent and certainly, that climate change is affecting the ice cover in the Arctic. Some seabirds breeding at sites that are vulnerable to the immediate effects of climate change such as sea level rise (low-lying islands and coastlines), or hurricanes are thought to be negatively affected. Birds breeding at very high latitudes, both in the Arctic (Ivory Gull *Pagophila eburnea*) and in the Antarctic (Emperor Penguin *Aptenodytes forsteri*) might also be negatively affected at their breeding sites. Climate change is further likely to affect feeding conditions in the seas and oceans, where these birds make a living.

14.6 Conclusions

- Hundreds of thousands of seabirds are bycaught and accidentally killed each year on longline hooks set in the world's oceans in various commercial longline fisheries. Longlining is now considered the major threat for many Southern Ocean seabird species, affecting particularly albatrosses and large petrels, at the population level.
- The species most frequently taken are albatrosses and petrels in the Southern Ocean, but in the North Atlantic and Pacific Oceans, albatrosses, northern fulmars and several gull species also suffer highly significant losses through longlining.
- The impact of longline fishing activities on seabirds is regarded as a serious threat, causing widespread declines in populations across the world. Earlier, drift netting was a similar major threat to seabirds, but several highly detrimental fisheries have been closed in the recent past. Several management options aimed at decreasing bycatches in longlining are being considered.
- Several seabirds have very restricted breeding ranges and/or very small population sizes, that make them very vulnerable for (further) human interference, including the introduction of alien predators to remote breeding sites, or to natural events.

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Appendix 14.1 Seabirds from the Sothern, Pacific, Atlantic and Indian Ocean. Their IUCN conservation status and threats.

Species		**Southern**	**Pacific**	**Atlantic**	**Indian**	**IUCN Conservation Status**	**Threats (IUCN, BirdLife)**											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
King Penguin	*Aptenodytes patagonicus*	x		x		Least concern												
Emperor Penguin	*A. forsteri*	x				Least concern				X	X							
Gentoo Penguin	*Pygoscelis papua*	x				Near-threatened			X				X					
Adelie Penguin	*P. adeliae*	x				Least concern				X								
Chinstrap Penguin	*P. antarcticus*	x		x		Least concern												
Fiordland Crested Penguin	*Eudyptes pachyrhynchus*		x			Vulnerable						X						
Rockhopper Penguin	*E. chrysocome*	x	x	x	x	Vulnerable			X		X	X		X				
Macaroni Penguin	*E. chrysolophus*	x		x		Vulnerable			X		X			X				
Royal Penguin	*E. schlegeli*					Vulnerable									X			
Little Penguin	*Eudyptula minor*		x			Least concern												
Red-throated Diver	*Gavia stellata*			x		Least concern								X				
Great Northern Diver	*Gavia immer*			x		Least concern								X				
Wandering Albatross	*Diomedea exulans*	x	x	x	x	Vulnerable	X											
Antipodean Albatross	*D. antipodensis*		x			Vulnerable									X			
Gibson's Albatross	*D. gibsoni*		x			Vulnerable									X			
Amsterdam Albatross	*D. amsterdamensis*				x	Critically endangered										X		
Tristan Albatross	*D. dabbenena*			x		Endangered	X											
Northern Royal Albatross	*D. sanfordi*	x	x	x		Endangered							X					
Southern Royal Albatross	*D. epomophora*	x	x	x		Vulnerable									X			
Waved Albatross	*Phoebastria irrorata*		x			Critically endangered									X			
Short-tailed Albatross	*P. albatrus*		x			Vulnerable									X			
Laysan Albatross	*P. immutabilis*		x			Vulnerable	X											
Black-browed Albatross	*Thalassarche melanophrys*	x	x	x	x	Endangered	X											
Campbell Albatross	*T. impavida*		x			Vulnerable									X			
Shy Albatross	*T. cauta*	x	x	x	x	Near-threatened									X			
Chattam Island Albatross	*T. eremita*		x			Critically endangered							X		X			
Salvin's Albatross	*T. salvini*		x			Vulnerable									X			

Appendix 13.1 Seabirds

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Grey-headed Albatross	*t. chrysostoma*	x	x	x		Vulnerable	X											
Atlantic Yellow-nosed Albatross	*T. chlororhynchos*					Endangered	X								X			
Indian Yellow-nosed Albatross	*T. carteri*					Endangered	X								X		X	
Buller's Albatross	*T. bulleri*		x			Vulnerable									X			
Sooty Albatross	*Phoebetria fusca*	x	x	x		Endangered	X											
Light-mantled Sooty Albatross	*P. palpebrata*	x	x	x		Near-threatened	X					X						
Southern Giant Petrel	*Macronectes giganteus*	x	x	x	x	Near-threatened	X											
Northern Giant Petrel	*M. halli*	x	x	x	x	Near-threatened												
Southern Fulmar	*Fulmarus galcialoides*	x	x	x		Least concern												
Northern Fulmar	*Fulmarus glacialis*		x	x		Least concern												
Antarctic Petrel	*Thalassoica antarctica*	x				Least concern												
Cape Petrel	*Daption capense*	x	x	x	x	Least concern												
Snow Petrel	*Pagodroma nivea*	x				Least concern												
Blue Petrel	*Halobaena caerulea*	x	x	x		Least concern												
Broad-billed Prion	*Pachyptila vittata*		x	x		Least concern						X						
Medium-billed Petrel	*P. salvini*		x	x		Least concern												
Antarctic Prion	*P. desolata*	x	x	x		Least concern						X						
Thin-billed Prion	*P. belcheri*	x	x	x		Least concern												
Fairy Prion	*P. turtur*	x	x	x		Least concern												
Fulmar Prion	*P. crassirostris*	x				Least concern												
White-chinned Petrel	*Procellaria aequinoctialis*	x	x	x	x	Vulnerable	X					X	X					
Spectacled Petrel	*P. conspicillata*			x		Critically endangered	X									X		
Westland Petrel	*P. westlandica*		x			Vulnerable	X					X	X					
Parkinson's Petrel	*P. parkinsoni*		x			Vulnerable	X					X				X		
Grey Petrel	*P. cinerea*	x	x	x		Near-threatened	X					X						
Bulwer's Petrel	*Bulweria bulweria*		x	x	x	Least concern												
Jouanin's Petrel	*B. fallax*				x	Near-threatened						X						

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Cory's Shearwater	*Calonectris diomedea*			x, M		Least concern												X
Cape Verde Shearwater	*C. edwarsi*			x		Near-threatened												X
Streaked Shearwater	*C. leucomelas*		x			Least concern		X										X
Wedge-tailed Shearwater	*Puffinus pacificus*		x	x		Least concern			X			X						X
Buller's Shearwater	*P. bulleri*		x			Vulnerable						X			X			
Flesh-footed Shearwater	*P. carneipes*		x	x		Least concern	X											
Pink-footed Shearwater	*P. creatopus*		x			Vulnerable						X						X
Great Shearwater	*P. gravis*	x		x		Least concern									X			
Sooty Shearwater	*P. griseus*	x	x	x	x	Least concern		X		X								X
Short-tailed Shearwater	*P. tenuirostris*	x	x			Least concern		X		X								
Christmas Shearwater	*P. nativitatis*		x			Least concern												
Manx Shearwater	*P. puffinus*			x		Least concern												
Yelkouan Shearwater	*P. yelkouan*			M		Least concern					X	X	X					
Balearctic Shearwater	*P. mauretanicus*			x, M		Critically endangered	X					X				X		
Townsend 's Shearwater	*P. auricularis*		x			Critically endangered						X				X		
Newell's Shearwater	*P. newelli*		x			Vulnerable				X		X	X		X			
Black-vented Shearwater	*P. opisthomelas*		x			Near-threatened						X	X		X			
Fluttering Shearwater	*P. gavia*		x			Least concern	X					X						
Hutton's Shearwater	*P. huttoni*		x			Endangered							X		X			
Audubon's Shearwater	*P. lherminieri*		x	x	x	Least concern												
Heinroth's Shearwater	*P. heinrothi*		x			Vulnerable										X		
Little Shearwater	*P. assimilis*		x	x	x	Least concern						X						
Fiji Petrel	*Pseudobulweria macgillivrayi*		x			Critically endangered						X				X		
Tahiti Petrel	*P. rostrata*		x			Near-threatened						X	X			X		
Beck's Petrel	*P. becki*		x			Critically endangered										X		
Mascarene Petrel	*P. aterrima*				x	Critically endangered						X				X		
Kerguelen Petrel	*Lugensa brevirostris*	x				Least concern												
Barau's Petrel	*Pterodroma baraui*				x	Endangered						X	X		X			X

Appendix 13.1 Seabirds

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Trindade Petrel	*P. arminjoniana*			x	x	Vulnerable									X			
Juan Fernandez Petrel	*P. externa*		x			Vulnerable						X			X			
Kermadec Petrel	*P. neglecta*		x			Least concern												
Galapagos Petrel	*P. phaeopygia*		x			Critically endangered						X			X			
Hawaiian Petrel	*P. sandwichensis*		x			Vulnerable						X			X			
Henderson Petrel	*P. atrata*		x			Endangered						X			X			
Herald Petrel	*P. heraldica*		x			Least concern						X						
Phoenix Petrel	*P. alba*		x			Vulnerable						X			X			
Fea's Petrel	*P. feae*			x		Near-threatened						X				X		
Zino's Petrel	*P. madeira*			x		Critically endangered						X				X		
Soft-plumaged Petrel	*P. mollis*	x	x	x	x	Least concern												
Cahow	*P.cahow*			x		Endangered						X	X			X		
Black-capped Petrel	*P. hasitata*			x		Endangered						X	X			X		
Jamaica Petrel	*P. caribbaea*			x		Critically endangered						X	X			X		
Atlantic Petrel	*P. incerta*			x		Vulnerable						X			X			
White-headed Petrel	*P. lessonii*	x	x	x		Least concern						X						
Magenta Petrel	*P. magentae*	x	x			Critically endangered										X		
Great-winged Petrel	*P. macroptera*	x	x	x	x	Least concern						X						
Providence Petrel	*P. solandri*		x			Vulnerable									X			
Murphy's Petrel	*P. ultima*		x			Near-threatened						X			X			
Mottled Petrel	*P. inexpectata*	x	x			Near-threatened						X			X			
Pytcroft's Petrel	*P. pycrofti*		x			Endangered						X			X			
Stejneger's Petrel	*P. longirostris*		x			Vulnerable						X			X			
Collared Petrel	*P. brevipes*		x			Least concern						X						
Gould's Petrel	*P. leucoptera*		x			Vulnerable						X			X			
Cook's Petrel	*P. cookii*		x			Endangered									X			
Defilippi's Petrel	*P. defilippiana*		x			Vulnerable									X			

Species		**Southern**	**Pacific**	**Atlantic**	**Indian**	**IUCN Conservation Status**	**Threats (IUCN, BirdLife)**											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Bonin Petrel	*P. hypoleuca*		x			Least concern												
White-necked Petrel	*P. cervicalis*		x			Vulnerable									X			
Black-winged Petrel	*P. nigripennis*		x			Least concern						X						
Chattam Island Petrel	*P. axillaris*		x			Critically endangered										X		
Wilson's Storm Petrel	*Oceanites oceanicus*	x	x	x	x	Least concern						X		X				
White-vented Storm Petrel	*O. gracilis*		x			Data deficient										X		
New Zealand Storm Petrel	*O. maorianus*		x			Critically endangered										X		
Grey-backed Storm Petrel	*Garrodia nereis*	x	x	x		Least concern												
White-faced Storm Petrel	*Pelagodroma marina*		x	x	x	Least concern												
Black-bellied Storm Petrel	*Fregetta tropica*	x	x	x	x	Least concern												
White-bellied Storm Petrel	*F. grallaria*		x	x	x	Least concern												
White-throated Storm Petrel	*Nesofregetta fuliginosa*		x			Vulnerable									X			
European Storm Petrel	*Hydrobates pelagicus*			x, M		Least concern						X						
Least Storm Petrel	*Halocyptena microsoma*		x			Least concern												
Wedge-rumped Storm Petrel	*Oceanodroma tethys*		x			Least concern												
Madeiran Storm Petrel	*O. castro*		x	x		Least concern												
Swinhoe's Storm Petrel	*O. monorhis*		x	x	x	Least concern												
Leach's Storm Petrel	*O. leucorhoa*		x	x	x	Least concern						X		X				
Guadalupe Storm Petrel	*O. macrodactyla*		Extinct?			Critically endangered						X			X	X		
Markham's Storm Petrel	*O. markhami*		x			Data deficient												
Tristram's Storm Petrel	*O. tristrami*		x			Near-threatened						X						
Black Storm Petrel	*O. melania*		x			Least concern												
Matsudaira's Storm Petrel	*O. matsudairae*		x		x	Data deficient									X			
Ashy Storm Petrel	*O. homochroa*		x			Near-threatened						X	X	X		X		
Hornby's Storm Petrel	*O. hornbyi*		x			Data deficient							X					
Fork-tailed Storm Petrel	*O. furcata*		x			Least concern						X						
South Georgia Diving Petrel	*Pelecanoides georgicus*	x	x	x		Least concern												
Common Diving Petrel	*P. urinatrix*	x	x	x		Least concern												

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Red-billed Tropicbird	*Phaethon aethereus*		x	x	x	Least concern						X				X		
Red-tailed Tropicbird	*Phaethon rubricauda*		x		x	Least concern												
White-tailed Tropicbird	*Phaethon lepturus*		x	x	x	Least concern												
Northern Gannet	*Morus bassanus*			x		Least concern												
Australian Gannet	*Morus serrator*		x			Least concern												
Blue-footed Booby	*Sula nebouxii*		x			Least concern												
Peruvian Booby	*Sula variegata*		x			Least concern												
Masked Booby	*Sula dactylatra*		x	x	x	Least concern												
Nazca Booby	*Sula granti*		x			Least concern												
Red-footed Booby	*Sula sula*		x	x	x	Least concern												
Brown Booby	*Sula leucogaster*		x	x	x	Least concern												
Abbott's Booby	*Papasula abbotti*				x	Endangered							X		X	X		
European Shag	*Phalacrocorax aristotelis*			x, M		Least concern												
Pelagic Cormorant	*Phalacrocorax pelagicus*		x			Least concern												
Red-faced Cormorant	*Phalacrocorax urile*		x			Least concern												
Imperial Shag	*Phalacrocorax atriceps*	x	x	x		Least concern												
Pygmy Cormorant	*Phalacrocorax pygmeus*			M		Least concern							X					
Ascension Frigatebird	*Fregata aquila*			x		Vulnerable			X			X			X			
Christmas Frigatebird	*Fregata andrewsi*				x	Critically endangered			X									
Magnificent Frigatebird	*Fregata magnificens*		x	x		Least concern												
Great Frigatebird	*Fregata minor*		x	x	x	Least concern												
Lesser Frigatebird	*Fregata ariel*		x	x	x	Least concern												
Grey Phalarope	*Phalaropus fulicaria*		x	x		Least concern												
Red-necked Phalarope	*Phalaropus lobatus*		x	x	x	Least concern												
Great Skua	*Catharacta skua*			x		Least concern												
South Polar Skua	*Catharacta maccormicki*	x	x	x	x	Least concern												
Southern Skua	*Catharacta antarctica*	x	x	x	x	Least concern												
Brown Skua	*Catharacta lonnbergi*	x	x	x	x	Least concern												

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Pomarine Skua	*Stercorarius pomarinus*		x	x	x	Least concern												
Arctic Skua	*Stercorarius parasiticus*		x	x	x	Least concern												
Long-tailed Skua	*Stercorarius longicaudus*		x	x		Least concern												
Audouin's Gull	*Larus audouinii*			x, M		Near-threatened						X	X		X			
Ring-billed Gull	*L. delawarensis*			x		Least concern												
Common Gull	*L. canus*		x	x, M		Least concern												
Mew Gull	*L. brachyrhynchus*		x			Least concern												
Herring Gull	*L. argentatus*			x		Least concern												
American Herring Gull	*L. smithsonianus*		x	x		not listed												
Yellow-legged Gull	*L. michahellis*			x, M		Least concern												
Caspian Gull	*L. cachinnans*			x, M	x	Least concern												
Vega Gull	*L. vegae*		x			not listed												
Lesser Black-backed Gull	*L. graellsii*			x, M		Least concern												
Baltic Gull	*L. fuscus*			M	x	not listed												
Kelp Gull	*L. dominicanus*	x	x	x	x	Least concern												
Slaty-backed Gull	*L. schistisagus*		x			Least concern												
Greater Black-backed Gull	*L. marinus*			x		Least concern												
Glaucus-winged Gull	*L. glaucescens*		x			Least concern												
Glaucus Gull	*L. hyperboreus*		x	x		Least concern												
Iceland Gull	*L. glaucoides*			x		Least concern												
Kumlien's Gull	*L. kumlieni*			x		not listed												
Laughing Gull	*L. atricilla*		x	x		Least concern												
Grey-headed Gull	*L. cirrocephalus*			x	x	Least concern												
Franklin's Gull	*L. pipixcan*		x			Least concern												
Mediterranean Gull	*L. melanocephalus*			M		Least concern												
Brown-hooded Gull	*L. maculipennis*		x	x		Least concern												
Black-headed Gull	*L. ridibundus*		x	x, M	x	Least concern												
Slender-billed Gull	*L. genei*			M		Least concern												
Saunder's Gull	*L. soundersi*		x			Vulnerable							X			X		
Little Gull	*L. minutus*			x, M		Least concern												

Species		**Southern**	**Pacific**	**Atlantic**	**Indian**	**IUCN Conservation Status**	**Threats (IUCN, BirdLife)**											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Swallow-tailed Gull	*Creagrus furcatus*		x			Least concern												
Sabine's Gull	*Xema sabini*		x	x		Least concern												
Ivory Gull	*Pagophila eburnea*		x	x		Near-threatened				X								
Ross' Gull	*Rhodostethia rosea*		x	x		Least concern												
Black-legged Kittiwake	*Rissa tridactyla*		x	x		Least concern												
Red-legged Kittiwake	*R. brevirostris*		x			Vulnerable			X			X						
Aleutian Tern	*Onychoprion aleutica*		x			Least concern												
Sooty Tern	*Onychoprion fuscata*		x	x	x	Least concern												
Bridled Tern	*Onychoprion anaethetus*		x	x	x	Least concern												
Whiskered Tern	*Chlidonias hybrida*		x	M	x	Least concern												
White-winged Black Tern	*C. leucopterus*		x	M		Least concern												
Black Tern	*C. niger*		x	x, M		Least concern												
Gull-billed Tern	*Gelochelidon nilotica*		x	x, M	x	Least concern												
Caspian Tern	*Hydroprogne caspia*		x	x, M	x	Least concern												
Common Tern	*S. hirundo*		x	x, M	x	Least concern												
Arctic Tern	*S. paradisaea*	x	x	x	x	Least concern												
Antarctic Tern	*S. vittata*	x	x	x		Least concern												
Kerguelen Tern	*S. virgata*	x				Near-threatened										X		
Forster's Tern	*S. forsteri*			x		Least concern												
Roseate Tern	*S. dougallii*		x	x	x	Least concern						X	X					
White-fronted Tern	*S. striata*		x			Least concern												
Black-naped Tern	*S. sumatrana*		x		x	Least concern												
Grey-backed Tern	*S. lunata*		x			Least concern												
Fairy Tern	*S. nereis*		x			Least concern						X	X					
Little Tern	*S. albifrons*		x	x, M	x	Least concern												
Saunder's Tern	*S. saundersi*					Least concern												
Crested Tern	*S. bergii*		x		x	Least concern												
Royal Tern	*S. maxima*			x		Least concern												
Lesser Crested Tern	*S. bengalensis*		x		x	Least concern												

Species		Southern	Pacific	Atlantic	Indian	IUCN Conservation Status	Threats (IUCN, BirdLife)											
							Long lining	net entangl	Over fishing	climate change	Distur-bance	intr. pred.	breeding habitat degradation	pollution	restr. breeding range	small population	disease	harvest/ hunt
Elegant Tern	*S. elegans*		x			Near-threatened			X	X					X			
Sandwich Tern	*S. sandvicensis*			x		Least concern												
Cayenne Tern	*S. (sandvicensis) eurygnatha*			x		not listed												
Inca Tern	*Larosterna inca*		x			Near-threatened			X	X								
Grey Noddy	*Procelsterna cerulea*		x			Least concern												
Brown Noddy	*Anous stolidus*		x	x	x	Least concern												
Lesser Noddy	*A. tenuirostris*				x	Least concern							X					
Black Noddy	*A. minutus*		x	x		Least concern												
White Tern	*Gygis alba*		x	x	x	Least concern												
Common Guillemot	*Uria aalge*		x	x		Least concern												
Brunnich's Guillemot	*Uria lomvia*		x	x		Least concern												X
Razorbill	*Alca torda*			x, M		Least concern												
Black Guillemot	*Cepphus grylle*			x		Least concern												
Little Auk	*Alle alle*			x		Least concern												
Ancient Murrelet	*Synthliboramphus antiquus*		x			Least concern												
Japanses Murrelet	*S. wumizusume*		x			Vulnerable		X			X	X				X		
Parakeet Auklet	*Aethia psittacula*		x			Least concern												
Crested Auklet	*A. cristatella*		x			Least concern												
Least Auklet	*A. pusilla*		x			Least concern												
Atlantic Puffin	*Fratercula arctica*			x, M		Least concern												
Horned Puffin	*F. corniculata*		x			Least concern												

15 Marine mammals[52]

15.1 Introduction

Marine mammals are part of marine ecosystems and by definition form part of the biodiversity of the respective systems. Changes in distribution and abundance of marine mammals will therefore influence the biodiversity of the ecosystem they live in. Changes in the distribution and abundance of marine mammals are brought about by responses of marine mammals to human induced or natural changes in their habitat. It is therefore in our opinion appropriate to evaluate the biodiversity of the high seas with respect to marine mammals, by assessing population status and those factors that influence the quality of their habitat.

Marine mammals, like other marine organisms use the seas and oceans in a way that reflects a balance between favourable and non-favourable environmental factors. Favourable habitat characteristics encompass e.g. high density of prey, refuges for breeding, water quality (temperature, chemistry), suitable ice conditions (particularly for ice-associated species), migratory corridors for species with different breeding and feeding grounds. Unfavourable characteristics are e.g. habitat degradation through human activities, and global or regional changes in physical oceanography and ecology (such as loss of ice), particularly in the Arctic, Antarctic and Southern Ocean. Shifts from favourable to unfavourable habitat characteristics determine the impact on marine mammals. This can range from more dangerous, unhealthy, to reduced or completely removed or inaccessible habitat. Marine mammals may react by leaving their preferred area for a less optimal one, or stay and undergo adjustments, both may result in e.g. effects on population size.

Before embarking on the topic of marine mammals and biodiversity at high seas, it seems appropriate to us to indicate which sea mammals we consider to be real marine mammals. These include 34 species of pinnipeds (comprising seals, fur seals, sea lions and walrus), 78 species of cetaceans (comprising whales – toothed and baleen, dolphins and porpoises), and 3 species of sirenians (2 species of manatees and 1 species of dugong). In addition we consider also the polar bear, the sea otter and marine otter being marine mammals. In the context of the high seas, it is obvious that in this chapter the focus will be more on oceanic species compared to the coastal and shelf sea dwelling species. However, where relevant the latter will be included in the discussion as well.

In recent literature on responses of marine top predators to environmental variability, marine mammals have been shown to be good indicators for local environmental conditions (Reilly 1990, Reilly and Fiedler 1994, Redfern et al. 2006). Consequently marine mammalogists have started to investigate the possibility of studying environmental changes by deploying instruments on marine mammals. These instruments record simultaneously e.g. movements, diving behaviour, and in situ oceanographic features such as vertical salinity and water temperature. An elegant example of the power of this approach is given by the multi-national research on southern elephant seals, linking their behaviour and condition to oceanographic conditions (Biuw et al. 2007). Within the scope of this chapter, we will not address this aspect further, but emphasise that for monitoring of future changes in biodiversity of high seas, marine mammals provide a useful tool to be used in research and for management purposes.

In this chapter we explore how the biodiversity status of the high seas with respect to marine mammals is determined, by discussing the different worldwide threats and population status of marine mammals. These include: historic and present whaling, bycatch (entanglement) in fisheries, prey depletion, pollution, noise, ship strikes, whale watching, and climate change. It could be argued that sealing should also be included here, since it is known that some pinniped species (Antarctic, Guadalupe and Juan Fernández fur seal, and northern elephant seal) have become virtually extinct by excessive exploitation (see Reijnders et al. 1993). However, most pinniped species are coastal (with some notable exceptions such as elephant seals and fur

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seals) and not really high seas inhabitants, and that most of the reported present catches are relative low compared to the size of the population from which they are taken, therefore we have left sealing out.

15.2 Historic and present whaling

The earliest records of whaling date back to the 9th century when Norsemen of northwestern Europe hunted whales. Somewhat later (11th century) the Basques started hunting in the Bay of Biscay (Allen 1990). These activities can still be considered as subsistence hunting. Gradually whaling spread north- and eastwards and in the 16th century when the Basques hunted in Greenland, and their hunt developed into real commercial whaling. From 1600 onwards, Dutch whalers became active, quickly followed by British whalers. By the end of the 20th century whaling collapsed in this region, as the whales were depleted.

Some whaling on the eastcoast of North America started from the 1600s onwards. In the 18th century New England whalers moved southwards in the Atlantic and around Cape Horn into the Pacific. In the first half of the 19th century, whaling took place in the cooler waters of the South Pacific (New Zealand, Australia and Kerguelen Islands) and from the 2nd half of the 19th century in the North Pacific (e.g the Bering Sea). In this era Hawaii became a major whaling base with 500-800 ships (Slijper 1962).

The whaling in Japan developed independently from around 1600 onwards.

In the late 19th century, whaling became much more efficient by technical developments such as steam powered ships, enabling the hunting of the faster swimming blue and fin whales, and of the explosive harpoon. Until then, whaling was mainly limited to the relative slow sperm, humpback, gray, right and bowhead whales, that were pursued by sail and oar. The new technology, coupled with the depletion of whales in the North, led to the spread of hunting to the Antarctic, where huge feeding aggregates of whales made large scale whaling very profitable for another 60 years or so. In the first decades of the 1900s, about half of the world's annual catch was realized in the Southern Ocean, and South Georgia became the major centre of whaling operations housing processing in plants ashore or harbouring factory ships in its sheltered bays. With the introduction of the modern pelagic factory ships, with a slipway via which whales could be hauled onboard, whaling built up very quickly. In 1937-1938, for example, about 46,000 whales were taken. After a dip during World War II, catches did not really reach the pre-war level again, but between 1947 and 1965 annual catches still fluctuated around 30,000 whales (Bureau of International Whaling Statistics, Norway, established in 1930).

Whaling operations had a devastating effect on the world's whale stocks. Characteristic was the fact that the focus gradually shifted from hunting valuable and easy to catch species, to less attractive ones, because the stocks of original targets became depleted. In the North Atlantic stocks of right and bowhead whales were depleted by the end of the 18th century. Right whales nowadays are considered to be extinct in this region. In the southern hemisphere, right and bowhead whales decreased in a similar manner as bowheads in the North Atlantic. Sperm whaling also virtually stopped in that period, but it is unclear whether this was driven by the depletion of the stocks and/or the demand for oil lessened. However, as mentioned afore, due to technical developments there was a revival of whaling, particularly in the Antarctic. Pelagic whaling started in the North Pacific only in 1950.

A clear example of the devastating effect of whaling is given by the catch statistics of baleen whales in the southern hemisphere (Figure 15.1). A sequence of species taken can be observed: first blue whale catches dominated, followed by fin whales, humpback whales, sei whales, and finally the tiny minke whales. A similar story can be told for the 1947-1977 catches in the North Pacific.

By about 1925, whaling nations recognised that whales were overexploited and a need for regulating whaling became evident. Several attempts were made to come to restraints, with limited success. An International Convention for the Regulation of Whaling (ICRW) was established in 1937, but only survived for one year. Finally in 1948, the ICRW came into force, and from then onwards, whaling has been regulated by the International Whaling Commission (IWC).

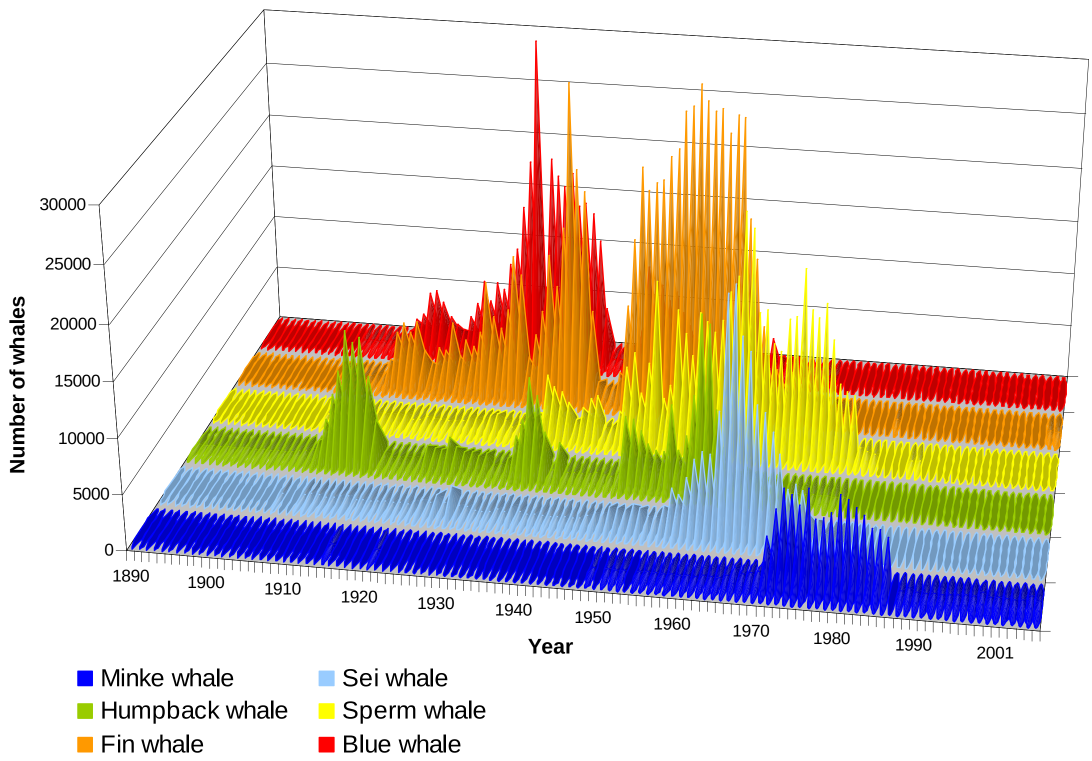

Figure 15.1 Catches of baleen whales in the southern hemisphere.

A relevant question with respect to whaling is how far have whale stocks been overexploited, or how do the present stock/population levels relate to the pre-exploitation levels? It is generally accepted that due to intensive overexploitation, many populations have been reduced to small fractions of their original size (Clapham et al. 1999, Reeves and Smith 2006). However, accurate estimates of both pre-exploitation and present abundance of populations are largely lacking. The major sources for historical reconstruction of whale populations' abundance are catch statistics and indirect information such as records on landed oil and baleen (Tillman and Donovan 1983, Reeves and Smith 2006). The key source from which historic whaling catches can be derived from, is the whaling voyage logbooks (Sherman 1983). But despite the fact that catch statistics are kept, it is obvious that these do not necessarily reflect the true numbers. Revelations of e.g. illegal catches by the Soviet Union indicate that the Soviets took in excess of 100,000 whales in the Antarctic than they reported to the IWC (Yablokov 1994, Yablokov et al. 1998).

Despite the fact that our knowledge on the present status of the word's large whale populations varies considerably from species to species, it is considered that the prospect for the majority of them is probably good. For example humpback whales, in spite of their catch history - they were hunted down to less than 10% of their original size - are strongly recovering (Clapham et al. 1999). It is generally thought that fin, sei, minke and Brydes whales have somewhat recovered and are abundant throughout much of their ranges. However, the observed increase does not automatically imply that their status is satisfactory. They are slow breeders and full recovery may take a century. Estimates for some whale populations in the southern hemisphere indicate that fin and sei whale numbers are still less than 10% of the pre-whaling population levels, and humpback whales have recovered to no more than 20% (Olavarria et al. 2007). Albeit some populations are recovering strongly, e.g. eastern Pacific gray whales are back at their pre-exploitation levels, some populations are still highly endangered given their low abundance. These include the northern right whale: numbering only tens in the eastern North Pacific, 300 in the western North Pacific, extinct in the eastern North Atlantic; the bowhead whale: about 450 in the Davis Strait/Hudson, tens in Spitsbergen/Barents Sea and low hundreds in the Okhotsk Sea; the gray whale: extinct in the Atlantic, and about 250 in Korea/Okhotsk Sea; blue whale: only 1-2% of its pre-whaling population level. There are no reliable estimates available on the blue whale, but there are indications that the stocks are still small. One exception being the blue whale population in the eastern North Pacific. This shows an increasing trend and numbers about 2000 animals (Calambokidis and Steiger 1995).

Besides the ongoing impact of historic whaling on whale stocks, significant numbers are still hunted today (Figure 15.2), despite the Moratorium on commercial whaling established by the IWC in 1986. There are three forms of present whale hunting: 1) commercial whaling as carried out by Norway and Iceland, 2) aboriginal subsistence whaling carried out by indigenous people such as the Inuit (Canada, Greenland, USA, Siberia), and 3) scientific whaling. The number of whales taken continues to increase over the years, and in some cases prevent recovery of endangered populations (Clapham et al. 1999). Aboriginal subsistence whaling receives broad support in the IWC, and quotas are set in the context of reaching a balance between the cultural and developmental rights of native peoples and the need to protect whales. It is basically accepted that recovery of some depleted stocks is slowed down, however, not to the extent that it endangers the stock in question.

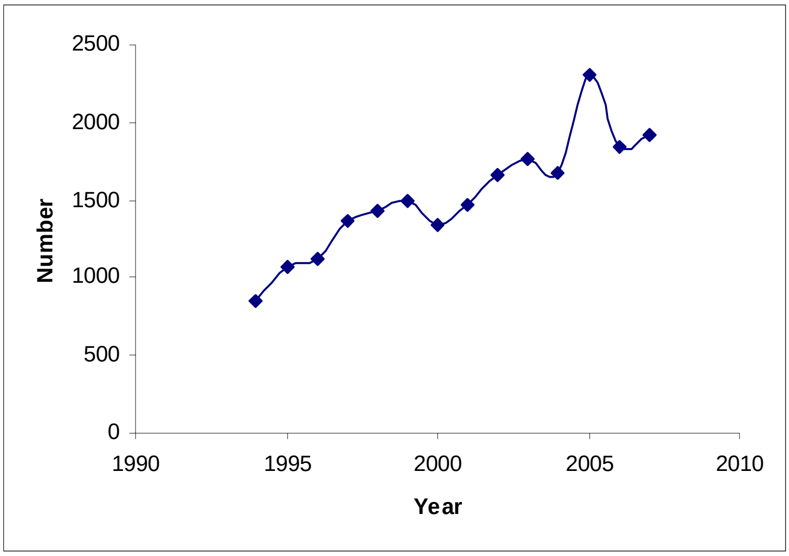

Figure 15.2 Number of whales killed in recent commercial, aboriginal subsistence, and scientific whaling activities.

Commercial whaling by Norway is legally correct, viz. within the provisions of the ICRW, as they lodged an objection to the Moratorium. Present levels of minke whales taken by Norway in the northeast Atlantic are within the accepted range of quotas the IWC would have set, if the Moratorium would not have been in place and the Revised Management Scheme had been applied.

Scientific whaling as practiced by Japan and to a much lesser extent by Iceland, is very controversial. These countries make use of a loophole in the Whaling Convention, by applying a provision in the ICRW that entitles Contracting Parties to issue Special Permits. These permits can be issued for the taking of whales for scientific research, if that is necessary for the management of the whales. It is beyond the context of this paper to discuss in details the heated debate in the IWC on this issue. Suffice to say that the whaling issue debate not so much addresses the question of whale abundance, but is rather a serious critique to Japan for its poor use of science, imperfect stock assessments, and the untenable argument that culling is a good way to manage marine mammal populations in order to protect fisheries (Gales et al. 2005, Morishita 2006, Clapham et al 2006).

It is obvious that from a biodiversity point of view, it is critical that whale populations are restored. All whaling, commercial, aboriginal subsistence, and scientific, has to be scrutinised for its effect on the recovery of formerly overexploited stocks, based on the precautionary principle. A framework is e.g. given in Baker and Clapham (2004). It should be realised that whaling is only one of the several factors posing a threat to populations, the cumulative impact thereof is of particular concern for those populations that are already vulnerable due to their small size.

15.3 Incidental take

Bycatch of marine mammals is worldwide considered as one of the major threats to them, and probably one of the greatest and most pervasive threats to the entire marine environment. Bycatch occurs everywhere in all fisheries, particularly in fixed fishing gear such as gill nets, set nets, trammel nets, and to a lesser extent in seines and trawling nets (Perrin et al. 1994). Data from bycatch observer programmes and FAO data on fleet composition and fisheries landings have been used to estimate the global bycatch of marine mammals (Read et al. 2004). In the period 1990-1999, the estimated mean annual bycatch of cetaceans was approximately 308,000 and of pinnipeds approximately 346,000. It was concluded that the vast majority (98%) of all bycatches of the world's cetaceans and pinnipeds occurs in gillnet fisheries.

Estimates of the extent of bycatch are very relevant to assess the impact on the affected stock or population. At least 20 species of pinnipeds are known to be caught incidentally during fishing operations (Woodley and Lavigne 1991). Such catches appear to have contributed to the decline of several species such as northern fur seal, Kuril seal, and the Steller sea lion in the North Pacific. But data are generally insufficient to evaluate the impact on populations. The situation is different for cetaceans where bycatches are shown to significantly affect the demography of populations and even bring some species close to extinction (IWC 1997a, D'Agrossa et al. 2000, Reeves et al. 2003). The problem of bycatch, particularly in cetaceans, was recognised by management authorities and bycatch reduction measures were introduced e.g. in US fisheries. It was found that mitigation measures reduced bycatches of marine mammals by 40% between 1990 and 1999. This was almost entirely attributable to a reduction in the bycatch of cetaceans, which decreased by almost two-thirds. Some of this reduced cetacean bycatch was due to take reduction conservation measures (Bache 2001, Young 2001).

A most remarkable success was obtained in the reduction of dolphin bycatch in tuna purse seine fisheries in the Pacific. Here the number of bycaught animals was reduced to 2% of the catches before the reduction scheme came into place. This is a good example of an effective conservation measure, while maintaining viable fisheries (Hall 1998). However, it has to be emphasized that some of the reduced bycatch may also have come from reduced fishing effort brought about by the collapse of important fish stocks. For example bycatch of harbour porpoises and catches of Atlantic cod in New England (Read et al. 2004). A similar phenomenon was observed in the North Sea, where reduced fishing effort is suggested to have contributed to the halving of the bycatch of porpoises in Danish North Sea fisheries (Vinther and Larssen 2002). It is obvious that bycatch of marine mammals is a serious threat and that this problem can only be solved by co-operation between the fisheries industry, management authorities and scientists to develop and implement several mitigation measures including time-area closures, use of acoustic alarms (pingers), escape grids in nets, improved detectability of nets, as well as adjustments in fishing gear (e.g. different long line hooks). These measures should not be generic, but tailor made on a case by case basis.

15.4 Prey depletion – food competition

There is ample scientific literature on the ever increasing intensity of overfishing on the marine ecosystem (Jackson et al. 2001, Meyers and Worm 2003, Pauly 2007). Particularly the sequential depletion of harvested species poses a serious ecological risk (Berkes et al. 2006, Jørgensen et al. 2007). Examples where marine mammals were involved are e.g. sea otters at Aleutian Islands (Steneck et al. 2002), grey seals in Canada (Mohn and Bowen 1996, Frank et al. 2005) and right, sei, humpback and fin whales (Payne et al. 1990). Some examples show that shifts in foodwebs are not necessarily bad for all marine mammals, some may suffer while others will benefit (e.g. the grey seal and the four baleen whale species). Despite these and other known associations, it has to be noted that detailed information on the impact of reduced food availability due to overfishing is not available. In our view, the often stated postulation that marine mammals will face considerable difficulties in the future because the state of the world's fisheries is not looking good (given an estimated 75% of fish stocks being classified as either overfished or fished at the maximum, Pauly 2007), can not be substantiated. At the same token, the poor fish stocks status has often fuelled the view that marine mammals are in competition with fisheries, which is neither supported by solid scientific evidence. The reason for this lack of causality is that the ecological interactions in marine ecosystems and the role of marine mammals therein, is complex (see e.g. Beddington et al. 1985, Lavigne 1995). This is i.a. demonstrated by two studies related to the perception that a cull of marine mammals should be carried out to benefit fisheries. Lavigne (1995) noted that there has never been a single demonstrated case of competition in the ecological sense between a population of marine mammals and a commercial fishery. Butterworth et al. (1988) concluded that that there has never been a cull of marine mammals from which benefits to a fishery have been demonstrated. On the contrary, Punt and Butterworth (1995) showed that a cull of fur seals in Benguela (South Africa) could be detrimental to the hake fishery.

A different way to investigate the question of food competition between marine mammals and fisheries is the research by Kaschner and Pauly (2004). They modelled the degree of ecological resource overlap on a global scale. They generated estimates of global and regional food consumption by marine mammals and compared that with fisheries catches. The results indicate that marine mammals' consumption exceeded global fisheries catches. However, when they incorporated the types of food taken by marine mammals, it proved that most of the food consisted of prey species not targeted by fisheries. They also showed that there was little geographical overlap between marine mammals and fisheries. Actually less than 1% of all food consumed by any marine mammal species group (whales, dolphins, porpoises, pinnipeds) comes from areas of high overlap between marine mammals and fisheries. Similarly more than 85% of all fisheries operate in low overlap areas. Only in some small areas in the northern hemisphere the overlap is high, and primarily between pinnipeds and fisheries. The overall conclusion is that there is no evidence that food competition between marine mammals and fisheries is a global problem.

A different form of human induced fish stock depletion affecting marine mammals is displacement of animals out of their normal habitat, in search of food. The crash of the capelin stock in the Barents Sea, presumably through overfishing by the Soviet fleet, had immediate repercussions throughout the food web (Hamre 1994). The most dramatic was the drowning of over 80,000 starving harp seals in fishing nets, when they moved southwards out of the Barents Sea (Haugh et al. 1991).

15.5 Pollution

Environmental pollution incorporates several substances, including chemical compounds (inorganic such as phosphates, nitrates, trace metals, radionuclides, and organic e.g. pesticides, chlorinated hydrocarbons including PCBs, DDT, dioxins, PBBs, PCDFs, PBDEs), oil pollution derived substances, marine debris, and sewage related pathogens. Marine mammals are exposed to these compounds which can affect their health status. Clear cause and effect relationships between pollutants and marine mammals have only been demonstrated in a few cases: reproductive failure in harbour seals from the Netherlands (Reijnders 1986), reproductive impairment in Baltic grey and ringed seals (Helle 1980, Olsson et al. 1994). Pollutants have also been suggested to lower immunocompetence in seals and dolphins, thereby aggravating die-offs in dolphins (Aguilar and Borrell 1994, Lipscomb 1994) and seals (Dietz et al. 1989). It was indeed demonstrated in experimental studies with harbour seals that a diet of fish from polluted coastal waters led to immune suppression (Swart et al. 1994), and Jepson et al. (2005) unravelled the complex relation between PCB exposure and the health status in harbour porpoises stranded in the United Kingdom. His findings are consistent with a causal immunotoxic relationship between PCB exposure and infectious disease mortality. However, the ecological significance of the outcome of these studies in terms of increased disease susceptibility leading to lower individual survival, let alone survival at the population level, remains unclear. In order to make progress in adequately addressing the impact of pollutants on marine mammals, it is clear that a considerable amount of fundamental research is needed (Reijnders and Aguilar 2002). One such initiative is a programme “POLLUTION2000+” carried out under the auspices of the International Whaling Commission (Reijnders et al. 1999, Reijnders and Aguilar 2002). One of the studies in that programme showed through individual based modelling that the existing levels of PCBs in bottlenose dolphins from Sarasota bay (USA) led to lower calf survival and hampered population growth by 3.6% (Hall et al. 2006).

Exposure of marine mammals to contaminants differs regionally. Contamination by trace elements and organochlorines (OCs) are generally higher in marine mammals feeding in or close to polluted coastal waters. There are exceptions however, as relative high levels of e.g. cadmium have been found in belugas and narwhals from the Arctic (Muir et al. 1999). There is an overall trend that marine mammals in the northern hemisphere have accumulated higher concentrations than those in the southern hemisphere. The highest levels are found in the mid-latitudes of the northern hemisphere, which is attributed to the past production and use in the industrialised countries in that part of the world (Reijnders 1996, Reijnders and Aguilar 2002). However, this trend is gradually changing due to a continued use of e.g. organochlorine pesticides in developing countries. A low sinking rate in tropical waters and atmospheric transport to e.g. the Arctic and to some extent the Antarctic, causes global redistribution. It was predicted that particularly the Arctic waters and adjacent seas and oceans would become the major sink for OCs (Tanabe et al. 1994). However, recent studies show that concentrations of most highly persistent OCs significantly declined in Canadian Arctic biota including marine mammals (Muir et al. 1999). The overall temporal trend for PCBs and DDT levels in marine mammals is that concentrations have decreased since the mid-1970s, with a stronger decline for DDTs (Borrell and Reijnders 1999). DDT levels continued to decrease contrary to PCB levels which in some areas leveled off in the mid-1980s but are also declining now (Reijnders et al. 2008).

One aspect deserving attention in the context of this paper is the potential adverse effects of oil pollution. Increasing shipping, including fisheries, perhaps enhanced by more access to (Ant)Arctic waters due to climate change, may bring about higher risks of oil spills. It is generally accepted that fur-bearing marine mammals such as sea otters, fur seals, polar bear, are most vulnerable, as these substances can destroy the animals’ ability to maintain thermal balance. Reviews in the literature on impacts of oil on marine mammals reveal that our knowledge on this subject is rather poor. Some studies indicate that most marine mammals do not ingest much oil and avoid oil slicks, others are more cautious and state that baleen whales are the most vulnerable amongst cetaceans (Geraci and St Aubin 1990). A clear example of how fatal an oil spill can be is given by the incident with the Exxon Valdez in 1989 in Prince William Sound, Alaska. Particularly sea otters were hit, 3500-5500 animals died, but also 300 harbour seals (Loughlin 1994). It is concluded that chronic effects of this spill are still operative as in the decade after that spill, the affected population grew far below the growth rate observed prior to the spill.

It may be prudently concluded that marine mammals frequenting restricted areas such as bays and estuaries are at higher risks than the more oceanic species. However, the long term ecosystem response to the Exxon Valdez oil spill learned that assessing chronic, long term ecological risks of oil in the oceans, require ecosystem based risk analyses including cascades of indirect effects (Peterson et al. 2003).

15.6 Noise pollution

For some time, the scientific community, general public and management authorities have become increasingly aware of the potential detrimental effects of marine noise pollution on mammals. Marine mammals, and in particular cetaceans, rely very much on sound as their primary sense for communication and finding their way in the ocean. Toothed whales produce sounds (mid- and high frequencies) and receive the echoes coming back from objects in their environment. They receive clues on the environment around them by echolocation and they use sound in particular for detecting and catching prey. Baleen whales are known to produce low frequency calls for orientation and navigation. Call echoes provide them with information on e.g. characteristics of the sea bed, continental shelf, submarine mountain range, ice-edge).

Unfortunately, many man-made underwater sounds are also produced at low frequencies. Human generated noise comes from various sources including large commercial ships, ice-breakers, airguns, military sonar, ship-mounted sonar, acoustic harassment devices, and offshore drilling implements. In addition, underwater sound is also produced by natural occurrences including earth quakes, rainfall, wind-generated waves, currents and turbulence. It is clear that noise levels in the seas have steadily increased already since the onset of industrialisation in the mid-19th century. Long term studies of trends in ocean noise levels reveal increases of approximately 3-5 dB per decade (Andrew et al. 2002), corresponding to a doubling of noise power (3dB) every decade for the past six decades (NRC 2003).

Noise can impact marine mammals in different ways ranging from interfering with their detection of biologically important sounds, disturbing their behaviour to impairing hearing abilities and even death. The impacts of acoustic disturbance on cetaceans can be classified in direct and indirect effects. Direct effects are e.g. physical damage to the ear (temporary or permanent threshold shift) or to body tissue (gas bubble lesions in lung, liver), behavioural effects like displacement from an area, perceptual effects such as masking of communication and perception of the environment. Those direct effects will induce or bring about indirect effects including disruption of social behaviour, reduced prey detection possibilities, chronic stress, increased vulnerability to predation, increased risk for entanglement and collision with ships (see e.g. Ketten 2005, Hildebrand 2005, Simmonds et al. 2004, Dolman and Simmonds 2005, 2006).

There is a vast amount of literature on the impact of man-made noise on marine mammals as deduced from observed reactions of free ranging cetaceans to boat traffic and shipping noise, to seismic surveys and to the use of low frequency active sonar (see e.g. Richardson et al. 1995, IWC 2005, Simmonds et al. 2004). Nevertheless, it is fair to conclude that our knowledge on the impact of noise on marine mammals is still poor. An exception are the studies investigating incidents of cetacean mass strandings associated with high-intensity sound. Increased incidences of multi-animal beaked whale strandings correlate with naval manoeuvres (Greece 1996, Bahamas 2000, Canary Islands 2002, and Gulf of California 2002). The formation of air emboli in tissues of Cuviers beaked whale, either due to behavioural response or directly induced by sound, are a likely hypothesis in explaining the observed strandings (Jepson et al. 2003, Fernández et al. 2004). We therefore conclude that the increasing levels of man-made noise in the oceans could represent an increasingly serious threat to marine mammals and should therefore be taken into account in environmental impact assessments of noise producing activities in the marine environment, including the high seas. A framework to address this issue is provided in NRC (2003).

15.7 Ship strikes

Collisions between ships and marine mammals are mainly reported for cetaceans, and in particular large whales (Laist *et al.* 2001). In this section we restrict ourselves to large whales. It is evident that ship strikes to large whales occur worldwide. Records show that they occur e.g. in waters of Antarctica, Panama, Peru, Brazil, North America, South Africa and the Mediterranean (Jensen and Silber 2004). Collisions between ships and whales are obviously more common than previously thought, due to being undetected or unreported. With this in mind, it is clear that available databases can only be a minimum account of ship strikes to whales. In addition, data on vessel type and speed, geographical distribution, and fatality involved whales are incomplete and should be interpreted with caution. Taking this into account, it appears from the available records that in particular fin whales are hit most frequently, followed by northern and southern right whales, gray whales and humpback whales (Laist *et al.* 2001, Jensen and Silber 2004). The main source of severe injury or death to whales is attributed to large vessels.

It is unknown what percentage of animals struck were fatally injured. Nevertheless there is no doubt that for some highly endangered populations, ship strikes cause significant losses. This is well documented for the small populations (numbering in the low hundreds) of northern right whales in the western North Atlantic and western North Pacific, and for the western North Pacific gray whales. These species are slow swimmers rendering them extra vulnerable to collisions. Despite the fact that reported figures may not reflect the true story, they are considered a real threat to endangered species, in particular the right whale (Kraus *et al.* 2005).

US authorities have taken measures to reduce the threat of ship strikes to right whales. These hold for the US east-coast, and include realigning the traffic separation scheme, recommended routes, ship speed advisories and regulations, areas to be avoided, mariners training (Anonymous 2007).

It is concluded that the development of an international database of vessel strikes is necessary to make any progress in assessing the extent of impact of vessel strikes to cetaceans and to develop mitigation measures. It seems appropriate to liaise with the International Maritime Organisation to obtain relevant information from them and to facilitate implementation of conservation measures.

15.8 Whale watching

Whale watching is being viewed as a benign activity with welcomed educational, conservation and socio-economic benefits. This industry was valued over 1 billion US$ annually, and more than 9 million participants from 87 countries (Hoyt 2001). It is not yet considered a real threat compared to e.g. whaling, pollution, and bycatch. However, the industry is growing so fast both in numbers and geographical extension, and with the expected strong increase of visitors to Antarctica and surrounding waters we thought it justified to mention here some connected adverse effects, including confirmed incidents of collisions between whale watching boats and cetaceans, short term behavioural disruptions such as changes in diving behaviour, changes in acoustic and resting behaviour, and avoidance of particular areas (Clark et al. 2007). These short term effects been described in several studies, but it proved to be very difficult to quantify the ecological significance of such effects (Lusseau 2004). A modelling study demonstrated that longer term population level effects of whale watching are theoretically possible (Lusseau et al. 2006).

In order to mitigate or prevent the possible impact of whale watching on free ranging cetaceans, globally initiatives have been undertaken to design whale watching guidelines and regulations. Since 1995 the collection of information on whale watching regulations and guidelines around the world has been carried out and an updated report was produced by Carlson (2000). This report has been used by governments and organisations to develop whale watching guidelines on national and regional levels. This is evidently an ongoing process, and improvements will have to be made by assessing the effectiveness of the policies and the adjustments of the guidelines when information of studies on impact of whale watching becomes available.

15.9 Climate change

There is now unequivocal evidence that climate change is occurring (IPCC 2007) and that its impact will become clear in the marine environment as well (IPCC 2001, 2007). Expected changes in the marine environment are e.g. freshening (decreasing salinity) of sea water, sea level rise, sea water temperature change, ocean acidification, and loss of sea-ice. This combination of changes will lead to shifts in the composition and functioning of marine systems. Crucial is the question if these changes and particularly the direction thereof, can be predicted, in order to develop anticipatory management. Predicting the consequences of climate change for marine mammals is extremely problematic as changes in the food web will exert different effects in different species. It is obvious that the long-lived highly specialised species not capable of quick adaptation will be under serious pressure. Other species are more opportunistic and therefore more flexible. Species living in a relative restricted habitat (e.g. white-beaked dolphins as cold water species) will face a reduced range. The same holds for species living in the northern Indian Ocean, where they can not easily move northwards in search of cooler habitats. Marine mammals exhibiting specialised feeding habits will be more susceptible to changes in food webs (Learmonth et al. 2006). Many cetacean species concentrate spatially and temporally in areas where they expect to find high prey concentrations and changes in prey distribution (timely and in density) can seriously affect those marine mammals. There is general agreement that climate change will be most prominent (largest and rapid) in the Arctic, Antarctic and Southern Ocean (IPCC 2001). The impact of temperature changes on Arctic marine mammal habitat is i.a. described by Tynan and DeMaster 1997, Simmonds and Isaac 2007). An elegant paper on Arctic marine mammals and climate change, with a focus on impacts and resilience, has been produced by Moore and Huntingdon (2008).

Food webs of importance to marine mammals e.g. in the Arctic, are dependent on ice-related production and associated amphipod and fish fauna (Gulliksen and Lønne 1989). The reduction in the extent of sea-ice will likely impact ice-associated marine mammals. Beluga whales are one of the species associated with heavy ice cover (feeding on ice-associated Arctic cod). Narwhals actually live in the pack-ice (Moore et al. 2000). Pinnipeds depending on ice as a platform for resting, whelping and suckling, and polar bears needing ice as a platform for hunting seals, will be affected in different ways when ice becomes a less suitable habitat with respect to those functions. In several cases the result of reduced sea-ice is difficult to predict. Reduced ice-cover could expand foraging opportunities for bowhead whales, but it is unclear whether they will benefit as they may be heat intolerant (IWC 1997b, Bannister 2002). If they are able to visit their feeding grounds for longer periods, their food (eupausiids and copepods) has less time left to recover from predation compared to former long winter periods with absence of predators.

It has also been observed that temperature increase is not uniform and may influence the timing and location of polynyas. These are locations in the pack-ice, almost clear of ice due to e.g. upwelling and windpatterns. These polynyas are critical for many species such as minke whales in the Antarctic and typically for belugas, narwhals and bowhead whales to breathe and feed (Heide-Jørgensen and Laidre 2004). For example sea-ice in the Baffin Bay increased between 1950-2000, resulting in less open water (polynyas). It is suggested that wintering narwhals there may experience a high risk of becoming entrapped and die (Laidre and Heide-Jørgensen 2005).

The IPCC (2001) stated that climate change is likely to produce long-term effects in the physical oceanography and ecology of the Antarctic and Southern Ocean. Reductions in sea-ice extent will cause alterations in the productivity of this ecosystem. The effect will be exerted through changes in under-ice biota (algae) and subsequently krill abundance and distribution. The Southern Ocean supports one fifth of the world's cetacean species (eight species of baleen whales feed almost entirely on krill) and the most abundant pinniped the crabeater seal (numbering 12 million animals, Reijnders et al. 1993) which is also nearly exclusively a krill eater Changes in the food web, especially krill, will have a significant impact on those species. Reasons for concern are that krill populations have decreased e.g. by 80% in the Scotia Sea since the 1970s and are linked with loss of winter sea-ice (Atkinson et al. 2004). In addition, it was found that the biomass of krill in the 1990s to support land based krill-eating predators such as seals and penguins, was insufficient (Reid and Croxall 2001). A similar conclusion was reached for southern right whales (Leaper et al. 2006).

Less sea-ice can also have another, more indirect effect on marine mammals. As the extent of ice-cover in the Arctic decreases, there will be greater opportunities for human use and exploitation of formerly inaccessible areas. The Northwest Passage will be more used than at present, bringing about more disturbances for marine mammals in the Canadian Arctic, and indirectly a higher risk for chemical pollution and collisions of ships and marine mammals. Apart from commercial shipping, also fishing will intensify as well as oil and gas exploration and exploitation.

15.10 Concluding remarks

In this section we provide a brief concluding summary of the aspects discussed in the previous sections on different threats.

historic and present whaling

Historic whaling, particularly in the 20th century, has had a devastating effect on many baleen whale populations. Some have recovered, others (e.g. the southern hemisphere fin, sei and humpback whales), are still only 10-20% of their pre-whaling size. The largest species, the blue whale, is still only 1-2% of its pre-whaling population level. Full recovery of the baleen whales, being slow breeders, may take a century. It is important from a biodiversity point of view, that whale populations are restored. Consequently, all whaling, whether commercial, aboriginal subsistence or scientific, has to be scrutinised for its effects on formerly overexploited stocks, based on the precautionary principle.

incidental take

Incidental take, or bycatch, of marine mammals in fisheries is considered one of the major worldwide threats. Bycatch occurs in several fisheries but the vast majority (98%) happens in gillnet fisheries.

Assessment of the impact on pinniped populations is generally prevented due to insufficient data, despite the fact that some catches appear to have contributed to the decline of many species e.g. the northern fur seal, Kuril seal, the Steller sea lion in the North Pacific, and the New Zeeland fur seal.

The situation is different for cetaceans. Here bycatches have been shown to significantly affect the demography of populations and have brought some close to extinction.

Mitigation measures, including time-area closures, use of acoustic alarms (pingers), escape grids in nets, improved detectability of nets, as well as switch in fishing gear, have been shown to considerably reduce bycatch in dolphins and porpoises. These measures cannot be applied generically but necessitate tailor made solutions on a case by case basis.

prey depletion – food competition

Prey depletion and particularly competition for fish between marine mammals and fisheries is perceived worldwide as a serious problem. However, with the exception of some catastrophic events such as the massive drowning of harp seal in fyke nets due to their displacement as a consequence of overfishing of capelin stocks in the Barents Sea, clear evidence for either interaction is not available. We conclude that the often stated postulation that marine mammals will suffer from food shortage because of the worse state of the worlds fish stocks, 75% being overfished or fished at the maximum, cannot be substantiated.

At the same token, the often fuelled view that marine mammals are responsible for the poor fish stock status is equally not supported by solid scientific evidence.

The overall conclusion is that there are some small areas in the northern hemisphere where there is a high overlap in resources between pinnipeds and fisheries. However there is no evidence that competition for prey between marine mammals and fisheries is a global problem. The absence of proof for causality is partly caused by the lack of knowledge to fully comprehend the ecological interactions in marine ecosystems and the role of marine mammals therein.

pollution

Exposure of marine mammals to contaminants differs globally. Generally marine mammals in the northern hemisphere have accumulated higher concentrations than those in the southern hemisphere. Many studies have revealed high concentrations of organochlorines (OCs) and heavy metals in pinniped and cetacean tissues. However, only a limited number of studies proved a clear cause and effect relationship between high levels of specific compounds and the observed effects such as reproductive failure, pathological disorders and lowered immuno-competence. Despite the numerous eco-toxicological studies we conclude that that a considerable amount of fundamental research is needed to adequately address the impact of pollution on marine mammals, including the extrapolation of effects found in the individual animals to consequences at the population level.

It has been shown that levels of the highly persistent OCs in tissues of marine mammals in the northern hemisphere have declined since the mid-1970s, and are still declining.

Oil pollution is one form of pollution posing a threat to marine mammals. The effects of oil spills are still operative decades after the accident. Given the potential increased access to (Ant)Arctic waters due to climate change, bringing about a higher risk for oil spills, deserves special attention both in management, and in research on ecological risks of oil in oceans.

noise pollution

There is an increasing awareness amongst environmental policy makers and scientists of the potential detrimental effects of noise pollution on marine mammals. Particularly cetaceans rely very much on sound as their primary sense for communication, search for food and orientation in the ocean. Noise levels in the seas have increased significantly since the start of industrialisation in the mid-19th century. An average increase in ocean noise levels of 3-5 dB per decade has been observed, corresponding to a doubling of noise power (3dB) per decade in the past six decades.

Also for this threat we conclude that our knowledge on the impact of noise on marine mammals is still poor. It is therefore emphasised that in environmental impact assessment studies for all noise producing activities in the marine environment (incl. high seas), investigations on the effects of noise on marine mammals should have a high profile.

ship strikes

Collissions between ships and whales form a larger problem for these marine mammals than hitherto realised. Particularly highly endangered species such as the northern right whale, cannot sustain the significant losses due to fatal injuries by collisions with vessels. The US has taken steps to reduce this threat and these ship strike recduction actions have been adopted by the International Maritime Organisation. It is considered necessary that an international database of vessel strikes is developed in order to make any progress in assessing the extent of impact on cetacean populations and to design efficient mitigation measures.

whale watching

Whale watching is viewed upon as a benign activity with welcomed educational, conservation and socio-economic benefits. It is a very fast growing industry and not yet considered a real threat to marine mammals compared to e.g. pollution, whaling, and bycatch. Nevertheless, some adverse short term effects have been identified and we therefore endorse the global initiatives to design whale watching guidelines and regulations to mitigate or prevent negative effects of this activity on free ranging cetaceans.

climate change

Climate change is considered to have an effect on the marine environment through freshening of sea water, sea level rise, sea water temperature change, ocean acidification, and loss of sea-ice. This combination of changes will lead to shifts in the composition and functioning of marine systems. It is still extremely problematic to predict the consequences of climate change for marine mammals, as changes in the food web will exert different effects in different species. It is obvious that marine mammals in the polar regions will face the most prominent changes (extent and rate), as they are dependent on ice-related production and/or ice-associated for breeding and hunting. A special aspect in this context is the possible consequences of the expected increasing opportunities for human use and exploitation of formerly inaccessible polar areas. They will bring about more disturbances for marine mammals and indirectly a higher risk for chemical and oil pollution, and collisions of ships and marine mammals.

Habitat loss or change due to climate effects in other than the polar regions, should be taken into consideration as well.

A full assessment of the discussed threats on biodiversity at the high seas, with respect to marine mammals, is complex. Not only the nature and extent of potential impacts is largely unclear, but the cumulative and synergistic effects are even less understood. Nevertheless it is in our view valuable to evaluate the factors that may influence High Seas biodiversity. The relevance lies in the fact that this will enable management authorities to identify which factors are of importance, which information is lacking and should become the focus of future research.

15.11 Conclusions

- All whaling, whether commercial, aboriginal subsistence or scientific, should be scrutinised for its effects on formerly overexploited stocks, based on the precautionary principle.
- Bycatch occurs in several fisheries but the vast majority (98%) happens in gillnet fisheries.
- Mitigation measures have been shown to considerably reduce the bycatch of dolphins and porpoises. These measures necessitate tailor made solutions on a case by case basis.
- There is no evidence that competition for prey between marine mammals and fisheries is a global problem.
- Fundamental research is needed to adequately address the impact of pollution on marine mammals, including the extrapolation of effects found in individual animals to consequences at population level.
- Knowledge on the impact of noise on marine mammals is still poor. In environmental impact assessment studies for noise producing activities in the marine environment (incl. high seas), investigations on the effects of noise on marine mammals should have a high priority.
- Whale watching guidelines and regulations should be designed in order to mitigate or prevent negative effects of this activity on free ranging cetaceans.
- Habitat loss or change due to climate effects in polar and other regions, should be taken into consideration.

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16 Turtles[53]

Worldwide, there are only seven species of sea turtles that belong to two families (Table 16.1). The family Cheloniidae includes all sea turtles with *scutes* (horny plates) covering their shells. The family Dermochelyidae are scuteless turtles, covered with a leathery skin. The leatherback turtle is the only representative of this group.

Table 16.1 Sea turtles and their conservation status.

species	IUCN conservation status
green (*Chelonia mydas*), with two subspecies	endangered
loggerhead (*Caretta caretta*)	endangered
Kemp's ridley (*Lepidochelys kempii*)	critically endangered
olive ridley (*Lepidochelys olivacea*)	endangered
hawksbill (*Eretmochelys imbricata*)	critically endangered
flatback (*Natator depressus*)	data deficient
leatherback (*Dermochelys coriacea*)	critically endangered

In many parts of the world sea turtles form part of the bycatch in different fisheries and at the same time many turtle stocks appear to be in a poor state. FAO (2004) provides a review of turtle stocks, their conservation status and major threats. The main risks for the by-catch of turtles in offshore fisheries stems from fisheries with pelagic longlines, and the purse seine fishery, but several other threats are recognized.

In the Pacific, Indian and Atlantic Oceans and in the Mediterranean, altogether 59 turtle stocks were distinguished. Relative risk rating was assigned for the various regional stock groupings exposed to 13 different hazards, ranging from egg harvesting and deterioration of spawning sites to coastal and high seas fisheries.

Conservation status of these 59 stocks was classified as follows:

severely depleted	16	27%
depleted	3	5%
conservation concern	12	20%
critical	3	5%
threatened	13	22%
low risk	4	7%
unknown	8	14%

Conclusions drawn from the review by FAO (2004a) are:

- not all major threats to sea turtles are fisheries-related;
- major threats to sea turtles include non-fisheries related causes such as nesting habitat destruction and egg harvesting;
- coastal fisheries also pose a significant threat to sea turtles but are poorly documented in many cases;
- Pacific loggerheads have declined significantly and are at risk in various fisheries;
- Pacific leatherbacks have declined significantly and are at risk in various fisheries;
- olive ridleys along the east India coast are at risk in various fisheries;
- Atlantic hawksbills are at risk in various fisheries;

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- Mediterranean loggerheads are at risk in pelagic longline fisheries

Overall IUCN (2003) considers six of the seven species endangered, three of those critically endangered, and one species is calcified as data deficient (see text table above).

Figure 16.1 maps the species richness of marine turtles (and one marine snake).

There are many recent publications on the bycatch of turtles, gear modifications to reduce the bycatch and other management to reduce the bycatch, e.g. Robins *et al.* (2002), Gilman *et al.* (2006) and Báez *et al.* (2007).

Fisheries bycatch, in particular from longline fisheries, has been proposed as a primary source of turtle mortality. Although bycatch rates from individual longline vessels are extremely low, the amount of gear deployed by these vessels suggests that cumulative bycatch of turtles from older age classes is substantial. Current estimates suggest that even if pelagic longlines are not the largest single source of fisheries-related mortality, longline bycatch is high enough to warrant management actions in all fleets that encounter sea turtles. Nevertheless, preliminary data reviewed by Lewison & Crowder (2007) suggest that bycatch from gillnets and trawl fisheries is equally high or higher than longline bycatch with far higher mortality rates.

In certain areas bycatch quota are used and fisheries are closed when these quota have been reached, e.g. in the Hawaiian swordfish fishery (Earthjustice, 2006).

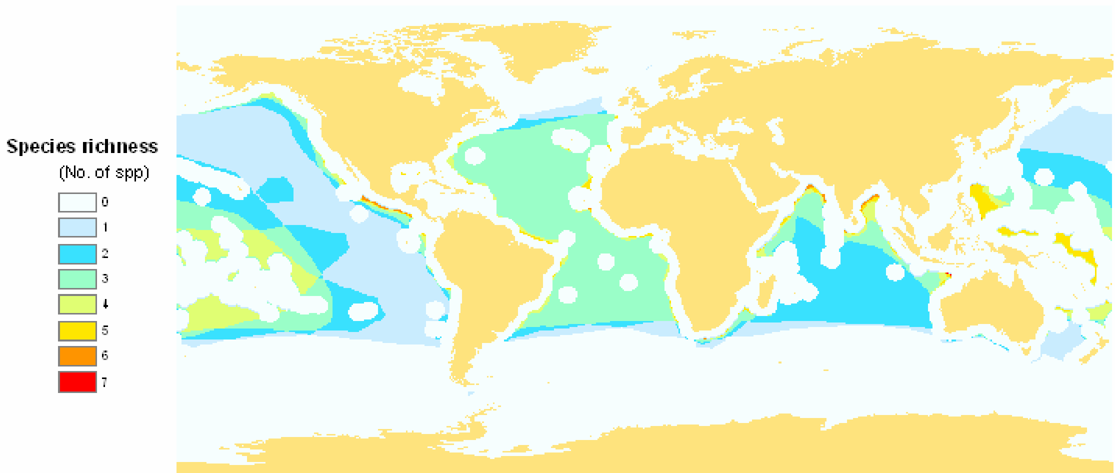

Figure 16.1 Map of species richness of marine turtles (7 species) and one pelagic sea snake found in the high seas, based on the distribution ranges of these 8 species (copied from UNEP 2005).

Conclusions

- Worldwide there are only 7 species 3 of which are critically endangered and 3 others are considered endangered.
- Gear modifications to prevent by-catches are being studied
- Not all major threats to sea turtles are fishery related

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17 The Food Web[54]

17.1 Introduction

All life on earth relies directly or indirectly on primary producers. They produce organic compounds, through the process of photosynthesis or chemosynthesis, which are at the base of all food webs.

17.2 Primary production

Primary producers, or autotrophs, lie at the base of the marine food web. They convert inorganic materials into energy-rich organic compounds using energy from solar radiation (photosynthesis; equation 1) or chemicals (chemosynthesis; equation 2).

$$CO_2 + H_2O + Light = CH_2O + O_2 \quad (1)$$

$$CO_2 + O_2 + 4H_2S = CH_2O + 4S + 3H_2O \quad (2)$$

Photosynthetic organisms

The majority of the primary production in oceans is carried out by phytoplankton which perform photosynthesis (Nybakken, 2001). The availability of sunlight is necessary for photosynthesis as it is used as an energy source. Hence, phytoplankton can be found in the upper part of the water column where sunlight can penetrate, also called the euphotic zone. Light is captured by means of pigments and processed for the photosynthesis. Different algae groups are characterized by specific pigment compositions. The colour of these pigments determines which part of the light spectrum can be absorbed for photosynthesis. Chlorophyll a is the most common pigment which can be found in all photosynthesizing algae. This pigment selectively absorbs blue (430 nm) and red (680 nm) light. Besides chlorophyll a, algae can possess secondary pigments which capture (other) specific parts of the light spectrum. The presence of the pigments determines the colour of the sea water as they reflect the colour they do not capture. These reflections can be measured with satellite sensors and provide information on the chlorophyll concentration in the water. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) project[55] monitors the chlorophyll concentration in the ocean amongst other things (Figure 17.1). The total amount of chlorophyll monitored is a direct measure of the total biomass of phytoplankton that is present. This, in turn, provides information on the primary production that is taking place (Joint & Groom, 2000).

In addition to light phytoplankton species need inorganic nutrients. These are used for the photosynthesis and for growth and reproduction. Primary production is therefore extremely high around upwelling areas (Kokkinakis & Wheeler, 1987). Upwelling is a process in which cold, usually nutrient-rich water is brought to the surface due to various causes. Coastal upwelling is the best-known type of upwelling. In certain coastal areas the wind and the Coriolis Effect (a result of the earth's rotation) are responsible for moving water along the coast offshore. This leaves a 'gap' which is filled up by water 'upwelling' from the deeper parts of the ocean, creating a nutrient-rich and diverse environment (Nybakken, 2001). It is therefore not surprising that these areas, e.g. off Peru and northwest Africa, support the most productive fisheries. A similar process occurs around the equator where the surface water turns away from the equator resulting in upwelling of deeper nutrient-rich water. In addition, underwater obstacles, such as seamounts, can bring

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[55] For further information: http://oceancolor.gsfc.nasa.gov/SeaWiFS

about local upwelling. They may create currents causing upwelling of nutrient-rich deeper water which will stimulate productivity in the surface waters.

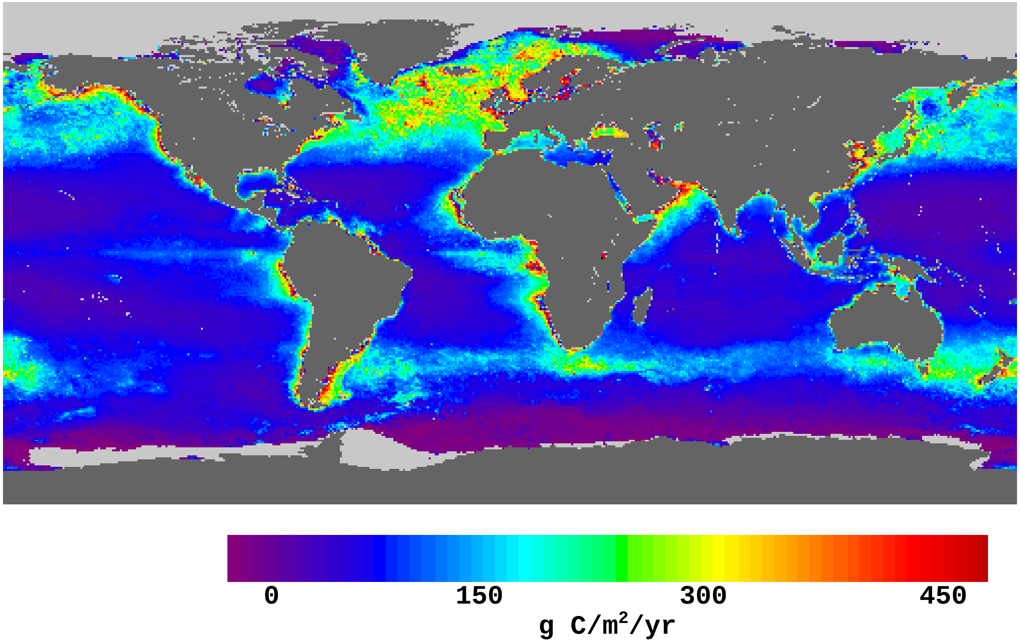

Figure 17.1 Global annual primary production estimates (http://marine.rutgers.edu/opp/)

Chemosynthetic organisms

A small fraction of the primary production is driven by organisms that use chemical nutrients as an energy source rather than sunlight. This process is called chemosynthesis. The obtained energy is used to form organic matter. These organisms derive their energy from oxidization of inorganic compounds such as hydrogen sulfide (H_2S). Such chemicals can be found around hydrothermal vents and cold seeps. Hydrothermal vents are hot-water geysers spewing out chemical compounds. They can be found in the deep sea on the seafloor around areas with volcanic activity such as the Mid Atlantic Ridge (MAR). Cold seeps, also referred to as cold vents, are situated on places in the deep sea where chemicals emerge (seep) from the sediment at the same temperature as the surrounding seawater.

17.3 Secondary production and the marine food web

All organisms in marine food webs are dependent on primary producers. The formed organic compounds are either ingested directly or through consumption of other organisms that have directly or indirectly ingested the organic compounds. This conversion of energy by consumers into new tissue is called secondary production.

The energy transfer from primary producers through a series of consumers is referred to as a food chain. Within a food web a series of food chains are interwoven with each other.

Marine food webs are continually influenced by variations in natural conditions and anthropogenic activities. Fisheries are thought to be a major factor influencing marine food webs. The selective removal of species of certain sizes will have a direct effect on the exploited species. In addition, fisheries also interact indirectly with the food web to which the exploited species belong to (Goñi, 1998; Coleman & Williams, 2002; Scheffer *et al.*, 2005). Removing species can thus cause a cascading effect along the food chain which will result in changes in the composition and structure of the community. For example, Stenneck *et al.* (2002) showed that the food web of the kelp forest changed radically after intensive fishing. The kelp forest began to disintegrate after cod was fished away in the Gulf of Maine. As there was not enough cod left to predate on sea urchins, the sea urchin population grew and ate more kelp. Furthermore, fishing gear, such as deepwater trawling, can bring about considerable damage to habitats (Koslow *et al.*, 2000). This will, in turn, affect the inhabiting species.

It has been shown that landings from global fisheries have shifted from large piscivorous fish towards smaller fish species (Pauly *et al.*, 1998; Pauly & Palomares, 2005). This process is known as "fishing down marine food webs" and is expected to result in major changes in the structure of marine food webs (Pauly *et al.*, 1998).

17.4 Anthropogenic impact

Fisheries affect the food web by selectively removing certain species and size components of the ecosystem, influencing the ecological interactions and energy flow within the food web.

17.5 Conclusions

- Primary producers are at the base of the food chain. They convert inorganic materials into energy-rich organic compounds using energy from solar radiation (photosynthesis) or chemicals (chemosynthesis).
- The majority of primary production in oceans is carried out by photosynthesizing phytoplankton.
- The conversion of energy by consumers into new tissue is called secondary production.
- The transfer of energy through a series of consumers is referred to as a food chain. In a food web several food chains are interwoven with each other.
- The removal of a species will have direct and indirect effects on species within the food web.

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18 Integration and conclusion[56]

The quantification of the impact of anthropogenic activities on marine biodiversity proved to be a major challenge, due to the lack of quantitative information on both the activities as well as the biodiversity. Quantitative data on the nature of the activities, the scale of operation and the impact on specific ecosystem components is largely lacking. In addition, our knowledge of biodiversity of the high seas is limited and many areas are still unexplored. For activities for which information is available, such as fishing, no distinction is made between the High Seas and the areas within the EEZ.

Despite these difficulties, we have attempted to quantify the impact of the various activities on several ecosystem components by estimating the severity of the activity to the ecosystem component, the extend of the activity relative tho the distribution area of the ecosystem component and the recoverability of the ecosystem component. Classification levels varied between 1 (negligible) and 3 (substantial) and were based on the characteristics of the activities and the biological description of the ecosystem components. The results are presented in Table 18.1. Note that the severity and recoverability is assessed from a population dynamic point of view by attempting to estimate the impact on mortality and reproductive rates of the population.

Table 18.2 summarises the estimated impact and presents the product of severity*recoverability. The impact ranges between 0 and 9. This index reflects the local impact as it does not take into account the extend of the activity. The comparison of the various activities indicates that the local impact is largest from fishing, in particular demersal fishing, and the exploitation of marine organisms for bioprospecting. Further, CO2 storage and the garbage from shipping may have a substantial impact on benthos and benthic habitats. A comparison of the impact of various activities within an ecosystem component again shows the dominant impact of fishing for all ecosystem components considered. The table also shows that the anthropogenic activities should not be pooled in too broad categories, as the impact may differ substantially in relation to the sub-category. For instance, birds are most impacted by longline fishing, but not by demersal trawls, whereas marine mammals will be mainly affected by pelagic purse seine. In Antarctica, tourism may negatively impact biodiversity, in particular affecting mammals and birds.

Taking into account the extend of the activity, reflecting the surface area impacted, it is obvious that fishing and shipping stand out as the dominant activities affecting marine biodiversity in the high seas. Exploiation of marine organisms for chemical compounds (bioprospecting) may become a threat as this may also cover larger surface areas.

It is noted that fishing, bioprospecting and Antarctic tourism are activities that will be concentrated in areas of high biomass or high biodiversity. This is in contrast to other activities such as shipping or infrastructure that will be unrelated to biodiversity hotspots.

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Table 18.1 Impact matrix of ecological resources and effect types. The impact is presented as severity/extent/ recovery (recoverability) (0 not applicable; 1 negligible ; 2 significant; 3 substantial). For further explication see also Chapter 1.

1: Fisheries

	Epipelagic species				Demersal species		
Ecological resource	**Longline**	**Gillnet**	**Purse seine**	**Trawl**	**Longline**	**Gillnet**	**Trawl**
Fish	3/2/2	3/2/2	3/2/2	3/2/2	3/2/3	3/2/3	3/2/3
Benthos	0/0/0	0/0/0	0/0/0	0/0/0	1/2/2	1/2/2	3/2/3
Benthic habitats	0/0/0	0/0/0	0/0/0	0/0/0	1/2/2	1/2/2	3/2/3
Birds	2/2/2	1/2/1	0/2/0	0/2/0	2/2/2	1/2/1	0/2/0
Marine mammals	0/2/0	1/2/1	2/2/2	1/2/1	0/2/0	1/2/1	0/2/0
Turtles	2/2/2	2/2/2	0/2/0	1/2/1	1/2/1	0/2/0	0/2/0
Food chain	2/2/2	2/2/2	2/2/2	2/2/2	2/2/2	2/2/2	2/2/2

2: Mining

Ecological resource	Mining
Fish	1/1/1
Benthos	2/1/2
Benthic habitats	2/1/2
Birds	0/1/0
Marine mammals	1/1/0
Turtles	0/1/0
Food chain	1/1/0

3: Shipping

Ecological resource	Oil	Chemicals	Garbage	Antifouling	Exotic species	Air pollution	Noise
Fish	0/1/0	0/2/0	1/2/1	0/2/0	0/2/0	0/2/0	0/0/0
Benthos	0/1/0	0/2/0	1/2/3	0/2/0	0/2/0	0/2/0	0/0/0
Benthic habitats	0/1/0	0/2/0	2/2/3	0/2/0	0/2/0	0/2/0	0/0/0
Birds	3/1/1	1/2/1	2/2/2	0/2/0	0/2/0	0/2/0	0/0/0
Marine mammals	1/1/0	0/2/0	1/2/1	0/2/0	0/2/0	0/2/0	2/2/1
Turtles	1/1/0	0/2/0	2/2/2	0/2/0	0/2/0	0/2/0	0/0/0
Food chain	1/1/0	0/2/0	1/3/3	0/2/0	0/2/0	0/2/0	0/0/0

4: Iron fertilization (pessimistic scenario):

Ecological resource	Iron fertilisation
Fish	2/2/0
Benthos	2/2/1
Benthic habitats	2/2/1
Birds	0/2/0
Marine mammals	0/2/0
Turtles	0/2/0
Food chain	1/2/1

5: CO2 storage:

Ecological resource	Emission	
	CO2	Contaminants
Fish	1/1/0	0/1/0
Benthos	3/1/2	1/1/1
Benthic habitats	3/1/3	1/1/1
Birds	0/1/0	0/1/0
Marine mammals	0/1/0	0/1/0
Turtles	0/1/0	0/1/0
Food chain	0/1/0	0/1/0

6: Antarctic tourism

Ecological resource	Tourism
Fish	0/0/0
Benthos	0/0/0
Benthic habitats	0/0/0
Birds	2/2/2
Marine mammals	2/2/2
Turtles	0/0/0
Food chain	2/1/2

7: Infrastructure

Ecological resource	Data cables	Power cables	Pipelines *)
Fish	0/1/0	1/1/1	0/0/0
Benthos	1/1/1	0/1/0	1/0/1
Benthic habitats	1/1/1	1/1/1	2/0/2
Birds	0/1/0	0/1/0	0/0/0 **)
Marine mammals	0/1/0	1/1/1	0/0/0
Turtles	0/1/0	0/1/0	0/0/0
Food chain	0/1/0	0/1/0	0/0/0

*) not on High Seas: extent = 0
**) mogelijk wel effect als rekening gehouden wordt met oil spill??

8: Bioprospecting

Ecological resource	Exploration	On shore isolation, testing	Exploitation	Bioprospecting/ MSR
Fish	0/1/0	0/0/0	0/1/0	0/1/0
Benthos	2/1/1	0/0/0	3/2/3	2/1/2
Benthic habitats	2/1/1	0/0/0	3/2/3	2/1/2
Birds	0/1/0	0/0/0	0/1/0	0/1/0
Marine mammals	0/1/0	0/0/0	0/1/0	0/1/0
Turtles	0/1/0	0/0/0	0/1/0	0/1/0
Food chain	0/1/0	0/0/0	0/1/0	0/1/0

Table 18.2 Local ecosystem impact of different activities: Severity * Recovery (calculated from values in Table 18.1).

		Fish	Benthos	Benthic habitats	Birds	Marine mammals	Turtles	Food chain
Fisheries	Epipelagic longline	6	0	0	4	0	4	4
	Epipelagic gillnet	6	0	0	1	1	4	4
	Epipelagic purse seine	6	0	0	0	4	0	4
	Epipelagic trawl	6	0	0	0	1	1	4
	Demersal longline	9	2	2	4	0	1	4
	Demersal gillnet	9	2	2	1	1	0	4
	Demersal trawl	9	9	9	0	0	0	4
Mining	Mining	1	4	4	0	0	0	0
Shipping	Oil	0	0	0	3	0	0	0
	Chemicals	0	0	0	1	0	0	0
	Garbage	1	3	6	4	1	4	3
	Antifouling	0	0	0	0	0	0	0
	Exotic species	0	0	0	0	0	0	0
	Air pollution	0	0	0	0	0	0	0
	Noise	0	0	0	0	2	0	0
Iron fertilisation	Iron fertilization	0	2	2	0	0	0	1
CO2 storage	CO2	0	6	9	0	0	0	0
	Contaminants	0	1	1	0	0	0	0
Tourism	Tourism	0	0	0	4	4	0	4
Infrastructure	Data cables	0	1	1	0	0	0	0
	Power cables	1	0	1	0	1	0	0
	Pipelines	0	1	4	0	0	0	0
Bioprospecting	Exploration	0	2	2	0	0	0	0
	On shore isolation, testing	0	0	0	0	0	0	0
	Exploitation	0	9	9	0	0	0	0
	Bioprospecting MSR	0	4	4	0	0	0	0

19 Glossary

ACAP	Agreement on the Conservation of Albatrosses and Petrels
APF	Antarctic Polar Front
APFIC	Asia Pacific Fisheries Commission
ASOC	Antarctic and Southern Ocean Coalition
ATCM	Antarctic Treaty Consultative Meetings
ATS	Antarctic Treaty System
Billfish	group of species including swordfish, sailfish, marlin, spearfish, etc
BOBP-IGO	The Bay of Bengal Programme Inter-Governmental Organisation
CARPAS	Regional Fisheries Advisory Commission for South-West Atlantic
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCBSP	Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea
CCS	Carbon dioxide Capture and Storage
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CECAF	Committee for the Eastern Central Atlantic Fisheries
CEP	Committee on Environmental Protection
CIFA	Committee for Inland Fisheries of Africa
CMS	Convention on the Conservation of Migratory Species of Wild Animals
COFI	FAO Committee on Fisheries
COFREMAR	Joint Technical Commission for the Argentina/Uruguay Maritime Front
COMHAFAT	Conférence Ministérielle sur la Coopération entre les Etats Africains Riverains de l'Océan Atlantique
COLREG	Collision Regulations
COMNAP	Council of Managers of National Antarctic Programs
COPESCAL	Comisión de Pesca Continental para América Latina
COREP	Regional Fisheries Committee for the Gulf of Guinea
CPPS	Permanent Commission for the South Pacific
CPUE	Catch Per Unit of Effort
CS-SSGS	CO_2 Sequestration in Sub-Seabed Geological Structures
CWC	cold water coral
DMS	dimetylsulphide
DWT	Deadweight tons
EEZ	Exclusive Economic Zone
EIFAC	European Inland Fisheries Advisory Commission
EPO	Eastern Pacific Ocean
FAD	Fish aggregating (or aggregation) device (used in the fishery for tuna and tuna-like fish)
FAO	Food and Agriculture Organisation
FCC	Federal Communications Commission
FFA	Forum Fisheries Agency
FPSO	Floating production, storage, and overload vessels
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GFCM	General Fisheries Commission for the Mediterranean
GRT	Gross tons
GT	Giga ton = 10^9 metric ton = 10^{12} kilogram
GT miles	Giga ton miles, or 10^{12} miles
High Seas	The open ocean lying beyond the 200 nautical mile Exclusive Economic Zones (EEZ) of coastal States. 'High seas' with lower case 'h' and 's' covers both the High Seas and the Area. In this report we also use the term "areas beyond national jurisdiction" to denote the High Seas and the Area.
HNLC	High-nutrient, low-chlorophyll
HSVAR	High seas vessels authorization record

HVDC	High Voltage Direct Current
IAATO	International Association of Antarctic Tour Operators
IATTC	Inter-American Tropical Tuna Commission
IBSFC	International Baltic Sea Fishery Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Councilfor the Exploration of the Sea
IMO	International Maritime Organisation
Income	is defined according to the definition of gross national product (gross value added) containing labour income, profit, depreciation and interest.
IO	Indian Ocean
IOFC	Indian Ocean Fishery Commission
IOTC	Indian Ocean Tuna Commission
IUCN	International Union for the Conservation of Nature
IUU	Illegal, Unreported and Unregulated fisheries
IPHC	International Pacific Halibut Commission
IPOA	International Plan of Action
IPCC	Intergovernmental Panel on Climate Change
ISA	International Seabed Authority
IWC	International Whaling Commission
KP	Kyoto protocol
Kton	10^3 ton
LC	London Convention
LP	London Protocol
LVFO	Lake Victoria Fisheries Organisation
MARPOL	International Convention for the Prevention of Pollution From Ships
MEPC	Marine Environment Protection Committee
MRC	Mekong River Commission
MSR	Marine Scientific Research
Mton	10^6 ton
NAFO	Northwest Atlantic Fisheries Organisation
NAMMCO	North Atlantic Marine Mammal Commission
NASCA	North American Submarine Cable Association
NASCO	North Atlantic Salmon Conservation Organisation
NEAFC	North East Atlantic Fisheries Commission
NGO	Non Governmental Organisation
NOAA	National Oceanographic and Atmospheric Administration
NPAFC	North Pacific Anadromous Fish Commission
Nm	Nautical miles (1 nm = 1851 meter)
OLDEPESCA	The Latin American Organization for Fisheries Development
PICES	The North Pacific Marine Science Organization
PSC	Pacific Salmon Commission
RECOFI	Regional Commission for Fisheries
RFMO	Regional Fisheries Management Organisation
ROV	remotely operated vehicle
SEAFO	South-East Atlantic Fisheries Commission
SEAFDEC	Southeast Asian Fisheries Development Center
Seerfish	group of species including Spanish mackerel, king mackerel, seerfish (all species belonging to the genus *Scomberomorus*) and wahoo (*Acanthocybium solandri*)
SIOFA	South Indian Ocean Fisheries Agreement
SMS	Seabed massive sulphides
SOLAS	Survival Of Life At Sea
SPC	South Pacific Commission
SPRFMO	South Pacific Regional Fisheries Management Organisation
SRCF	Sub-Regional Commission on Fisheries
SWIOFC	South-West Indian Ocean Fisheries Commission
TBT	tributyl tin

The Area	The seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environmental Program
UNSFA	UN Fish Stocks Agreement
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WECAFC	Western Central Atlantic Fishery Commission
WHOI	Woodshole Oceanographic Institution
WIOTO	Western Indian Ocean Tuna Commission

Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen IMARES.

Approved: Prof. Dr. H.J. Lindeboom
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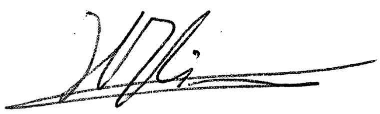
Signature: 

Date: 17 November 2008

Approved: drs. J. Asjes
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Date: 17 November 2008