



RAPID RESPONSE ASSESSMENT

# IN DEAD WATER

**MERGING OF CLIMATE CHANGE WITH POLLUTION, OVER-HARVEST,  
AND INFESTATIONS IN THE WORLD'S FISHING GROUNDS**

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# PREFACE



The world's oceans are already under stress as a result of over-fishing, pollution and other environmentally-damaging activities in the coastal zones and now on the high seas.

Climate change is presenting a further and wide-ranging challenge with new and emerging threats to the sustainability and productivity of a key economic and environmental resource.

This new, rapid response report attempts to focus the numerous impacts on the marine environment in order to assess how multiple stresses including climate change might shape the marine world over the coming years and decades.

It presents worrisome findings and requests governments to respond with ever greater urgency in order to combat global warming and to conserve and more strategically manage the oceans and seas and their extraordinary but shrinking resources.

The challenge of the seas and oceans in terms of monitoring has always been a formidable one with the terrestrial world more visible and easier to see. This is despite fisheries contributing to the global food supply and a supporter of livelihoods and cultures for millennia.

However, there is growing and abundant evidence that the rate of environmental degradation in the oceans may have progressed further than anything yet seen on land. This report highlights the situation in 2007 in the economically important

10 to 15% of the oceans and seas where fish stocks have been and remain concentrated.

These fishing grounds are increasingly damaged by over-harvesting, unsustainable bottom trawling and other fishing practices, pollution and dead zones, and a striking pattern of invasive species infestations in the same areas.

According to the report, these same areas may lose more than 80% of their tropical and cold water coral reefs due to rising sea temperatures and increasing concentrations of carbon dioxide (CO<sub>2</sub>) leading to a decrease in seawater pH (acidification).

Finally, these same areas are also facing rapidly growing pollution from coastal development, potential consequences of climate change such as possible slowing of 'flushing' mechanisms and increasing infestations of invasive species.

We are now observing what may become, in the absence of policy changes, a collapsing ecosystem with climate the final coup d'grace. There are many reasons to combat climate change, this report presents further evidence of the need to act if we are to maintain ecosystems and services that nourish millions; provide important tourism income and maintain biodiversity.

**Achim Steiner**  
Executive Director  
United Nations Environment Programme



# SUMMARY

The World's oceans play a crucial role for life on the planet. Healthy seas and the services they provide are key to the future development of mankind. Our seas are highly dynamic, structured and complex systems. The seafloor consists of vast shelves and plains with huge mountains, canyons and trenches which dwarf similar structures on land. Ocean currents transport water masses many times larger than all rivers on Earth combined.

In this report, the locations of the most productive fishing grounds in the World – from shallow, coastal waters to the deep and high seas – are compared to projected scenarios of climate change, ocean acidification, coral bleaching, intensity of fisheries, land-based pollution, increase of invasive species infestations and growth in coastal development.

## Half the World catch is caught in less than 10% of the ocean

Marine life and living resources are neither evenly nor randomly distributed across the oceans. The far largest share of marine biodiversity is associated with the sea bed, especially on the continental shelves and slopes. Seamounts, often rising several thousand meters above their surroundings, provide unique underwater oases that teem with life. Environmental parameters and conditions that determine the productivity of the oceans vary greatly at temporal and spatial scales. The primary and most important fishing grounds in the World are found on and along continental shelves within less than 200 nautical miles of the shores. The distribution of these fishing grounds is patchy and very localized. Indeed more than half of the 2004 marine landings are caught within 100 km of the coast with depths generally less than 200 m covering an area of less than 7.5% of the world's oceans, and 92% in less than half of the total ocean area. These treasure vaults of marine food play a crucial role for coastal populations, livelihoods and the economy.

Whether they will provide these functions and services in the future depends on needed policy changes and the continuation of a number of environmental mechanisms to which marine life has evolved and adapted. These natural processes include



clean waters with balanced temperature and chemistry regimes as well as currents and water exchanges that provide these areas with oxygen and food, to name just a few. However, there are alarming signals that these natural processes to which marine life is finely attuned are rapidly changing.

## With climate change, more than 80% of the World's coral reefs may die within decades

In tropical shallow waters, a temperature increase of up to only 3° C by 2100 may result in annual or bi-annual bleaching events of coral reefs from 2030–2050. Even the most optimistic scenarios project annual bleaching in 80–100% of the World's coral reefs by 2080. This is likely to result in severe damage and wide-spread death of corals around the World, particularly in the Western Pacific, but also in the Indian Ocean, the Persian Gulf and the Middle East and in the Caribbean.

## Ocean acidification will also severely damage cold-water coral reefs and affect negatively other shell-forming organisms

As CO<sub>2</sub> concentrations in the atmosphere increase so does ocean assimilation, which, in turn, results in sea water becoming more acidic. This will likely result in a reduction in the area

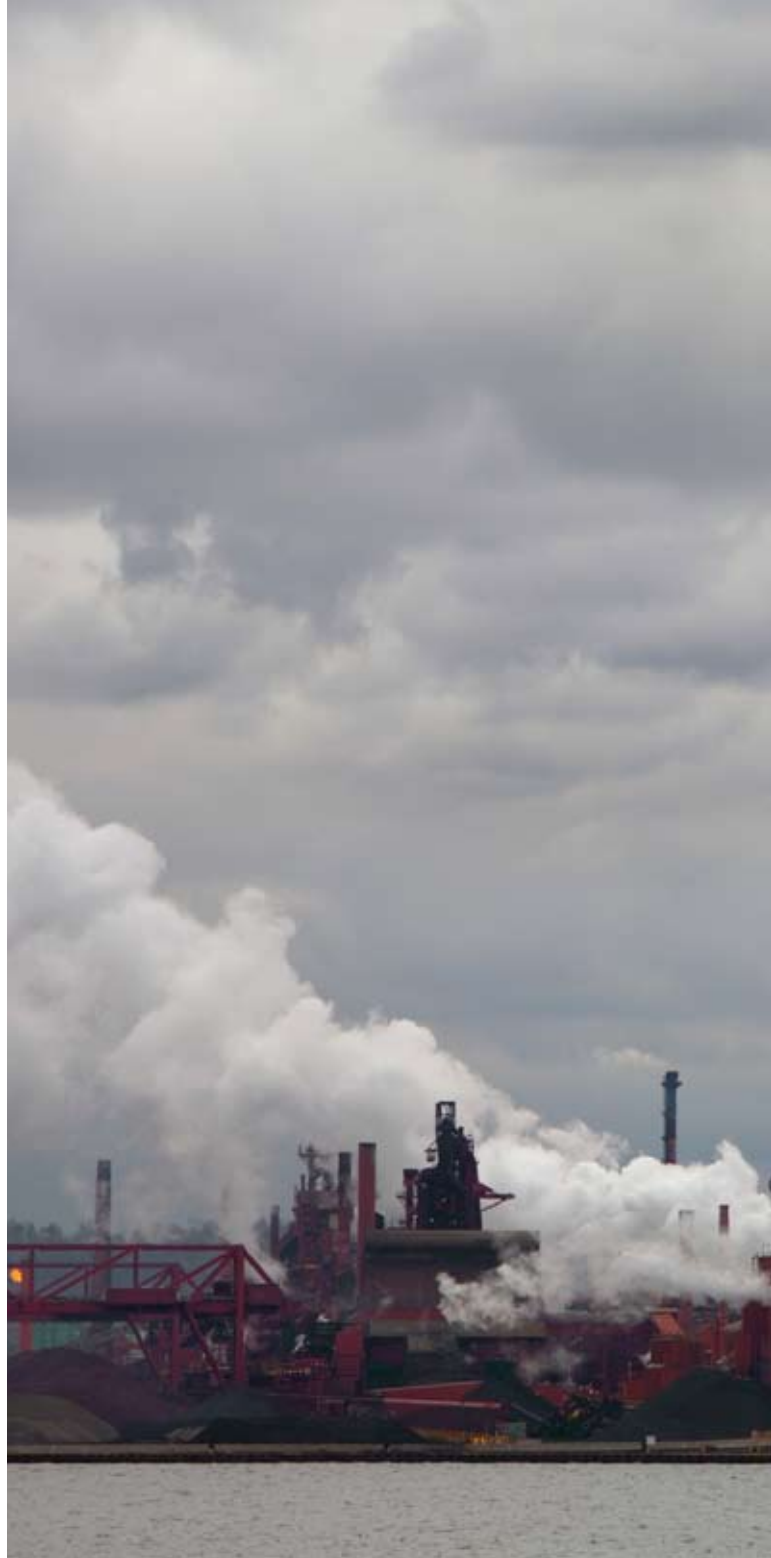
covered and possible loss of cold-water coral reefs, especially at higher latitudes. Besides cold-water corals, ocean acidification will reduce the biocalcification of other shell-forming organisms such as calcareous phytoplankton which may in turn impact the marine food chain up to higher trophic levels.

**Coastal development is increasing rapidly and is projected to impact 91% of all inhabited coasts by 2050 and will contribute to more than 80% of all marine pollution**

Marine pollution, more than 80% of which originates from land-based sources, is projected to increase, particularly in Southeast and East Asia, due to rising population and coastal development. Increased loads of sediments and nutrients from deforestation, sewage and river run-off will greatly diminish the resilience of coral reefs. The effects of pollution are exacerbated by the destruction of mangroves and other habitats due to the rapid construction taking place on coastlines. As much as 91% of all temperate and tropical coasts will be heavily impacted by development by 2050. These impacts will be further compounded by sea level rise and the increased frequency and intensity of storms that easily break down weakened or dead corals and are likely to severely damage beaches and coast lines.

**Climate change may slow down ocean thermohaline circulation and continental shelf “flushing and cleaning” mechanisms crucial to coastal water quality and nutrient cycling and deep-water production in more than 75% of the World’s fishing grounds**

Of major concern is that many of these productive fishing grounds depend extensively upon sea currents for maintaining life cycle patterns for the sustainable production of fish and other marine life. Large scale water exchange mechanisms, which periodically “flush and clean” continental shelf areas, are observed in and near at least ca. 75% of all the major fishing grounds. These mechanisms, however, depend entirely on







cooler and heavier seawater sinking into the deep sea, often using and carving channels and canyons into the continental shelf. New research suggests that while climate change may not necessarily stop the major thermohaline currents, climate change may potentially reduce the intensity and frequency of the coastal flushing mechanisms, particularly at lower to medium latitudes over the next 100 years, which in turn will impact both nutrient and larval transport and increase the risk of pollution and dead zones.

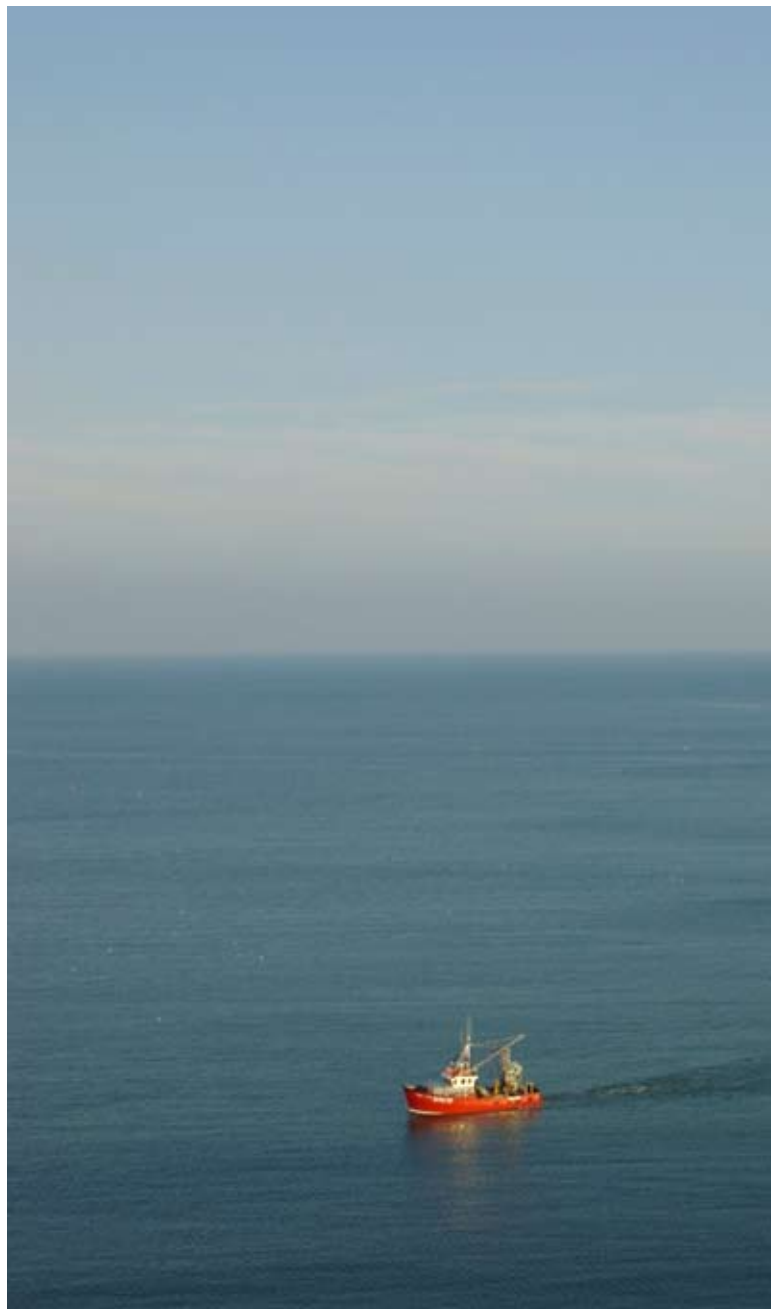
### **Increased development, coastal pollution and climate change impacts on ocean currents will accelerate the spreading of marine dead zones, many around or in primary fishing grounds**

The number of dead zones (hypoxic or oxygen deficient areas) increased from 149 in 2003 to over 200 in 2006. Given their association with pollutants from urban and agricultural sources, together with the projected growth in coastal development, this number may multiply in a few decades, unless substantial changes in policy are implemented. Most dead zones, a few of which are natural phenomena, have been observed in coastal waters, which are also home to the primary fishing grounds.

## Over-harvesting and bottom trawling are degrading fish habitats and threatening the entire productivity of ocean biodiversity hotspots, making them more vulnerable to climate change

Recent studies indicate that fishery impacts in shelf areas may potentially become even worse in deeper water. Due to advances in technology and subsidies, fishing capacity is now estimated to be as much as 2.5 times that needed to harvest the sustainable yield from the world's fisheries. Up to 80% of the world's primary catch species are exploited beyond or close to their harvest capacity, and some productive seabeds have been partly or even extensively damaged over large areas of fishing grounds. With many traditional, shallow fishing grounds depleted, fisheries (especially large industrial vessels/fleets operating for weeks/months at sea) are increasingly targeting deep-water species on the continental slopes and seamounts. Over 95% of the damage and change to seamount ecosystems is caused by bottom fishing, mostly carried out unregulated and unreported with highly destructive gear such as trawls, dredges and traps.

Trawling has been estimated to be as damaging to the sea bed as all other fishing gear combined. Unlike only a decade ago, there are now numerous studies from nearly all parts of the world, documenting the severe long-term impacts of trawling. The damage exceeds over half of the sea bed area of many fishing grounds, and worse in inner and middle parts of the continental shelves with particular damage to small-scale coastal fishing communities. Indeed, while very light trawling may be sustainable or even increase abundance and productivity of a few taxa, new studies, including data from over a century ago, clearly indicate damage to the sea bed across large portions of the fishing grounds, and at worst reductions in pristine taxa of 20–80% including both demersals and benthic fauna. Unlike their shallow water counterparts, deep sea communities recover slowly, over decades and centuries, from such impacts. Some might not recover at all if faced with additional pressures including climate change and might lead to a permanent reduction in the productivity of fishing grounds. There are now discussions ongoing within several bodies including the FAO on developing better international guidelines for the management of deep-sea fisheries in the high seas, but substantial action is urgently needed given the cumulative threats that the oceans are facing.





## **Primary fishing grounds are likely to become increasingly infested by invasive species, many introduced from ship ballast water.**

The vulnerability of impacted ecosystems to additional stresses is also demonstrated by the increase of invasive species infestations that are concentrated in the same 10–15% of the World's oceans. Heavily disturbed and damaged marine areas are more likely to have a higher vulnerability to infestations brought in by ships plying the World's oceans despite recommendations in many areas for mid-ocean exchange of ballast water. Geographical distribution of invasive species suggests a strong relationship between their occurrence and disturbed, polluted and overfished areas and in particular the location of major shipping routes at a global scale. It appears that the most devastating outbreaks of such marine infestations have been brought in along the major shipping routes and primarily established in the most intensively fished and polluted areas on the continental shelves. Growing climate change will most likely accelerate these invasions further.

## **The worst concentration of cumulative impacts of climate change with existing pressures of over-harvest, bottom trawling, invasive species, coastal development and pollution appear to be concentrated in 10–15% of the oceans concurrent with today's most important fishing grounds**

Climate change, with its potential effects on ocean thermohaline circulation and a potential future decline in natural 'flushing and cleaning' mechanisms, shifts in the distributions of marine life, coral bleaching, acidification and stressed ecosystems will compound the impacts of other stressors like over-harvest, bottom trawling, coastal pollution and introduced species. The combined actions of climate change and other human pressures will increase the vulnerability of the world's most productive fishing grounds – with serious ecological, economic and social implications. The potential effects are likely to be most pronounced for developing countries where fish are an increasingly important and valuable export product, and there is limited scope for mitigation or adaptation.

## **A lack of good marine data, poor funding for ocean observations and an 'out of sight – out of mind' mentality**

## **may have led to greater environmental degradation in the sea than would have been allowed on land.**

The lack of marine information and easy observation by humans as land-living organisms, along with insufficient funds for monitoring, may result in these and other pressures to progress farther than anything we have yet seen or would have permitted without intervention on land, even though the oceans represent a significant share of global economies and basic food supply. Lack of good governance, particularly of the high seas, but also in many exclusive economic zones (EEZs) where the primary focus is economic gain, and has resulted in limited flexibility or incentive to shift to ecosystem based management. The potential for climate change to disrupt natural cycles in ocean productivity, adds to the urgency to better manage our oceans. The loss and impoverishment of these highly diverse marine ecosystems on Earth and modification of the marine food chain will have profound effects on life in the seas and human well-being in the future.

## **Substantial resources need to be allocated to reducing climate and non-climate pressures. Priority needs to be given to protecting substantial areas of the continental shelves. These initiatives are required to build resilience against climate change and to ensure that further collapses in fish stocks are avoided in coming decades.**

Urgent efforts to control accelerating climate change are needed, but this alone will not be sufficient. A substantially increased focus must be devoted to building and strengthening the resilience of marine ecosystems. Synergistic threats and impacts need to be addressed in a synergistic way, via application of an ecosystem and integrated ocean management approach. Actions for a reduction of coastal pollution, establishment of marine protected areas in deeper waters, protection of seamounts and parts (likely at least 20%) of the continental shelves against bottom trawling and other extractive activity, and stronger regulation of fisheries have all to go hand in hand. Unless these actions are taken immediately, the resilience of most fishing grounds in the world, and their ability to recover, will further diminish. Accelerating climate change and in-action risks an unprecedented, dramatic and wide-spread collapse of marine ecosystems and fisheries within the next decades.

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# WHY OCEANS MATTER

Oceans are crucial to life on Earth, support livelihoods and are vital to the World economy in numerous ways, including food as fish,

income to coastal communities from tourism, shipping and trade, and through petroleum reserves, to mention a few (FAO, 2006).



## Benefits from Marine and Coastal Ecosystems and Activities

### Coastal tourism



The volume of global tourist arrivals increased more than 20 times between 1950 and 1995, making tourism the world's fastest-growing industry. The present number of tourists is expected to double by 2010 – particularly in the Caribbean and Asia-Pacific regions, where much of the industry is concentrated in coastal areas.

**\$ 161 billion**

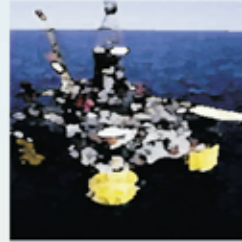
### Trade and shipping



Since the 1950s, the annual volume of shipping and seaborne trade has risen sixfold, to more than 5 billion tonnes of oil, dry bulk goods and other cargo. In 1995, there were 27,000 freighters over 1,000 tonnes in operation. Industrial countries account for 50% of the cargo loaded – and 75% of that unloaded.

**\$ 155 billion**

### Offshore oil and gas



Since gasoline was first used in California a century ago, the oil and natural gas industry has skyrocketed to meet soaring energy demands. Today, about 20% of the world's oil and natural gas comes from offshore drilling installations in the Middle East, the United States, Latin America, and the North Sea.

**\$ 132 billion**

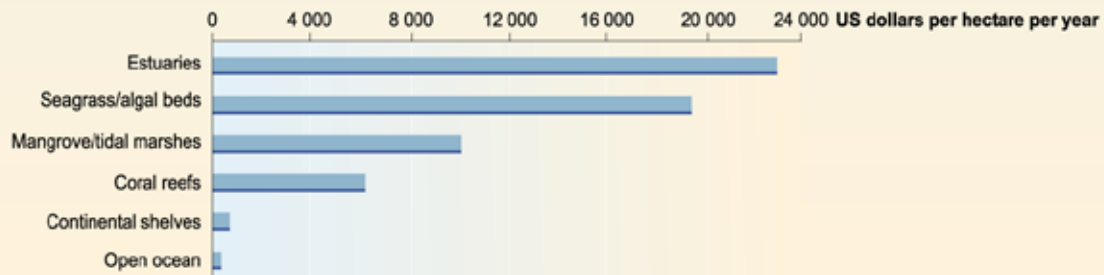
### Fisheries



Between 1950 and 1997, global fish production from capture and culture fisheries grew from 20 million tonnes to 122 million tonnes, with the per capita supply doubling from 8 kg to 15 kg. Over 200 million people rely on fishing for their livelihoods, with more than 80% of all fish (by value) sold in industrial countries.

**\$ 80 billion**

## Estimated Mean Value of Marine Biomes



DELPHINE DIGOUT  
MAY 2002

Source: Anne Platt McGinn, *The Health of Oceans*, Worldwatch paper 145, Worldwatch Institute, 1999, Washington DC ([www.worldwatch.org](http://www.worldwatch.org)) ; Costanza, R., et al, *The Value of the World's Ecosystem Services and Natural Capital*, Ecological Economics, 1998.

# THE SEA – ONE OF THE LARGEST FOOD FACTORIES ON THE PLANET

The World's oceans provide one of the largest (not domesticated) food reserves on the planet. Overall, seafood provided more than 2.6 billion people with at least 20 per cent of their average per capita animal protein intake (FAO, 2006). Capture fisheries and aquaculture supplied the world with about 106 million tonnes of food fish in 2004, providing an apparent per capita supply of 16.6 kg (live weight equivalent), which is the highest on record (FAO, 2006). Capture fishery production has, however, remained static, and it is only the rise in aquaculture, now accounting for 43% of the total consumption, that enabled this increase (FAO, 2006). Worldwide, aquaculture has grown at an average rate of 8.8 per cent per year since 1970, compared with only 1.2 per cent for capture fisheries in the same period. Despite fishing capacity now exceeding current harvest four-fold, marine capture has declined or remained level since 2000, reflecting over-harvest in many regions (Hilborn *et al.*, 2003; FAO, 2006). A major reason why the decline has not become more evident is likely because of advances in fishing efficiency, shift to previously discarded or avoided fish, and the fact that the fishing fleet is increasingly fishing in deeper waters.

The overall decrease in landings is mostly related to declines in fishing zones in the Southeast and Northwest Pacific oceans (FAO, 2006). In addition, the living resources in the World's oceans, including those so essential to mankind, are not randomly or evenly distributed. They are largely concentrated in small regions/areas and hotspots, of which continental shelves and seamounts – under-water mountains – play a crucial role. The safety of the World's oceans as a food source for future generations is however insecure. Over the last decades, there has been continuing exploitation and depletion of fisheries stocks. Undeveloped fish reserves have disappeared altogether since the mid-1980s. During the last decades, there has been a continued decline in fish resources in the 'developing' phase, and an increase of those in the depleted or over-exploited phase. This trend is somewhat offset by the emergence of resources in the 'recovering' phase (Mullon *et al.*, 2005; FAO, 2006; Daskalov *et al.*, 2007). There is little evidence of rapid recovery in



World fisheries and aquaculture production (million tonnes)

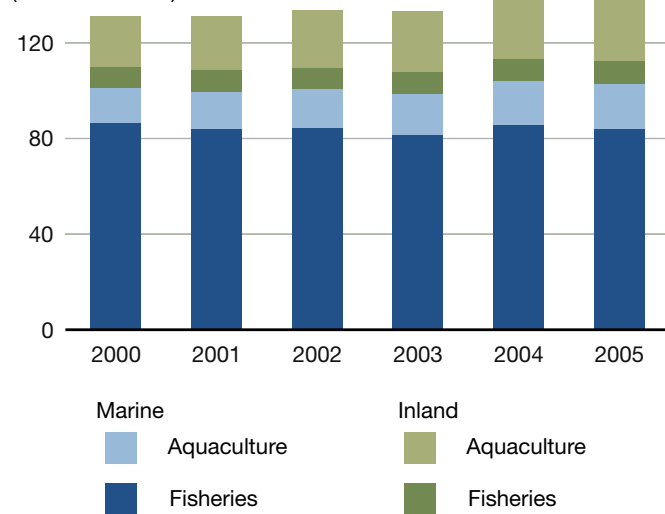
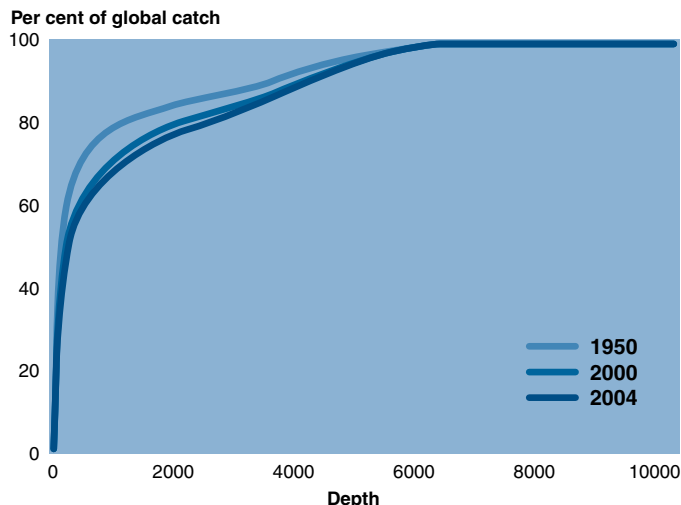


Figure 1. The World's marine fisheries have stagnated or slightly declined in the last decade, offset only by increases in aquaculture production (Source FAO, 2006).

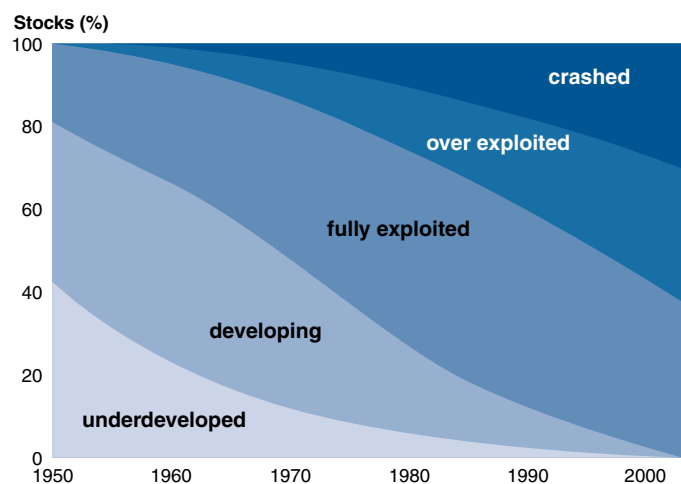


heavily harvested fish populations, except, perhaps herring and similar fish that mature early in life. An investigation of over 90 different heavily harvested stocks have shown little, if any, recovery 15 years after 45–99% reduction in biomass (Hutchings, 2000). This is particularly true as most catch reductions are introduced far too late (Shertzer *et al.*, 2007). Indeed, ma-

rine extinctions may be significantly underrated (Casey and Meyers, 1998; Edgar *et al.*, 2005). More importantly in this context is not the direct global extinction of species, but the regional or local extinctions as abundance declines. Local and regional extinctions are far more common than global extinctions, particularly in a dynamic environment like the oceans.



**Figure 2.** Estimated per cent of the global catch taken at depths for the years 1950, 2000 and 2004, which illustrates how fishers are moving further offshore (and often deeper) to catch fish.



**Figure 3.** The state of the World's fishery stocks.

# SEAMOUNTS AND CONTINENTAL SHELVES – THE OCEAN’S UNPROTECTED TREASURE VAULTS

Continental shelves are the gently sloping areas of the ocean floor, contiguous to the continent, that extend from the coastline to the shelf-break. The shelf break, which is located around 150–200 meters depth, is the area of the continental margin where there is an abrupt change between the shelf and the steeper continental slope.

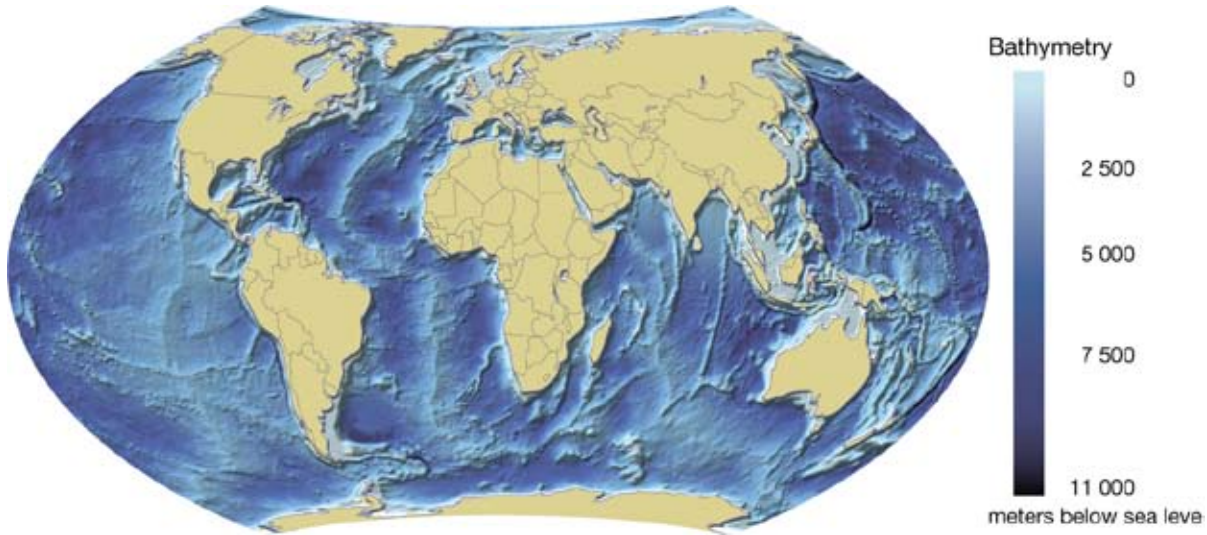
Primary production in the oceans, i.e. the production of organic compounds from dissolved carbon dioxide and nutrients through photosynthesis, is often associated with upwellings (Botsford *et al.*, 2006). Upwelling occurs when winds blowing across the ocean surface push water away from an area and subsurface water rises up from beneath the surface to replace the diverging surface water. These subsurface waters are typically colder, rich in nutrients, and biologically productive. The relation between primary production and coastal upwelling, caused by the divergence of coastal water by land or along-shore blowing winds, is clearly shown in ocean primary production maps. Therefore, good fishing grounds typically are found where upwelling is common. For example, the ecosystems supporting the rich fishing grounds along the west coasts of South America and Africa are maintained by year-round coastal upwelling. However, these systems are affected by changing oceanographic conditions and how they – and the dependent fisheries – will respond to sea temperature change as a consequence of climate change is highly uncertain. These upwelling fishing grounds, especially in South America provide the raw materials for feeds used in intensive animal production and so any decreases in production will have effects on the price of farmed fish, chicken and port.

The far largest share of all life in the oceans is in direct contact with or dwells just above the sea floor. Continental shelves and

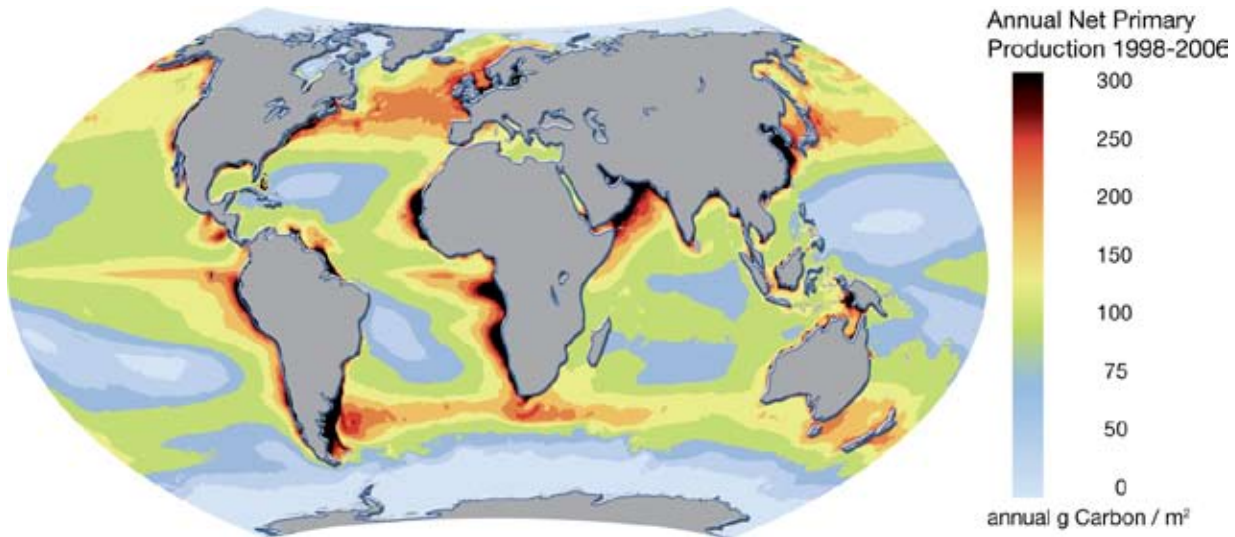
seamounts host – in addition to petroleum and mineral reserves – by far the largest share of the World’s most productive fishing grounds (Ingole and Koslow, 2005; Roberts *et al.*, 2006; Garcia *et al.*, 2007; Mossop, 2007). Technological advances have made continental shelves and shallow seamounts easily accessible to the World’s fishing fleet and to coastal communities all across the planet. However, they are also critically placed in relation to threats from (land-based) pollution, sea bed and habitat destruction from dredging and trawling, and climate change. With traditional fishing grounds depleted and/or heavily regulated, fisheries are increasingly targeting productive areas and new stocks in deeper waters further offshore, including on and around seamounts.

Seamounts are common under-water features, numbering perhaps as many as 100,000, that rise 1000 m or more from the seabed without breaking the ocean’s surface (Koslow *et al.*, 2001; Johnston and Santillo, 2004). The rugged and varied topography of the seamounts, and their interaction with nutrient-rich currents, creates ideal conditions and numerous niches for marine life. Compared to the surrounding deep-sea plains and plateaus, they are some of the primary biodiversity hotspots in the oceans.

Seamounts can be home to cold-water corals, sponge beds and even hydrothermal vents communities. They provide shelter, feeding, spawning and nursery grounds for thousands of species, including commercial fish and migratory species, such as whales (Roberts and Hirschfield, 2004; Roberts *et al.*, 2006; UNEP, 2006). Separated from each other, seamounts act like marine oases, often with distinct species and communities. Some, like the Coral Sea and Tasman seamounts, have endemism rates of 29–34%.



**Figure 4.** The continental shelves and under-water mountain ranges, so called seamounts (light blue shaded areas), are of immense importance to fisheries. Indeed, over half of the World's marine landings are associated with ca 7.5% of the oceans, concentrated on the continental shelves.



**Figure 5.** Primary production in the World's oceans provide a quite similar pattern to the World's fisheries (see Figure 6), concentrated along the continental shelves.

These unique features make seamounts a lucrative target for fisheries in search of new stocks of deep-water fish and shellfish, including crabs, cod, shrimp, snappers, sharks, Pacific cod, orange roughy, jacks, Patagonian toothfish, porgies, groupers, rockfish, Atka mackerel and sablefish. Our knowledge of seamounts and their fauna is still very limited, with only a tiny fraction of them sampled and virtually no data available for seamounts in large areas of the world such as the Indian Ocean (Ingole and Koslow, 2005). Often, fishermen arrive before the scientists. For a short time period, sometimes less than 3 years, the catches around seamounts can be plentiful. However, without proper control and monitoring, especially

in areas beyond national jurisdiction, stocks are exploited unsustainably and collapse rapidly. The reason for this ‘boom and bust’ are the characteristics of many deep-water organisms: unlike their counterparts in traditional, shallow-water fishing grounds, the deep-sea fish targeted around seamounts are long-lived, slow to mature and have only a few offspring (Glover and Smith, 2003; Johnston and Santillo, 2004). This makes them highly vulnerable to over-fishing by industrial fishing practices (Cheung *et al.*, 2007). In addition, the benthic communities, which support these fish stocks and their recovery, are seriously damaged or completely destroyed by the impact of heavy bottom trawling and other fishing gear

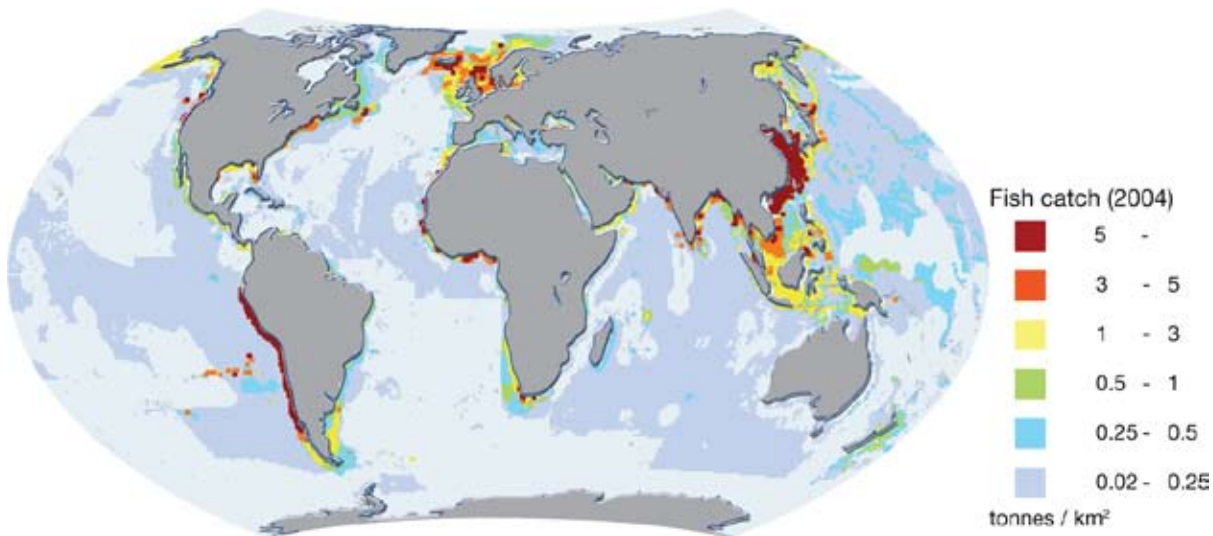




(Johnston and Santillo, 2004; Morato *et al.*, 2006b). Once depleted and devastated, often for decades to centuries, fishermen move on to the next seamount to start the next cycle. However, with many known seamounts already (over)exploited, recovery of fish stocks on seamounts varies with each species. Stocks of orange rough on the Chatham Rise in New Zealand, for example, show possible improvements after 5 years, whereas the grenadier stocks in the Northwest Atlantic show no signs after a number of years of reduced quotas.

The depletion of seamount populations indicates that the current focus and levels of fishing on seamounts is not sustainable. More depletion, extirpations, and even species extinctions may follow if fishing on seamounts is not reduced (Morato *et al.*, 2006). Very common however, rather than fishing until near extinction, is that the fishing vessels will move on to the next location as soon as the first is exhausted. With the large capacity of the fleet, the result is that more and more locations become impacted and damaged.

When primary production and bathymetric maps (showing the distribution of continental shelves) are compared to the intensity of fisheries (catch), a clear pattern erupts, reflecting the productivity and accessibility of these ocean hotspots.



**Figure 6. The World's most productive fishing grounds are confined to major hotspots, less than 10% of the World oceans.** The maps shows annual catch (tonnes per km<sup>2</sup>) for the World's oceans. Notice the strong geographic concurrence of continental shelves, upwelling and primary productivity (see Figures 4 and 5) and the amount of fish caught by fisheries.

# CORAL REEFS

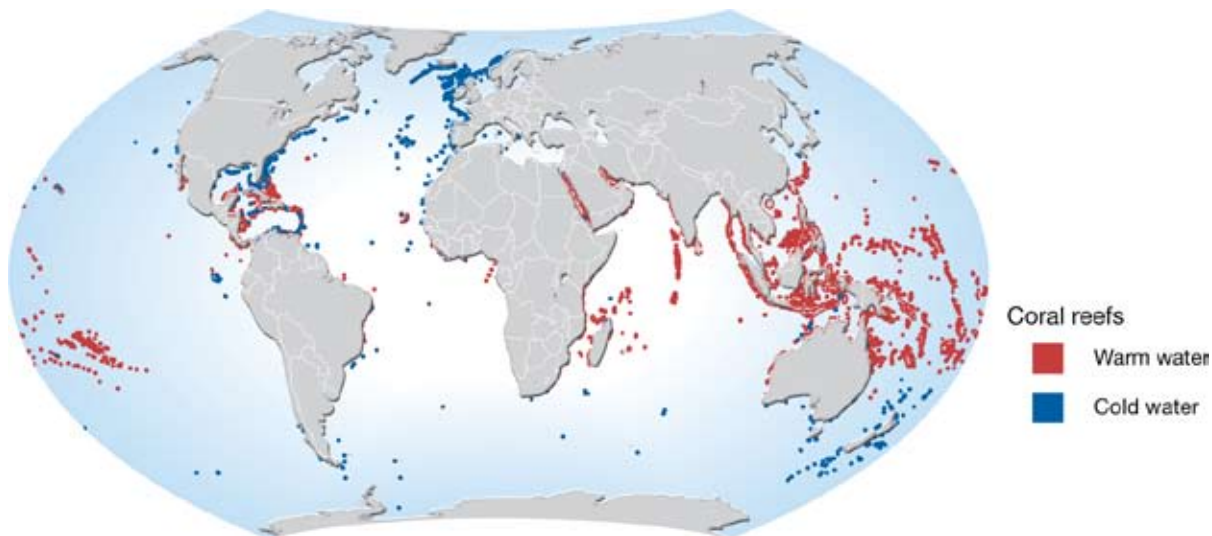
Coral reefs are marine ridges or mounds, which have formed over millennia as a result of the deposition of calcium carbonate by living organisms, predominantly corals, but also a rich diversity of other organisms such as coralline algae and shellfish.

Coral reefs provide a unique habitat able to support a high diversity and density of life. They occur globally in two distinct marine environments; deep, cold water (3–14°C) coral reefs, and shallow, warm water (21–30°C) coral reefs in tropical latitudes.

Cold-water corals have been recorded in 41 countries worldwide (Freiwald *et al.*, 2004), but they are most likely distributed throughout the World's oceans. They occur wherever the environmental conditions (cold, clear, nutrient-rich waters) are present, from Norwegian fjords in 39 meters depth to several thousand metres in the deep-sea. Living mostly in perpetual darkness, cold-water corals do not possess symbiotic, single-celled algae, and rely solely on zooplankton and detritus, which

they capture with their tentacles. Some species, such as *Lophelia*, can form large, complex, 3-dimensional reef structures several metres in height. The largest reef so far was discovered in 2002 is the Rost reef off the Norwegian coast. It spans twice the size of Manhattan, is part of the *Lophelia* reef belt stretching all along the eastern Atlantic continental shelf and slopes from within the Arctic Circle to the coast of South Africa. Other soft corals living in colder waters such as *Gorgonia* species do not form reefs but large 'gardens', covering vast areas for example around the Aleutian island chain in the North Pacific. The ecological functions of such reefs and gardens in the deeper waters are very similar to tropical reefs: they are biodiversity hotspots and home, feeding and nursery grounds for a vast number of other organisms, including commercial fish and shellfish species.

Living in highly productive areas, cold-water coral reefs and gardens are threatened by bottom fishing, especially with trawls and dredges. Observations with submersibles and remotely



**Figure 7. Distribution of coldwater and tropical coral reefs.** The coldwater reefs are highly susceptible to deep-sea trawling and ocean acidification from climate change, which has its greatest impacts at high latitudes, while tropical reefs will become severely damaged by rising sea temperatures.

operated vehicles revealed that most of the reefs found on the continental shelf in the North Atlantic show signs of impact by trawling. Lost fishing gear entangled in the corals, and scars from the heavy net doors, rollers and lines, are a common sight. In some places reefs that took over 8,000 years to grow have been completely destroyed, leaving only coral rubble behind.

Warm-water coral reefs are found in circum-tropical shallow waters along the shores of islands and continents. Here, corals feed by ingesting plankton, which the polyps catch with their tentacles, and also through the association with symbiotic algae called zooxanthellae. Stony corals deposit calcium carbonate, which over time forms the geological reef structure. Many other invertebrates, vertebrates, and plants live in close association to the scleractinian corals, with tight resource coupling and recycling, allowing coral reefs to have extremely high biodiversity in nutrient poor waters, so much so that they are referred to as the 'Tropical Rainforests of the Oceans'. Corals have certain ranges of tolerance to water temperature, salinity, UV radiation, opacity, and nutrient quantities. The extreme high diversity of coral reefs have led to the erroneous belief that they prefer nutrient rich environments, but, in fact, corals are extremely sensitive to

silt and sewage at far lower concentrations than what is classified as hazardous to humans (Nyström *et al.* 2000). Hence, even minor pollution in apparently clear waters can severely impact coral reefs and their ability to support thousands of fish species and other marine life. Sea water quality and human impacts are particularly critical to coral reefs when they are exposed to other stressors or when they are recovering from storms or bleaching events (Burke *et al.*, 2002; Wilkinson, 2002; Brown *et al.*, 2006; UNEP, 2006)

Corals are beautiful living animals that are enjoyed by millions of snorkelers and divers world wide, but they are also of vital importance for the whole coral reef ecosystem and for coastal fisheries. One of the largest declines in fishing has, in fact, been recorded in the catches of coral reef fishes, probably as a result of overexploitation of the more vulnerable species (Cheung *et al.*, 2007). If corals die, the characteristic three dimensional structure of reefs that is essential to so many of the services provided, will be lost through natural physical and biological erosion as waves, storms, tsunamis, predators, and other factors affecting corals break it down to rubble. Coral reefs support over a million animal and plant species and their economic value exceeds US\$30 billion a year.









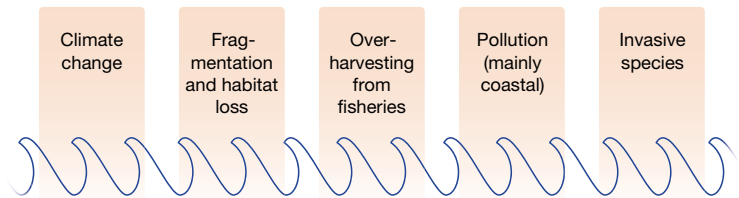
*More and more coral reefs are being degraded and destroyed by human impact and climate change*



# THREATS TO THE MARINE ENVIRONMENT



Each of the big five stressors (not in order of magnitude), 1) **Climate change**; 2) **Pollution** (mainly coastal), 3) **Fragmentation and habitat loss** (from e.g. dredging/trawling, use of explosives in fishing on coral reefs etc.), 4) **Invasive species infestations**, and 5) **Over-harvest from fisheries** may individually or combined result in severe impacts on the biological production of the worlds oceans and the services they provide to billions of people today. If climate change accelerates, the impacts on marine life from the other stressors will become severely exacerbated and the ability of ecosystems to recover will be impaired.



**Figure 8. Primary threats to the Worlds oceans include the 'Big Five' stressors.**



# CLIMATE CHANGE IN THE SEA

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change states that warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Natural systems, including oceans and coasts, are being affected by regional climate changes, particularly by temperature increases. Besides rising surface water temperatures and sea level, impacts are or will be associated with changes in the wave climate, circulation, ice cover, fresh water run-off, salinity, oxygen levels and water acidity.

Shifts in ranges and changes in algal, plankton and fish abundance have already been observed in high-latitude oceans. Besides these there are other effects that, based on published literature, have not yet become established trends as they are difficult to discern due to adaptation and non-climatic drivers. Sea level-rise is negatively contributing to coastal erosion, losses of coastal wetland ecosystems, including salt marshes and mangroves, and increasing damage from coastal flooding in many areas. These effects will be exacerbated by increasing human-induced pressures on coastal areas.



# CORAL BLEACHING

Corals, especially those which build reefs in tropical, shallow waters, are highly attuned to their environmental surroundings. Bleaching occurs when the corals are subjected to repeated and/or sustained stresses which exceed their tolerances. When this occurs, the symbiotic algae living in the coral tissue are ejected. The corals lose their colour and their white, calcareous skeleton shines through the transparent tissue.

Corals can survive this condition for a short time and even take up their symbionts if the stresses subside. However, if the stresses persist, the corals will die. One well documented cause of bleaching is increase of sea surface temperatures (SSTs). A prolonged rise in SST during the hottest months of the year by as little as 1°C above the usual monthly average can result in a bleaching event (Glynn, 1996). The first major

HadCM3 model, SRES A2a scenario  
2030-2039



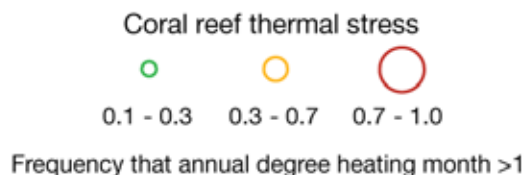
2050-2059



PCM-PCM model, SRES A2a scenario  
2030-2039



2050-2059

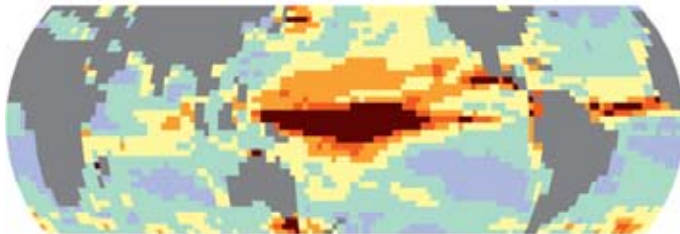


**Figure 9. Projected areas of above normal sea temperature where coral bleaching is likely to occur for the SRES A2 scenario by two different models, the PCM (1.7°C increase in 100 years) and the HadCM3 (3°C increase in 100 years) by ca. 2035 (a) and by 2055 (b). Both models project severe annual bleaching in more than 80% of the World's coral reefs by 2080 (Donner *et al.*, 2005).**

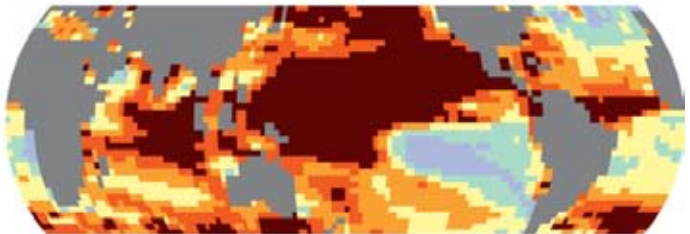
global bleaching event was recorded in 1998. Since then, several regional and local events occurred, such as in the Caribbean in 2005 (Wilkinson, C. and Souther, D., 2008). Bleaching affects the majority of the tropical reefs around the World, with a large proportion dying. The rate of recovery is different from region to region, with healthy reefs (i.e. reefs not or only marginally stressed by other pressures) generally recovering

and re-colonising quicker than reefs in poor condition. Some of the latter did not recover at all. The dead coral skeletons are broken down by wave activity and storms into coral rubble, leading to a change in the whole ecosystem from a rich and diverse coral reef into a much more impoverished community dominated by algae.

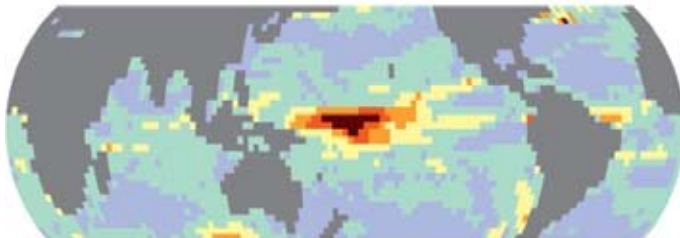
HadCM3 model, SRES A2a scenario  
2030-2039



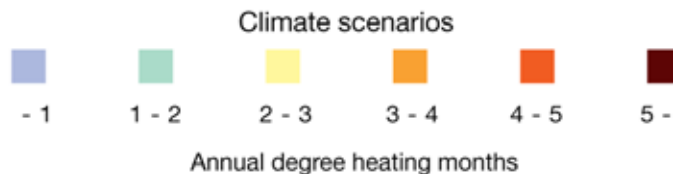
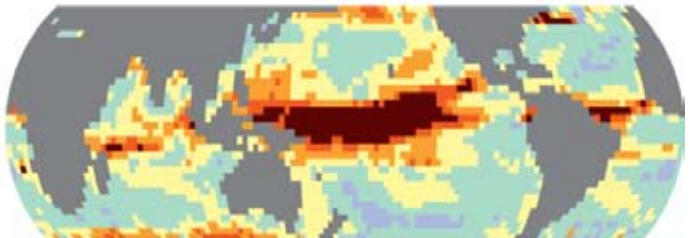
2050-2059



PCM-PCM model, SRES A2a scenario  
2030-2039



2050-2059

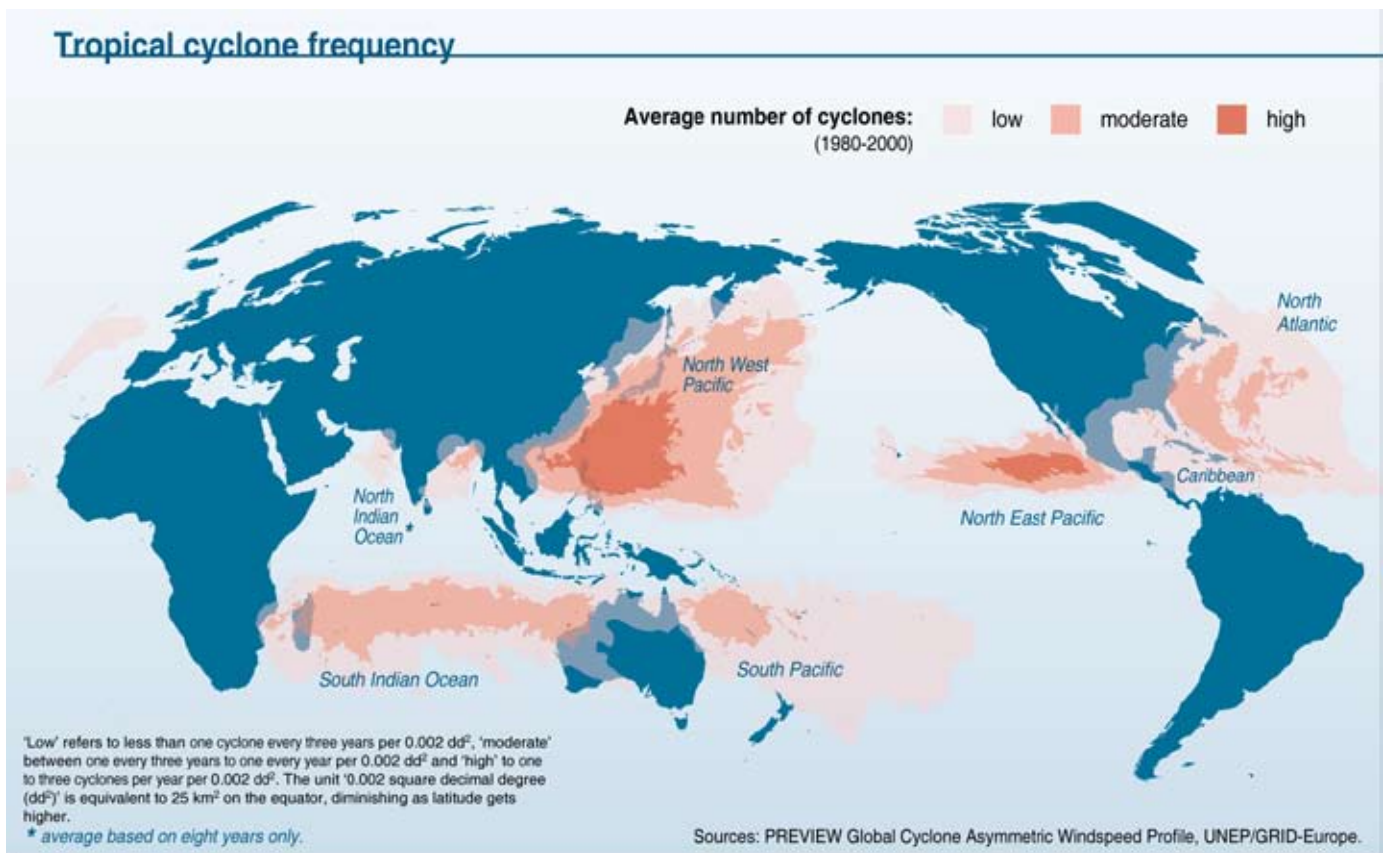


**Figure 10. The impacts of coral reefs from rising sea temperatures.** When coral reefs become heat-exposed they die, leaving the white dead coral, also known as bleaching. With even moderate pollution, the coral are easily overgrown with algae, or broken down by wave activity or storms, leaving only 'coral rubble' on the ocean bed (Donner *et al.*, 2005).

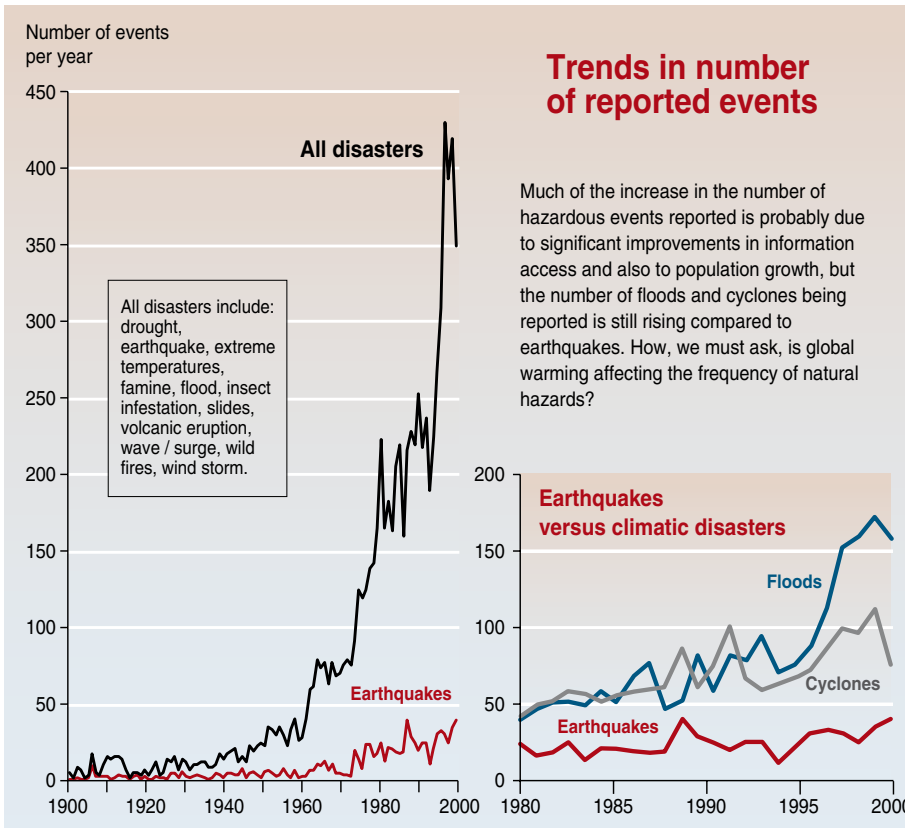
# EXTREME WEATHER AND HURRICANES IMPACT COASTS

With growing population and infrastructures the world's exposure to natural hazards is inevitably increasing. This is particularly true as the strongest population growth is located in coastal areas (with greater exposure to floods, cyclones and tidal waves). To make matters worse any land remaining available for urban growth is generally risk-prone, for instance flood plains or steep slopes subject to landslides.

The amount of sediments and nutrients into the ocean from rivers associated with unsustainable land uses, as well as from storms and sewage, also result in the eutrophication of some coastal ecosystems and the coverage of corals by silt or algae, reduced visibility and light in the water column, and hence, subsequently dramatically reduced ability of corals to recover.

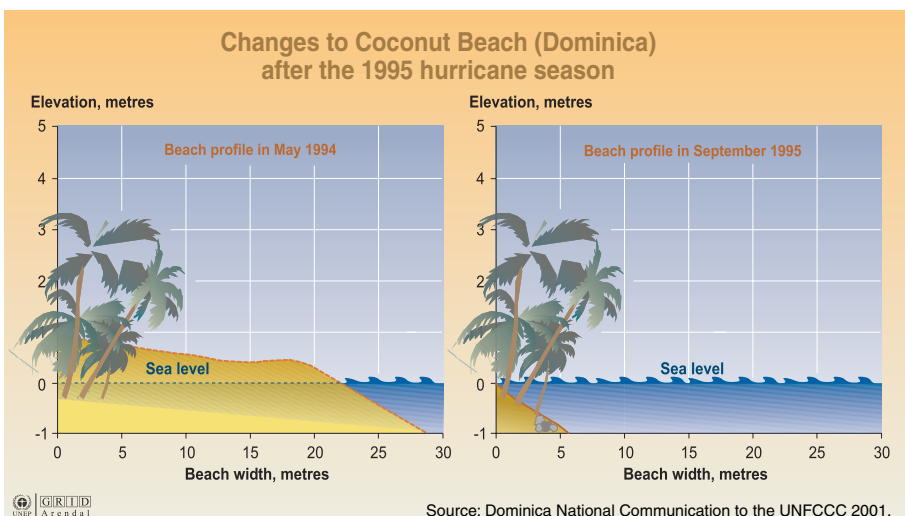


**Figure 11. Tropical cyclones, or hurricanes or typhoons, are storm weather systems, characterised by a low pressure centre, thunderstorms and high windspeeds.** As the name testifies, these occur in the tropical areas. Cyclones can, after they have formed in the oceans, move in over populated areas, creating much damage and even natural disasters. They erode beaches and destroy coral reefs, and loss of natural flood-buffers like mangroves due to coastal development increases damage further.



**Figure 12. The number of reported extreme climatic based disasters is increasing dramatically worldwide (IPCC, 2006).** While part of this increase in the number of weather related disasters, as claimed by some, may be due to better reporting mechanisms and communication, similar increases in reports has not taken place in relation to other types of disasters like the number of reported earthquakes.

**Figure 13. During a period between May 1994 to September 1995 the profile of Coconut Beach dramatically changed as a result of storm surges washing away the sand.** A rising sea level in the future, combined with more storms, will wash away vulnerable beaches. With the sand gone, the coast is more vulnerable to waves going further inland, threatening fresh water wells with salinisation, leading to land erosion, and making the areas less attractive for tourism. When a beach starts to deteriorate, the process can be amazingly quick. It is very likely that the 20th century warming has contributed significantly to the observed rise in global average sea level and the increase in ocean heat content. Warming drives sea level rise through thermal expansion of seawater and widespread loss of land-based ice. Based on tide gauge records, after correcting for land movements, the average annual rise was between 1 and 2 mm during the 20th century.



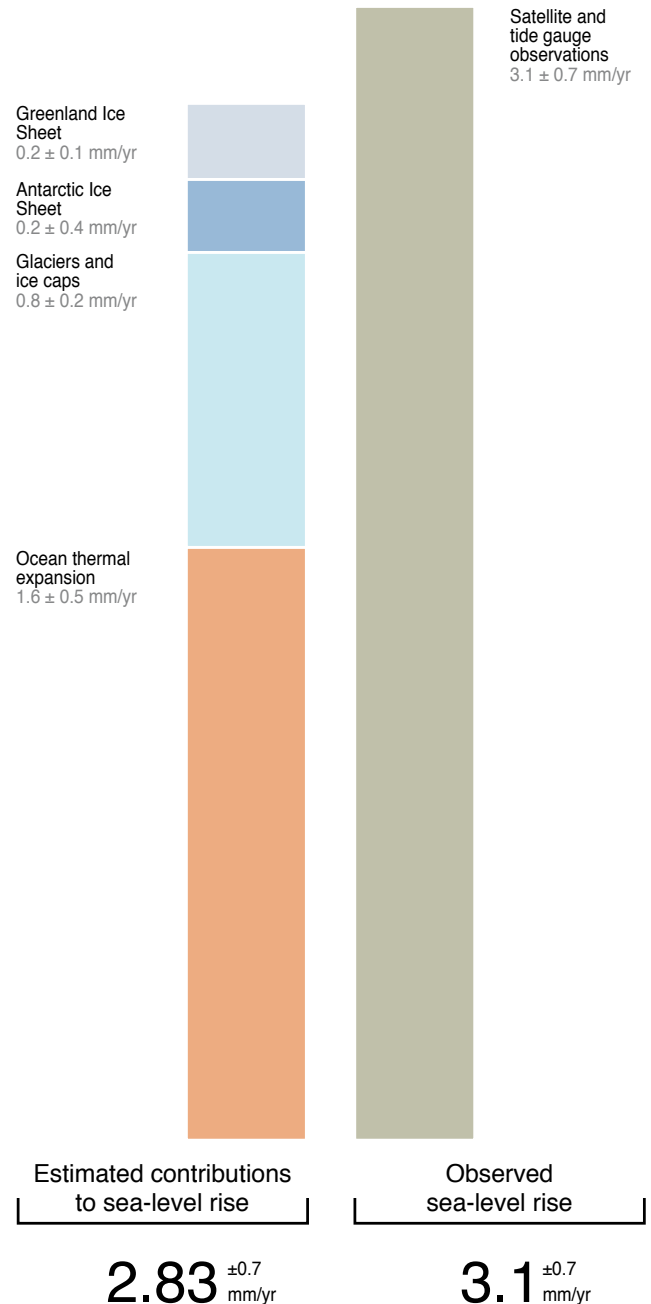
# SEA LEVEL RISE

A significant sea level rise is one of the major anticipated consequences of climate change (IPCC, 2007; UNEP 2007).

Global warming from increasing greenhouse gas concentrations is a significant driver of both contributions to sea-level rise. From 1955 to 1995, ocean thermal expansion is estimated to have contributed about 0.4 mm per year to sea level rise, less than 25 per cent of the observed rise over the same period. For the 1993 to 2003 decade, for which the best data are available, thermal expansion is estimated to be significantly larger, at about 1.6 mm per year for the upper 750 m of the ocean alone, about 50 per cent of the observed sea level rise of 3.1 mm per year. Scientists estimate the melting of glaciers and ice caps (excluding the glaciers covering Greenland and Antarctica) contributed to sea level rise by about 0.3 mm per year from 1961 to 1990 increasing to about 0.8 mm per year from 2001–2004.

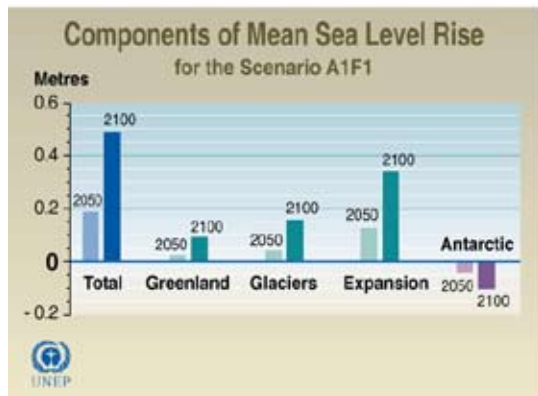
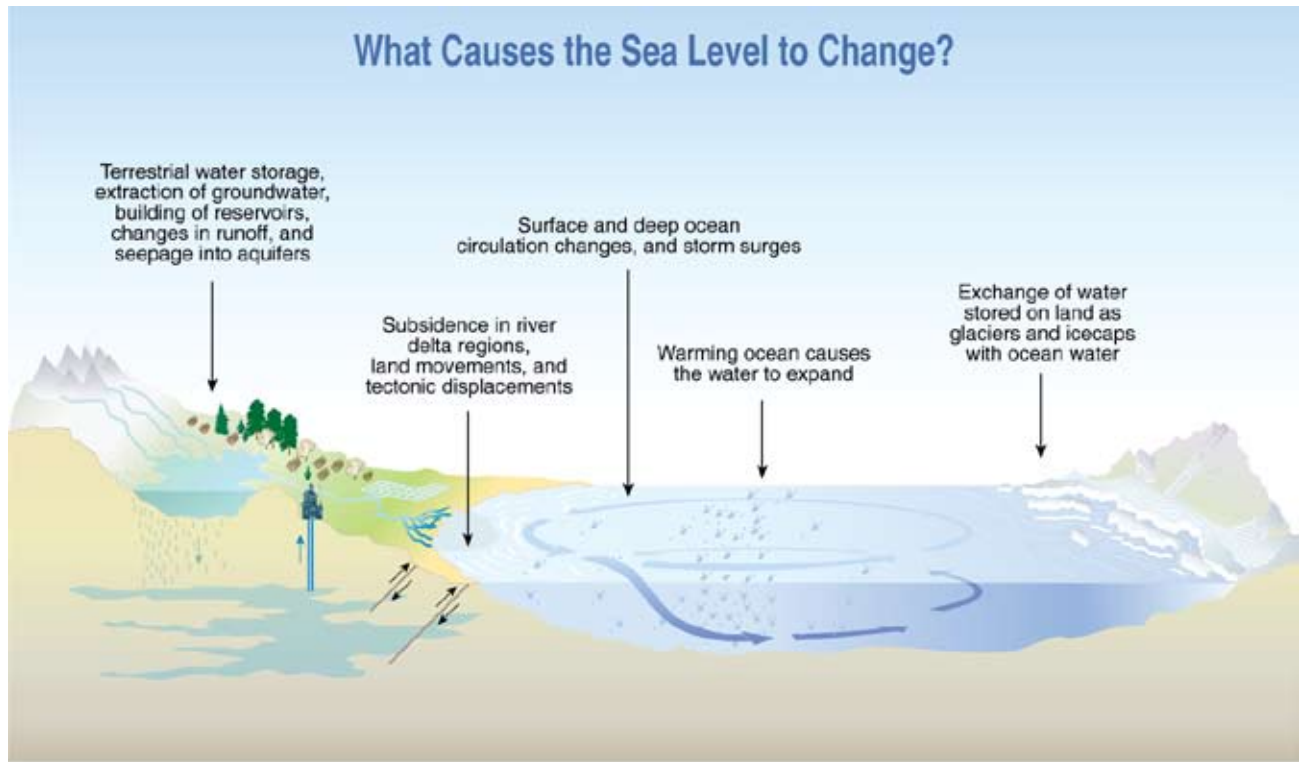
Even for today's socio-economic conditions, both regionally and globally, large numbers of people and significant economic activity are exposed to an increase and acceleration of sea level rise. The densely populated megadeltas such as those of Ganges-Brahmaputra, Mekong and Nile are especially vulnerable to sea level rise. Some 75 per cent of the population affected live on the Asian megadeltas and deltas, with a large proportion of the remainder living on deltas in Africa. Globally, at least 150 million people live within 1 metre of high tide level, and 250 million live within 5 metres of high tide (UNEP, 2007).

**Figure 14. The projected and observed sea level rise.** Observed sea level rise is currently larger than that projected by current climate models. The bar to the left also shows the contribution of different factors to sea level rise, the two most important being a) thermal expansion of ocean waters as they warm, and b) increase in the ocean mass, principally from land-based sources of ice (glaciers and ice caps, and the ice sheets of Greenland and Antarctica).





## What Causes the Sea Level to Change?

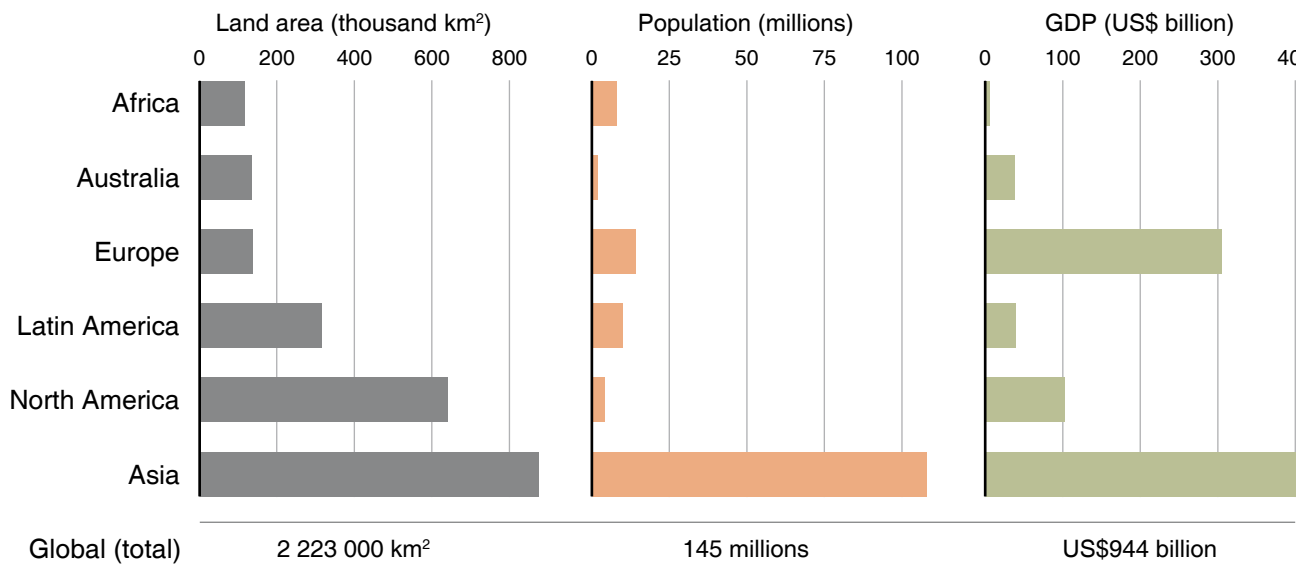


**The A1 scenario family** describes a future of rapid economic growth, a global population that peaks in the middle of the 21st century and then declines, and the rapid introduction of new and more efficient technologies. The major underlying themes are convergence among regions, capacity-building, and increased cultural and social interaction, with a substantial reduction in regional differences in per capita incomes. The A1 scenario family develops into three groups with alternative directions of technological change according to their energy systems: fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance of both (A1B)

PHILIPPE BEKAERT  
MARCH 2002

Source: David Griggs, in *Climate Change 2001, Synthesis report, Contribution of working groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 2001.

**Figure 15. How sea level rise will happen.** Expansion of the ocean and melting of land ice are two of the largest contributing factors to sea level rise.



**Figure 16. Land area, number of people impacted and projected economic losses from a 1 metre uniform sea level rise in different regions** (Anthoff *et al.*, 2006; UNEP, 2007).



# OCEAN ACIDIFICATION

The oceans act as a natural reservoir for  $\text{CO}_2$ . The dissolved  $\text{CO}_2$  reacts with the seawater to form hydrogen ions. The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in pH of 0.1 units. However, the effects of observed ocean acidification on the marine biosphere are yet mostly undocumented. Progressive acidification of the oceans due to increasing atmospheric carbon dioxide is expected to reduce biocalcification of the shells, bones and skeletons most marine organisms possess. Though the limited number of studies available makes it difficult to assess confidence levels, potentially severe ecological changes would result from ocean acidification, especially for corals both in tropical and cold water, and may influence marine food chains from carbonate-based plankton up to higher trophic levels.

The oceans are naturally alkaline, with an average pH of around 8.2, although this can vary up to 0.3 units depending on location and season. Atmospheric carbon dioxide dissolves naturally in the ocean, forming carbonic acid ( $\text{H}_2\text{CO}_3$ ), a weak acid. The hydrogen ions released from this acid lower the pH. These reactions are part of a natural buffer system, but recent studies have shown that the huge amounts of  $\text{CO}_2$  created by burning fossil fuels are over-stretching the rate by which the natural process can neutralise this acidity. The pH of the oceans has decreased 0.1 unit compared to pre-industrial levels, which equals an increase of 30 per cent in hydrogen ions. While records show that the pH of the seas can vary slightly over time and in certain areas, the continued increases in atmospheric  $\text{CO}_2$  are expected to alter ocean pH values within a very short time – an effect greater than any experienced in the past 300 million years (Caldeira *et al.*, 2003).





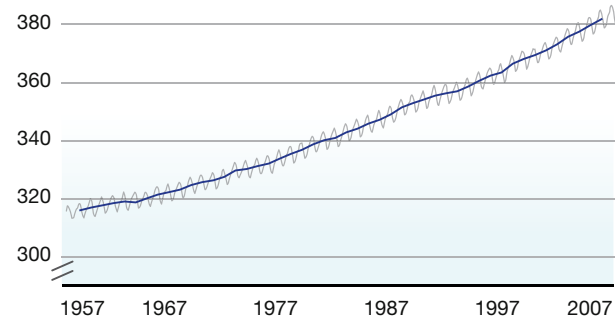
More parts of the oceans will become undersaturated with calcium carbonate, even most or all surface waters in the polar regions. All marine organisms which need carbonate to build their calcareous skeletons and shells, such as corals, seashells, crabs and crayfish, starfish and sea urchins, could be affected. Even single-celled, planktonic organisms with calcareous shells (e.g. coccolithospores, certain foraminifera etc.), which form the basis of many marine food chains, may be affected.

The impacts of ocean acidification are potentially widespread and devastating, and may change marine life as we know it. The first effects will be felt in deeper waters and the polar regions. It is expected that by 2100, around 75% of all cold-water corals will live in calcium carbonate undersaturated waters. Any part of their skeleton exposed to these waters will be corroded. Dead coral fragments, important for the settlement of coral larvae e.g. to re-colonise a reef after a bleaching event, will be dissolved. The base of the reefs will be weakened and eventually collapse. Even those organisms which might be able to cope with the undersaturated conditions will have to spend more energy in secreting their shells and skeletons, which makes them more vulnerable to other stresses and pressures.

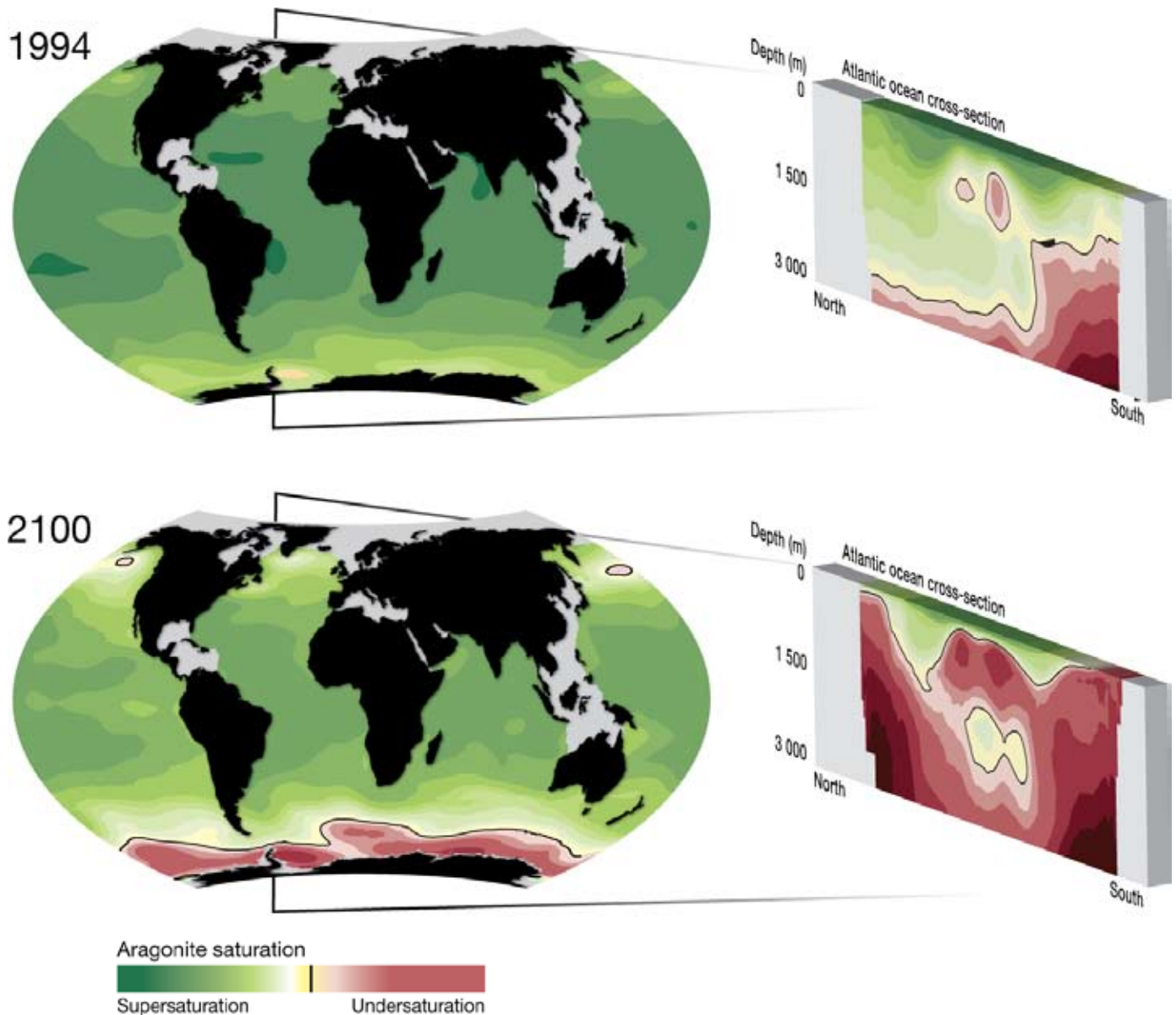
Tropical areas will remain saturated, but experience a severe fall from the optimal aragonite (a metastable form of calcium carbonate used by corals) concentrations in pre-industrial times to marginal concentrations predicted for 2100. This will add to the already increasing stresses from rising sea temperatures, over-fishing and pollution.

Ocean acidification may have severe impacts on scleractinian cold-water and deep-sea corals (Royal Society 2005; Guinotte *et al.* 2006; Turley *et al.*, 2007). Projections suggest that Southern Ocean surface waters will begin to become undersaturated with respect to aragonite 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. Studies have suggested that conditions detrimental to high-latitude ecosystems could develop within decades, not centuries as suggested previously (Orr *et al.*, 2005).

Atmospheric CO<sub>2</sub> concentration (ppm)



**Figure 17. Atmospheric concentration of CO<sub>2</sub> is steadily rising, and oceans directly assimilate CO<sub>2</sub>.** As ocean concentration of CO<sub>2</sub> increases, the oceans automatically become more acidic. This, in turn, may have severe impacts on coral reefs and other biocalcifying organisms. There is little debate on the effect as this is a straight-forward chemical process, but the implications for marine life, that may be severe due to many very pH-sensitive relationships in marine ecosystems, are still unknown.



**Figure 18.** As carbon concentrations in the atmosphere increase, so do concentrations in the ocean, with resultant acidification as a natural chemical process. The skeletons of coldwater coral reefs may dissolve, perhaps already within a few decades. The impacts will be greatest at high latitudes.

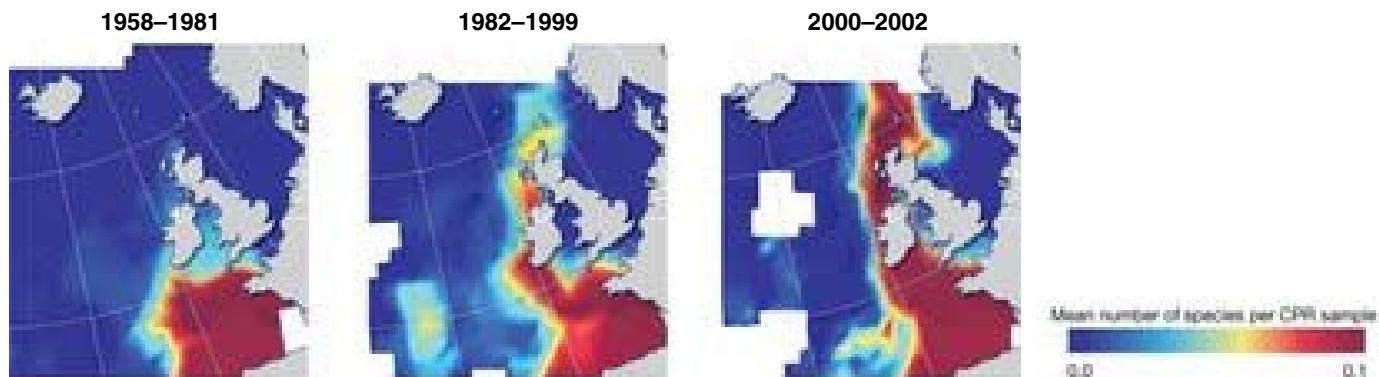
# INCREASING SEA TEMPERATURES ALREADY CAUSE CHANGES IN DISTRIBUTION OF MARINE LIFE

There is increasing evidence from a number of regions in the world of a poleward movement of warmer water species of plankton, fish, benthic and intertidal organisms in the last 50 years. These biogeographic changes have been observed in both the northern and southern hemispheres (e.g. NE Atlantic, Tasman Sea, China Sea, Bering Sea). The clearest evidence of the changes has been obtained by the Continuous Plankton Recorder (CPR) survey in the Northeast Atlantic. Here, warmer water copepod species (crustaceans) moved northwards by 10° of latitude (~1000 km) within 40 years up to 1999, a pattern that has continued since.

Species that are representative of Arctic and cold temperate waters have shown a similar movement, retreating to the north. Other studies have shown an increase in the northerly range of a number of warm temperate and subtropical fish species with evidence for dispersion along the continental slope to the west

of Europe and in some cases establishment of breeding populations of species such as red mullet, anchovies and sardines in the North Sea, much further north than ever recorded before.

In the case of the Northeast Atlantic the changes are clearly linked to rising sea temperatures and are correlated with Northern Hemisphere temperature and the North Atlantic Oscillation (NAO), the dominant mode of atmospheric variability in the North Atlantic. These correlations suggest that the changes may be a response at an ocean basin scale to what may be a global signal. The changes observed so far in the North Sea have taken place with a temperature increase of only about 0.5°C. Temperatures are expected to continue to increase, with a possible annual average increase of 6°C north of the latitude of Scotland by 2100 which, if it occurs, will lead to a further poleward movement of marine organisms.

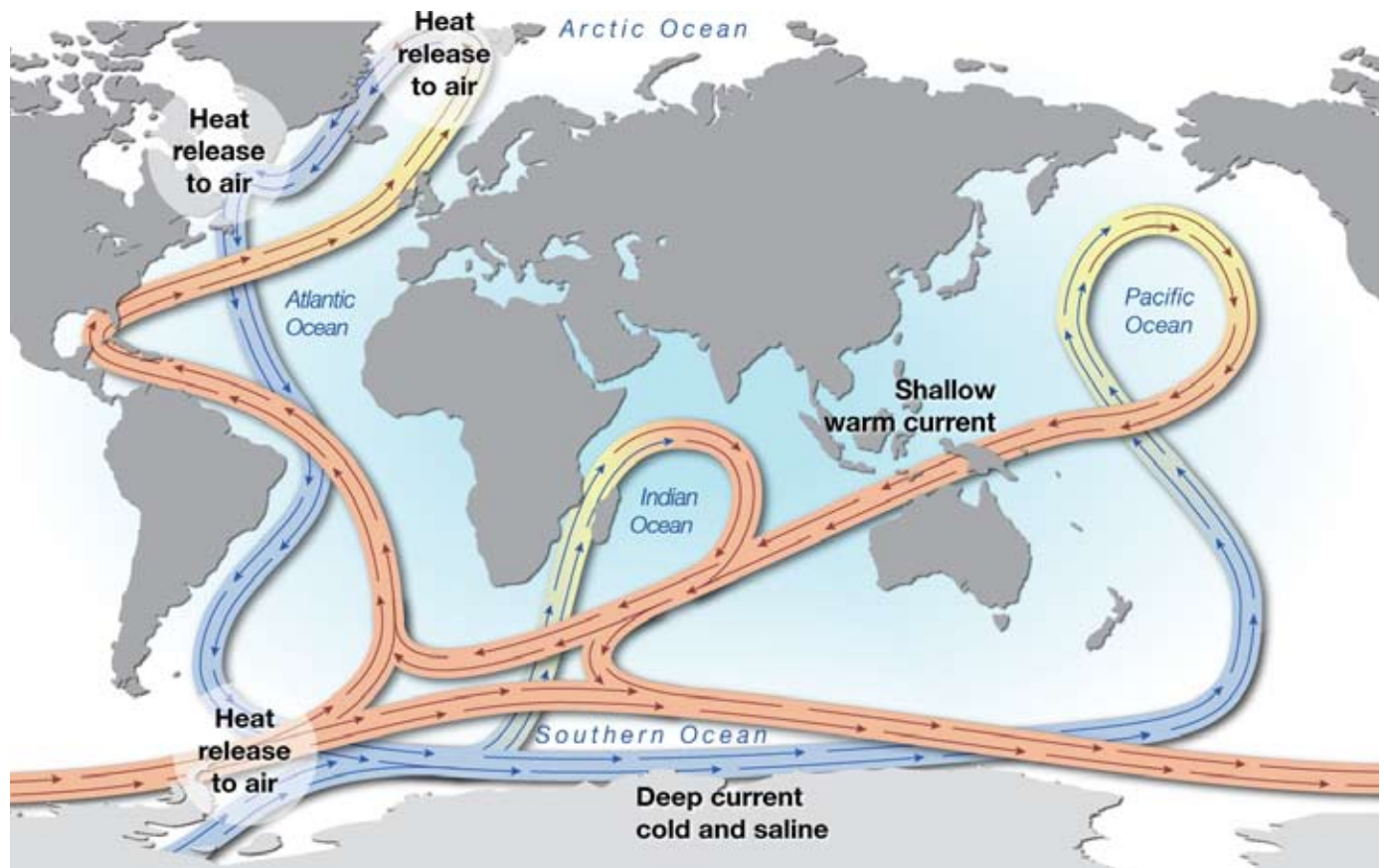


**Figure 19.** With melting sea ice and warming of the oceans, marine species change their distributions, affecting entire food chains and ocean productivity. In 2005 the subtropical dinoflagellate *Ceratium hexacanthum* was found in CPR samples from the North Sea at levels that were 6 standard deviations above previous measurements since 1958. Further evidence of this warning signal is seen in the appearance of a Pacific planktonic plant (a diatom *Neodenticula seminae*) in the Northwest Atlantic for the first time in 800,000 years, by transfer across the top of Canada due to the rapid melting of Arctic ice in 1998.

# SLOWING DOWN OF THERMOHALINE CIRCULATION AND CONTINENTAL MARGIN DENSE-WATER EXCHANGE MECHANISMS

A fifth very serious impact of climate change may be on ocean circulation. Palaeo-analogues and model simulations show that the Meridional Overturning Circulation (MOC) can react abruptly and with a hysteresis response, once a certain forcing threshold is crossed. Discussion on the probability of the forc-

ing thresholds being crossed during this century lead to different conclusions depending on the kind of model or analysis (Atmosphere-Ocean General Circulation Models, Earth system models of intermediate complexity or expert elicitations) being used. Potential impacts associated with MOC changes within the marine



**Figure 20.** The Meridional Overturning Circulation plays a crucial role for life in the oceans. If this ocean conveyor belt slows down or changes as a result of melting ice and increasing ocean temperatures, the impacts on marine life may become severe.

environment include changes in marine ecosystem productivity, oceanic CO<sub>2</sub> uptake, oceanic oxygen concentrations and shifts in fisheries. Adaptation to MOC-related impacts is very likely to be difficult if the impacts occur abruptly (e.g., on a decadal time-scale). Overall, there is high confidence in predictions of a MOC slowdown during the 21st century, but low confidence in the scale of climate change that would cause an abrupt transition or the associated impacts. However, there is high confidence that the likelihood of large-scale and persistent MOC responses increases with the extent and rate of anthropogenic forcing.

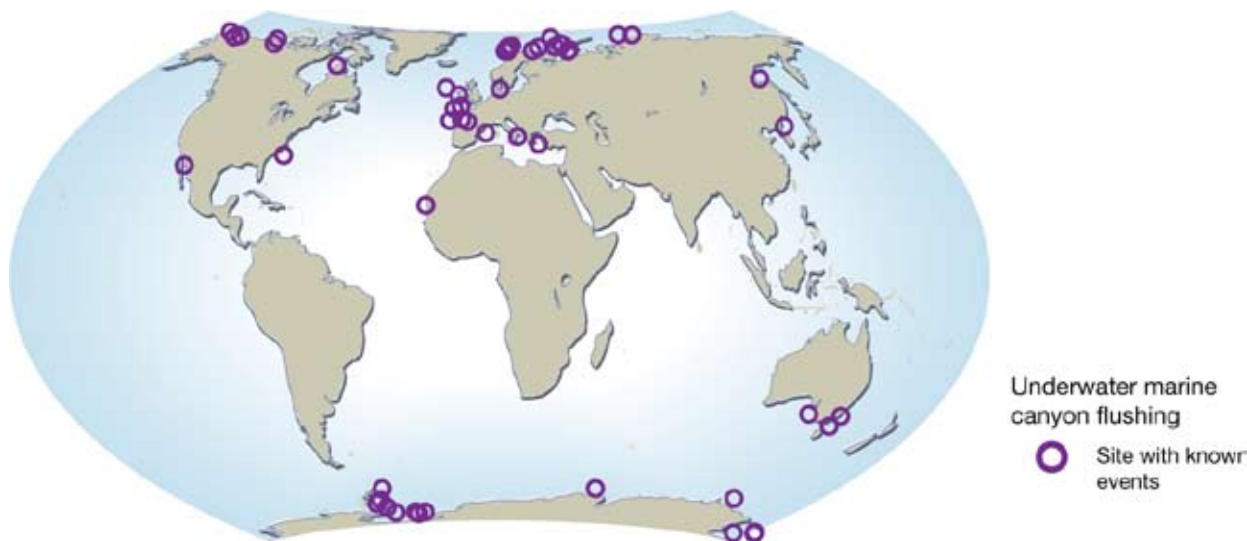
Dense shelf water cascading is a type of marine current driven exclusively by seawater density contrast. The cascading process is normally seasonal and triggered by the formation, on the shelf, of dense water by cooling and/or evaporation and its sinking down slope towards deeper offshore areas.

There are a number of places around the world where dense water masses flow 'over the edge' of the continental shelf into

the deep sea, often using and carving submarine canyons. This margin exchange process provides an essential link/exchange between shallow and deep waters and involves water and considerable particulate and dissolved loads, especially when operating in a 'flushing' pattern.

Due to their proximity to land areas, continental shelves are the locus of input, transit and accumulation of land born particulate substances, including pollutants. Dense shelf water cascading transports these particulate substances for recycling into the deep sea. Any future climate change driven alterations in the temperature regime of the oceans, such as the predicted increase in the horizontal layering ('stratigraphy') of water masses, will have a significant impact in the frequency and intensity of cascading events, and thereby on the biogeochemical budgets of shallow waters and the ventilation of deep water areas.

Scientists working under the large deep-sea research project HERMES (Hotspot Ecosystem Research on the Margins of Eu-



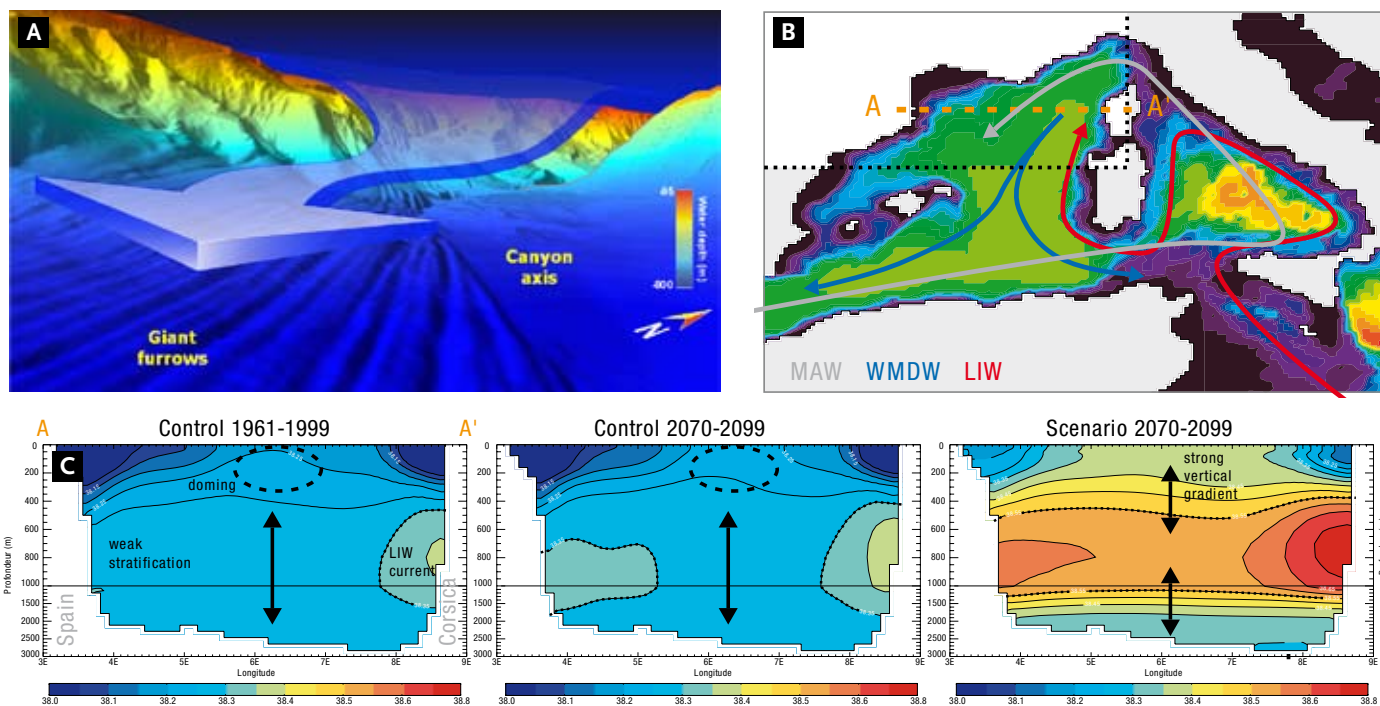
**Figure 21. Coastal regions in the World where dense shelf water cascading 'flushing' has been observed.** Knowledge and mapping of these processes is still scarce due to uneven research effort. The map shows sites with known dense shelf water cascading phenomena, which often may involve the 'flushing' effect (Ivanov *et al.*, 2004; Durrieu *et al.*, 2005; Heussner *et al.*, 2006). It is most likely that this phenomenon is also active off the coast of Alaska, Chile, Argentina and West and southern Africa and in parts of the Indian Ocean. Dense shelf water cascading is highly sensitive to increases in temperature, and hence, climate change. Data from Canals *et al.* (2006).



ropean Seas) – of which UNEP is a partner – documented, three years ago, the occurrence and effects of a dense shelf water cascading phenomenon in the Gulf of Lions (North-western Mediterranean) (Canals *et al.*, 2006). The amount of water transported in 4 months from the Gulf of Lions to the deep Western Mediterranean, via the Cap de Creus canyon, equalled around 12 years of the water input from the river Rhone, or 2 years of input from all rivers draining into the Mediterranean. How this dense shelf water cascading in the Gulf of Lions affects the population of the deep-sea shrimp *Aristeus antennatus* (marketed as ‘crevette rouge’) was only recently discovered (Company *et al.*, 2008). Initially, the strong currents (up to 80 centimetres per second) associated with intense cascading events displace shrimp populations from the normal fishing grounds, producing a temporary fishery collapse. However, despite this initial negative effect, the food (particulate matter) provided by the currents soon leads to a large increase in recruitment and juveniles of this highly valuable species. This mit-

igates overexploitation, and results in plentiful landings of large, adult deep-sea shrimp between 3 and 5 years after major cascading events.

A decrease of winter deep water formation in the Gulf of Lions is expected to occur during the twenty-first century according to modelling results using the IPCC-A2 scenario which could obviously decrease the frequency and intensity of dense shelf water cascading events. Without this regenerative mechanism, fishery pressure could quickly deplete the stocks of *Aristeus antennatus* and other valuable deep-sea living resources in the area. If the predicted reduction of deep water formation in high latitudes as in the Nordic and Arctic regions (Gregory *et al.*, 2006) would affect the frequency of dense shelf water cascading in the margins of the polar regions, the impacts on the biogeochemistry of the global ocean could be considerable.



**Figure 22. Climate change models (B, C1–3) predict that the flow of dense shelf water (DSW) into the deep sea (A) will decrease in the next 100 years.** (A: Courtesy of GRC Marine Geosciences-University of Barcelona, CEFREM-CNRS/University of Perpignan, and ICM Barcelona-CSIC; B,C: Based on Somot *et al.*, 2006.)

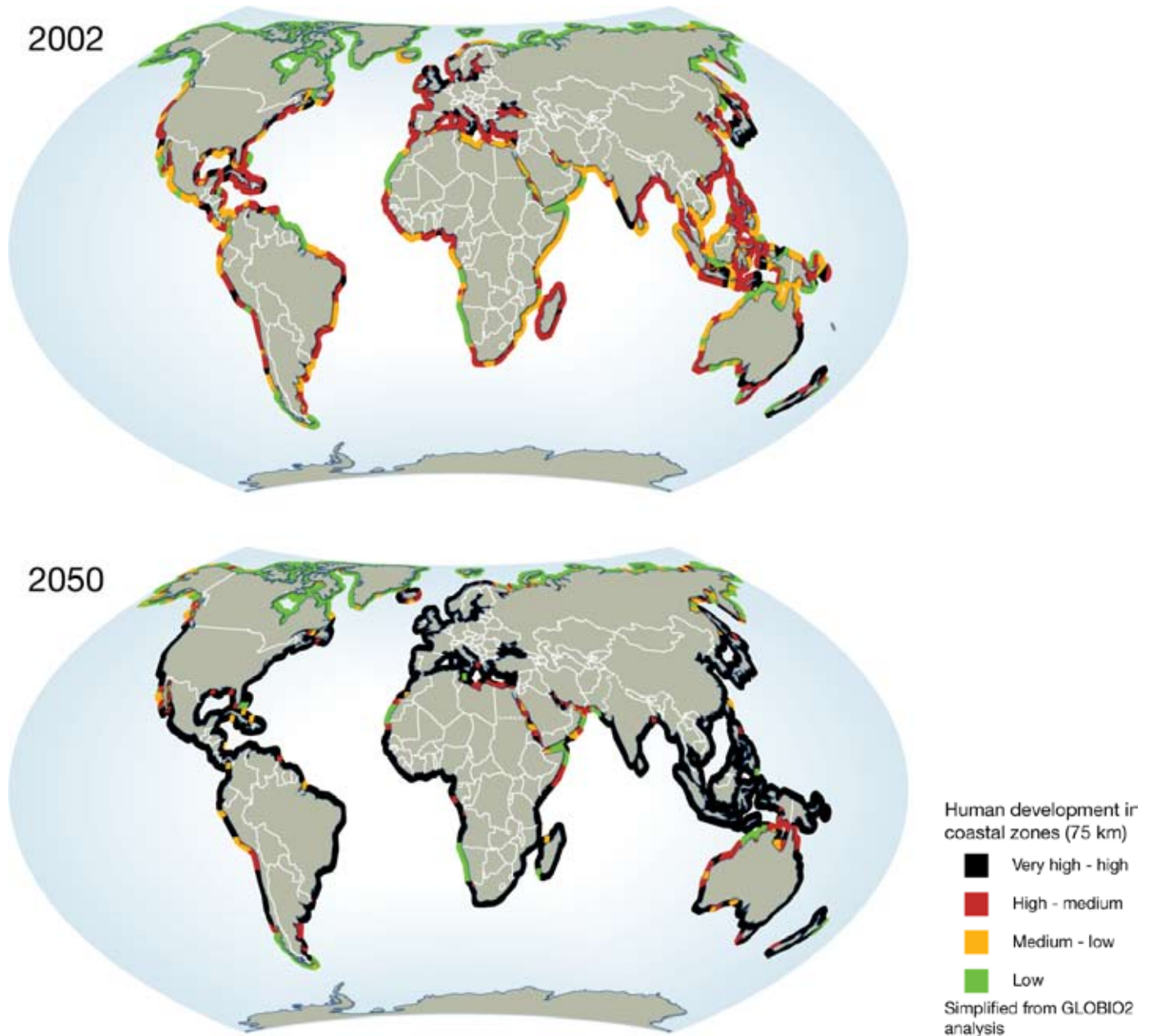
# MARINE POLLUTION AND COASTAL DEVELOPMENT



A major threat beyond overexploitation of fisheries and physical destruction of marine coastal habitats by unsustainable fishing practices is undoubtedly the strong increase in destruction of coastal habitats (Lotze *et al.*, 2006) by coastal development and discharge of untreated sewage into the near-shore waters, resulting in enormous amounts of nutrients spreading into the sea and coastal zones (Burke *et al.*, 2002; Wilkinson, 2002; Brown *et al.*, 2006; UNEP, 2006).

Around 60% of the waste water discharged into the Caspian Sea is untreated, in Latin America and the Caribbean the figure is close to 80%, and in large parts of Africa and the Indo-Pacific the proportion is as high as 80–90% (UNEP, 2006). An estimated US\$ 56 billion is needed annually to address this enormous waste water problem. However, the costs to coral reefs, tourism and losses in fisheries and human health risks may be far more expensive. Waste water treatment is also one of the areas where least progress is being made globally. Many marine species, including cold-water corals like *Lophelia* sp., are highly sensitive to temperature changes and dissolved oxygen, making them highly vulnerable to climate change and pollution (Dodds *et al.*, 2007). This, in turn, makes them vulnerable to diseases (Hall-Spencer *et al.*, 2007). The poor management of sewage not only presents a dire threat to health and ecosystems services, it may also increase poverty, malnutrition and insecurity for over a billion people (UNEP, 2006).

Marine pollution includes a range of threats including from land-based sources, oil spills, untreated sewage, heavy siltation, eutrophication (nutrient enrichment), invasive species, persistent organic pollutants (POP's), heavy metals from mine tailings and other sources, acidification, radioactive substances, marine litter, overfishing and destruction of coastal and marine habitats (McCook 1999, Nyström *et al* 2000, Bellwood *et al.* 2004). Overall, good progress has been made on reducing persistent organic pollutants (POPs), with the exception of



**Figure 23. Infrastructure development, intensive agricultural expansion, urbanisation and coastal development are increasing the flow of sediments and sewage into the ocean. The situation is most severe around Europe, the East coast of the United States, East of China and in Southeast Asia. These are also primary fishing grounds.**

the Arctic. Oil inputs and spills to the Seas has been reduced by 63% compared to the mid-1980s. Oil releases from tanker accidents have gone down by 75%, from tanker operations by 90% and from industrial discharges by some 90%, a result partially obtained through the shift to double-hulled tankers (UNEP, 2006; Brown *et al.*, 2006). Progress on reducing emissions of heavy metals is reported in some regions, while increased emissions are observed in others, including from electronic waste and mine tailings in Southeast Asia. Sedimentation has decreased in some areas due to reduced river flows as a result of terrestrial overuse for agricultural irrigation, while increasing in other regions as a result of coastal development and watershed deforestation as well as declines in mangroves (Burke *et al.*, 2002; McCulloch *et al.*, 2003; Brown *et al.*, 2006; UNEP, 2006).

Together with agricultural run-off to the sea or into major rivers and eventually into the ocean, nitrogen (mainly nitrate and ammonium) exports to the marine environment are projected to increase at least 14% globally by 2030 (UNEP, 2006). In Southeast Asia more than 600,000 tons of nitrogen are discharged annually from the major rivers. These numbers may become further exacerbated as coastal population densities are projected to increase from 77 people/km<sup>2</sup> to 115 people per km<sup>2</sup> in 2025. In Southeast Asia, the numbers are much higher and the situation more severe. Wetlands and mangroves are also declining rapidly, typically by 50–90% in most regions in the past 4 decades (UNEP, 2006). This, in turn, will severely exacerbate the effects of extreme weather, the ability of coral reefs to resist and recover from climate change and reduce the productivity of coastal ecosystems which supply livelihoods and basic food to the impoverished.



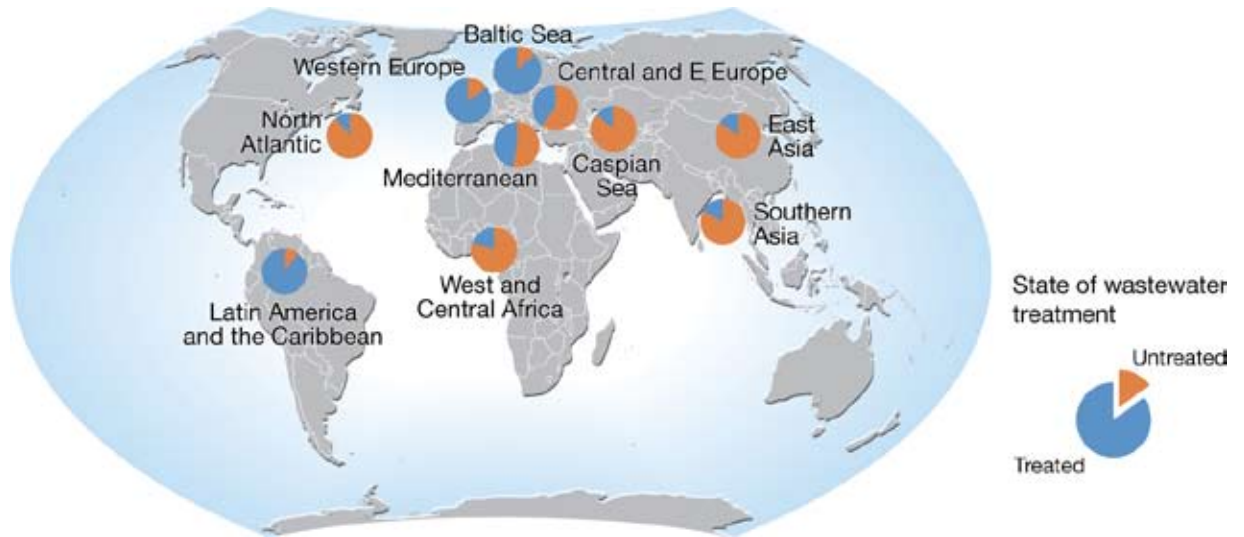


Figure 24. Sewage treatment is low or absent in many parts of the World, leading to eutrophication of the coastal zone, (toxic) algae blooms and dramatically reduce the ability of coral to recover from bleaching events dramatically.



Figure 25. Dead zones (hypoxic i.e. oxygen deficient water) in the coastal zones are increasing, typically surrounding major industrial and agricultural centers.

# IMPACT OF UNSUSTAINABLE FISHING PRACTICES ON SEA BED AND OCEAN PRODUCTIVITY

Fishery resources, the harvest of the oceans, are concentrated in marine areas where the environmental conditions support a high productivity. Such areas are found in coastal waters as well as in deeper waters on the continental shelves and around seamounts (Roberts *et al.*, 2006; Garcia *et al.*, 2007).

The severe decline of stocks in many traditional coastal fishing grounds has given rise to an increase in regulations. This, in turn, has intensified the search for new and less controlled fish stocks and fishing grounds. Modern technology, such as remote sensing, sonar and Global Positioning Systems, together with incentives and subsidies, has brought deep-water and high sea areas and habitats with high production, such as continental slopes, seamounts, cold-water coral reefs, deep-sea sponge fields, into the reach of fishing fleets trying to exploit the last refuges for commercial fish species. Fishing vessels are now operating at depths greater than 400 metres, sometimes as great as 1,500 to 2,000 metres (Morato *et al.*, 2006a). New species are being targeted, often with great success and large catches in the first 2–3 years.

However, this success is in most cases only short-lived, and followed quickly by a complete collapse of stocks ('boom and bust' cycle). Especially seamounts with their unique and often endemic fauna are particularly vulnerable to trawling (Koslow *et al.*, 2001; Morato *et al.*, 2006b). The reason for this is the special life history of many deep-water organisms, including fish species of commercial interest. Unlike their counterparts which are adapted to live in the much more variable and dynamic shallow waters systems, deep sea fish species are characterised by low reproduction and fecundity, long life, and reach maturity at a late stage. Orange roughy, one of the species often targeted by deep-water and seamount fisheries, matures from 20 to 30 years of age. Individuals can live to more than 200 years of age, which means that a fish ending up on a dinner plate could have hatched at the time of Napoleon Bonaparte. These traits render deep-water fish stocks highly vulnerable to overfishing with little resilience to over-exploitation (Morato *et al.*, 2006b; Cheung *et al.*, 2007). With very few exceptions, and especially without proper control and management, deep-sea fisheries cannot be considered as a replacement for declining resources in shallower waters (Morato *et al.*, 2006a).



Among the most destructive fishing methods in the World is bottom trawling (Thrush and Dayton, 2002; Pusceddu *et al.*, 2005; Tillin *et al.*, 2006; de Juan *et al.*, 2007, Hixon *et al.*, 2007). Large nets, kept open and weighted down by heavy 'doors' and metal rollers, are dragged by a trawler across the sea bed. This virtually plows and levels the seafloor, picking up fish and shrimps but also catching, crushing and destroying other marine life.

The North Sea and Grand Banks have been major sites of bottom trawling, with some traditional and easily accessible areas being trawled multiple times per year. Indeed, landings data collated for round- and flatfish caught in the northern, central and southern North Sea from 1906 to 2000 as proxies for total otter and beam trawl effort, respectively, indicate that the southern and much of the central North Sea were fished intensively throughout the 20th century, whilst the northern North Sea was less exploited, especially in earlier decades. The fisheries efforts intensified markedly from the 1960s onwards. Biogeographical changes from the beginning

to the end of the century occurred in 27 of 48 taxa. In 14 taxa, spatial presence was reduced by 50% or more, most notably in the southern and central North Sea; often these were long-lived, slow-growing species with vulnerable shells or tests. By contrast, 12 taxa doubled their spatial presence throughout the North Sea. Most biogeographical changes had happened by the 1980s. Given that other important environmental changes, including eutrophication and climate change, have gained importance mainly from the 1980s onwards, the study concluded that the changes in epibenthos observed since the beginning of the 20th century have resulted primarily from intensified fisheries (Callaway *et al.*, 2007). Whereas trawling in shallow coastal waters is often carried out by smaller vessels, deep-water and high sea bottom trawling requires large and powerful ships. Such fleets are mostly based in industrialised countries, but fish intensively and for months at a time across the World's oceans. Often these distant water fishing fleets are fuelled and kept afloat (literally) by subsidies and incentives, without which their operation would hardly be economically viable.









A decade ago, there was still much debate on the impacts on bottom trawling, as summarized in several reviews including those by the FAO. Today, there is a much larger growing body of empirical evidence, along with improved models, that document severe impact of trawling worldwide (Hiddink *et al.*, 2006a, b, c; Hiddink *et al.*, 2006; 2007; Callaway *et al.*, 2007; Davies *et al.*, 2007; Gray *et al.*, 2006; Tillin *et al.*, 2006). This includes, but is not limited to, China (Yu *et al.*, 2007); the North Atlantic region (Tillin *et al.*, 2006; Callaway *et al.*, 2007; Eastwood *et al.*, 2007; Kensington *et al.*, 2007; Liwue *et al.*, 2007; Waller *et al.*, 2007); the Wadden Sea (Buhs and Reise, 1997; Lotze, 2005); the Mediterranean (Coll *et al.*, 2007); the Caribbean (Garcia *et al.*, 2007); the East and Western Pacific (Pitcher *et al.*, 2000; Hixon and Tissot, 2007; Fergusson *et al.*, 2008); and the South Atlantic (Keunecke *et al.*, 2007). Several of these studies have reported reductions in taxa and/or abundance in the range of 20–80% following years of intensive trawling (compared to pristine and/or historic data). This is especially so for demersals and benthic fauna, with reductions reported up to 80% on fishing grounds. The damage exceeds over half of the sea bed area of many fishing grounds, and is worst in inner and middle parts of the continental shelves, severely affecting in particular small-scale coastal fishing communities (Dacruz *et al.*, 1994; Liwue *et al.*, 2007). Unlike their shallow water counterparts, deep sea communities recover slowly, over decades. Indeed, the impact varies with type of trawl, habitat and frequency and intensity of trawling (Kaiser *et al.*, 2006; Quieros *et al.*, 2006). Trawling at the scales frequently observed today accounts for a major or even the most damaging practice in the fisheries industry. Studies have suggested that the impacts of trawling on the seabed equals or exceeds the impact of all other types of fishing combined (Eastwood *et al.*, 2007).

Bycatch is also a major problem associated with trawling (Kumar and Deepthi, 2006). For many coastal populations, large-scale, industrial bottom trawling of their traditional fishing grounds (often carried out unregulated illegally and unreported by distant fishing fleets) ruins local fisheries with devastating effects on local fishermen, industry and livelihoods. Many of the larger ships process the fish directly onboard in enormous quantities. Most likely over one-third of the World catch is simply discarded due to inappropriate fish sizes, or simply due to unintended bycatch, particularly as a result of bottom trawling (Kumar and Deepthi, 2006).



Bottom trawling physically impacts the seabed and thereby some of the most productive marine habitat. Moreover, the intensity of the fisheries is a critical factor as it may take place simultaneously with other pressures, including land-related or climate change threats. Over 65% of the World's seagrass communities have been lost by land reclamation, eutrophication, disease and unsustainable fishing practices (Lotze *et al.*, 2006), and nearly all cold-water coral reefs observed in the North East Atlantic show scars and impacts from bottom trawling.



It is important, however, to realize that many types of fishing gear other than trawling may be severely damaging as well. A major challenge is the fact that very modest levels of trawling may increase productivity of certain genera, and localized small-scale trawling practices will likely have limited impact. Much debate has taken place on fisheries and particularly bottom trawling, and many reviews have pointed to the effect that the practice sometimes may be sustainable in some regions. However, given the capacity of most of the world's fishing fleet, of growing pollution, climate change and coastal

development, little doubt now remains that trawling practices in very many places are quite unsustainable (Callaway *et al.*, 2007; Davies *et al.*, 2007).

In the light of the impact which bottom trawling has on the marine fauna, ecosystems and biodiversity, more than 1,400 scientists and marine experts have signed a petition. International policy and decision makers started to address this issue in 2003/4, and the 58th session of the United Nations General Assembly considered proposals for a moratorium on bottom trawling and called for urgent consideration of ways to integrate and improve, on a scientific basis, the management of risks to the marine biodiversity of seamounts, cold water coral reefs and certain other underwater features.

However, without marine protected areas and appropriate enforcement, especially in the deeper waters and the high seas, these damaging practices are continuing. Without increased regulation, governance, enforcement and surveillance on the high seas and on the continental shelves in many regions, unsustainable and damaging fishing practices will continue. Currently, there is virtually no protection of the vulnerable marine ecosystems and biodiversity occurring on continental shelves. Indeed, in most regions, marine protected areas (MPAs) are non-existent, in others they only amount to less than 1% of the marine area. Targets have been set for setting up MPA networks and systems, however, it is apparent that under the current rate of establishment, the CBD's target and the WPC (World Park Congress) target will not be met (Wood *et al.* in press).

Several countries have started some restrictions on bottom trawling in their national waters, but bottom trawling in areas beyond national jurisdiction is mostly unregulated. A few regional fisheries management organisations, such as the North East Atlantic Fisheries Commission (NEAFC), have (temporarily) closed some high risk areas beyond national jurisdiction to bottom fishing in order to protect vulnerable ecosystems. However, these measures apply only to member states (i.e. not to foreign fishing fleets) and cannot be properly controlled and enforced, which seriously weakens their effectiveness. There are now discussions ongoing with several bodies including the FAO on developing better international guidelines for the management of deep-sea fisheries in the high seas, but urgent action is needed.

# EXOTIC AND INVASIVE SPECIES INFESTATIONS – THE NEW PIRATES OF THE WORLD’S OCEANS

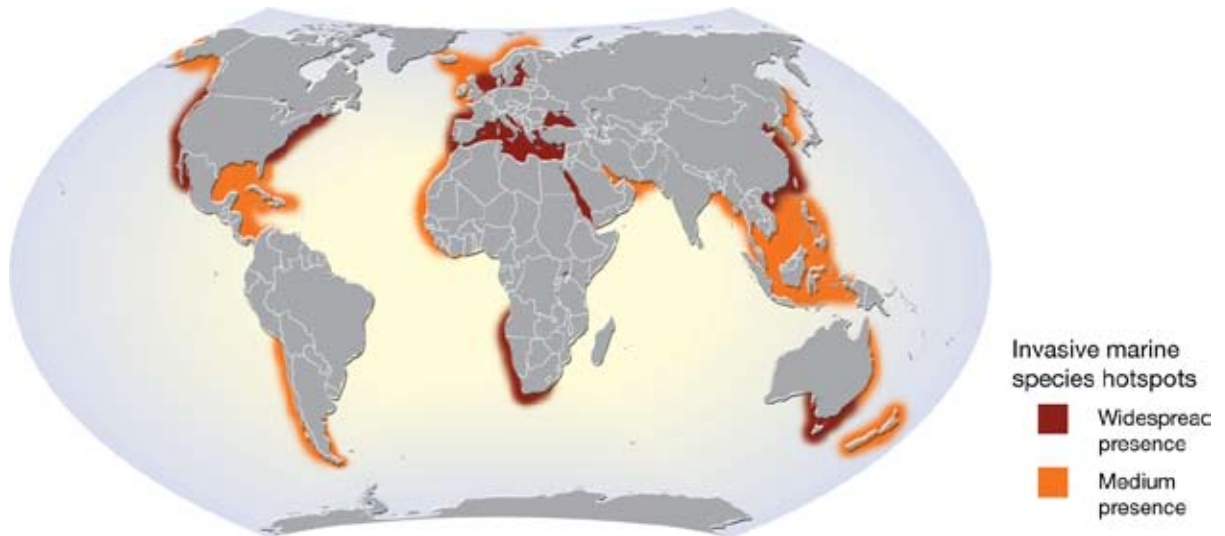
All across the planet, the number and severity of outbreaks and infestations of invasive species (i.e. species purposefully or accidentally introduced in non-native environments) is growing, and invasions of marine habitats are now occurring at an alarming rate (Ruiz *et al.* 1997). Exotic and invasive species have been identified by scientists and policymakers as a major threat to marine ecosystems, with dramatic effects on biodiversity, biological productivity, habitat structure and fisheries (Carlton 1999, Lotze *et al.* 2006). The combined number of invasive marine plant and invertebrates in Europe and North-America has increased from some 25 around 1900 to over 175 in 2000, and is still rising, particularly concurrent with the intensification of fishing and bottom trawling after 1950.

Although no habitat is immune to invasions (Lodge 1993), some habitats are more invaded than others. This can be explained in two, not mutually exclusive, conceptually different ways. The first is that the number of established exotic species is a direct function of the number introduced. Thereby, habitats that are more influenced by introduction vectors than others will harbour more exotic species (Williamson 1996). The second explanation is that some habitats are more readily invaded than others due to physical or biological factors that facilitate or prevent the success of exotic species (Elton 1958). One factor that may contribute to the success of exotic species is when the recipient ecosystem is heavily destabilized (Vermeij 1991) by human disturbance (e.g. pollution, overfishing etc.). In the Black Sea, overfishing and eutrophication triggered a trophic cascade leading to a massive bloom of the invasive comb jelly (*Mnemiopsis leidyi*) (Daskalov *et al.* 2007). In this study the depletion of

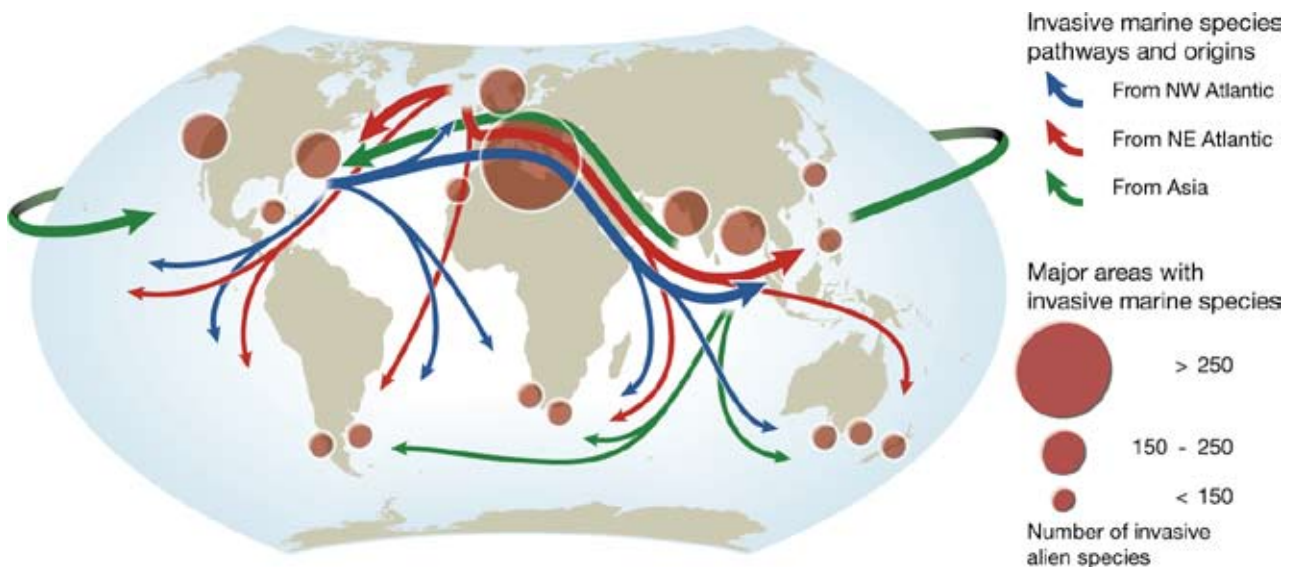
marine predators was detected as the first ‘regime shift’. There are several reports from around the world demonstrating a decline in the abundance of marine predators caused by intensive fishing (trawling etc.) (e.g. Stevens *et al.* 2000, Graham *et al.* 2001), probably resulting in habitats that are more susceptible to exotic species.

Most introductions of exotic and invasive species result from anthropogenic dispersal (Ruiz *et al.* 1997). The relative importance of different mechanisms of dispersal varies spatially and temporally, but the worldwide movement of ships seems to be the largest single introduction vector (ballast water and ship fouling) (Ruiz *et al.* 1997, Gollasch 2006). Indeed, the patterns of dispersal are strongly concurrent with major shipping routes, while the establishment globally appears to be strongly concurrent with intensity of fisheries, bottom trawling, pollution and other stressors. Hence, while some species may become invasive or exotic species may become infestations, it is clear that this pattern is so strongly concurrent with other man-made pressures to the oceans that their dispersal and establishment as pests appear to be caused by severe man-made disruptions of the marine ecosystems.

It may be true that exotic and invasive species have not caused extinction of native marine species (Briggs 2007), but there are examples of invasive species totally changing the relative abundance of species within a community (Daskalov *et al.* 2007). Thus, the invasions of exotic and invasive species to marine habitats becoming a subject of global environmental concern seem legitimate.



**Figure 27.** The locations of major problem areas for invasive species infestations or occurrence of exotic species in the marine environment. The impacted areas are concurrent with the areas subjected to the worst pollution, the most intensive fisheries and bottom trawling, and major shipping routes.

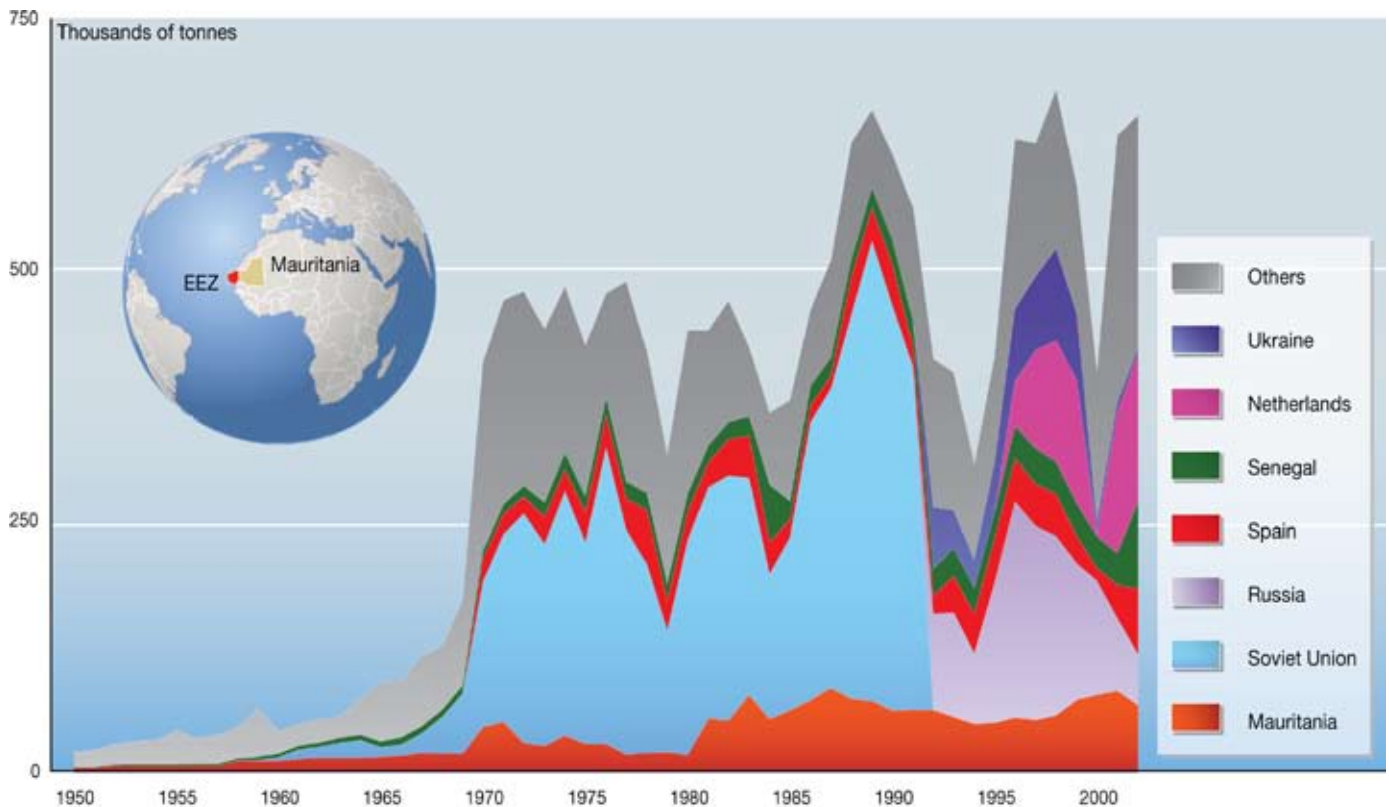


**Figure 28.** The major pathways and origins of invasive or exotic species infestations in the marine environment. These patterns are strikingly concurrent with major shipping routes.

# THE PRESSURES AND FATE OF THE CONTINENTAL SHELVES IS BOTH A NATIONAL AND INTERNATIONAL RESPONSIBILITY

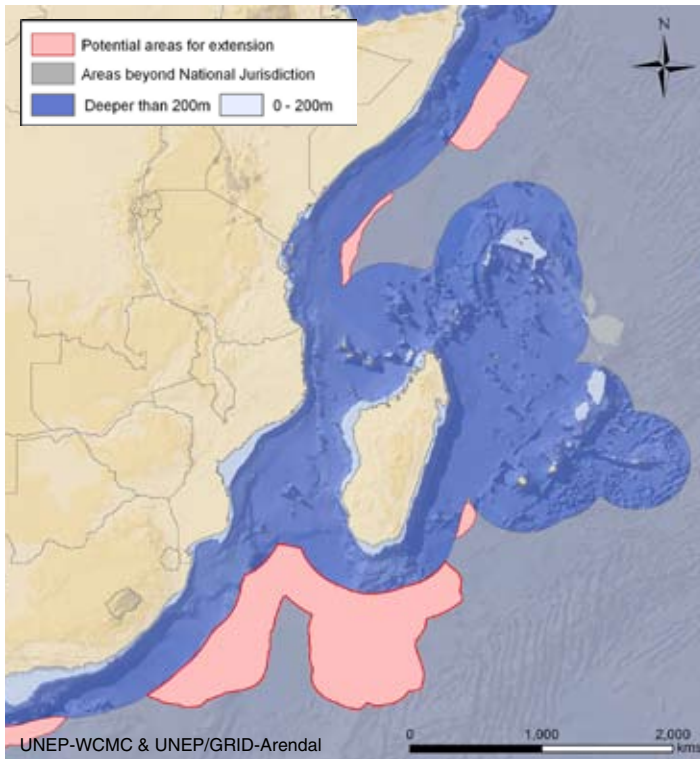
Marine fisheries represent a significant, but finite, natural resource for coastal countries. The majority of the catches in some offshore areas are not primarily by the coastal countries con-

cerned. Most of the fisheries off the coast of Mauritania (Figure 29), for example, are by countries from Europe and Asia (Japan and South Korea are in the 'others' group). According to this esti-



Source: Downloaded from Seas Around Us Project (University of British Columbia), <http://www.seararoundus.org/TrophicLevel/EEZTaxon.aspx?eez=478&fao=34&country=Mauritania&Hasnote=1&typeOut=4&Tx=1> (Accessed January 2006).

**Figure 29. Intensity of fisheries off the coast of Mauritania, West-Africa.** While the country's often impoverished coastal population is strongly dependent on the fisheries, the largest share of the fishing is done by an international fishing fleet.



**Figure 30. Deep waters within and beyond areas of national jurisdiction in East Africa.** The figure demonstrates that the overwhelming majority of marine areas under national jurisdiction in East Africa are deeper than 200 metres (dark blue). Areas in red indicate where the geology/geomorphology might justify (subject to further research and interpretation) a submission/claim to be made by coastal states individually or jointly to increase their national seabed and subsoil areas, which, in turn, may be of major economic potential.

mation, Mauritania only landed about 10% of the total catch in 2002, with The Netherlands as the nation with the largest catch (23%) in this zone. For developing countries, the intensive fisheries by foreign countries and climate change may become severe for income, livelihoods and food security for coastal communities. Fishery products are becoming one of the most important rising exports from developing countries (FAO, 2006). The fishery net exports of developing countries (i.e. the total value of their exports less the total value of their imports) showed a continuing rising trend in recent decades, growing from US\$4.6 billion in 1984 to US\$16.0 billion in 1994 and to US\$20.4 billion in 2004.

Waters below 200 metres depth cover around 336 million square kilometres world-wide, and can be found in areas within and beyond national jurisdiction. Overview analyses show that the total area of national waters deeper than 200 metres is around 124 million square kilometres, i.e. about five times larger than the total of national waters shallower than 200 metres (approximately 25 million square kilometres). In accordance with the provisions set out in Article 76 (Definition of the continental shelf) of UN Convention on the Law of the Sea, 1982 (UNCLOS), certain geologic and physiographic conditions (more precisely sediment thickness and/or change in slope gradient) of the continental margin might give a coastal State the right to delineate the outer limits of its continental shelf beyond 200 nautical miles (i.e. the limit of the Exclusive Economic Zone). This applies only to the seabed and the subsoil of the legal continental shelf, not to the water column. The procedure to identify whether there is a scope for such a claim, and to compile and interpret the necessary data for a submission to the Commission on the Limits of the Continental Shelf set up under UNCLOS, is complex and time-limited, as submissions have to be made by the year 2009 for most countries, and support is given through the UNEP Shelf Programme.

# THE CUMULATIVE IMPACTS

One of the main obstacles to assessing the state of the oceans and in planning for the conservation, protection and sustainable management/use of the marine environment is the slow responses of the seas to pressures. Many processes and changes in the oceans take place below the surface, silently, on large scales and over long time periods, i.e. they are not on the 'radar screen' of human perception. It can take more than 100 years for a deep-sea water molecule to come to the surface. The signal from the increased CO<sub>2</sub> released by anthropogenic activities in the last 50–100 years has so far penetrated to only around 3,000 meters water depth. An example of the time lag in response is the absorption of CO<sub>2</sub> in the oceans, with the signal of increased CO<sub>2</sub> concentrations. The oceans have a huge capacity to cope with impacts and change without apparent effect. However, once their resilience threshold has been overstepped, and effects are detected and becoming obvious, it is often too late to reverse the trend. Even if CO<sub>2</sub> emissions would stop today, it would take the oceans many decades to respond.

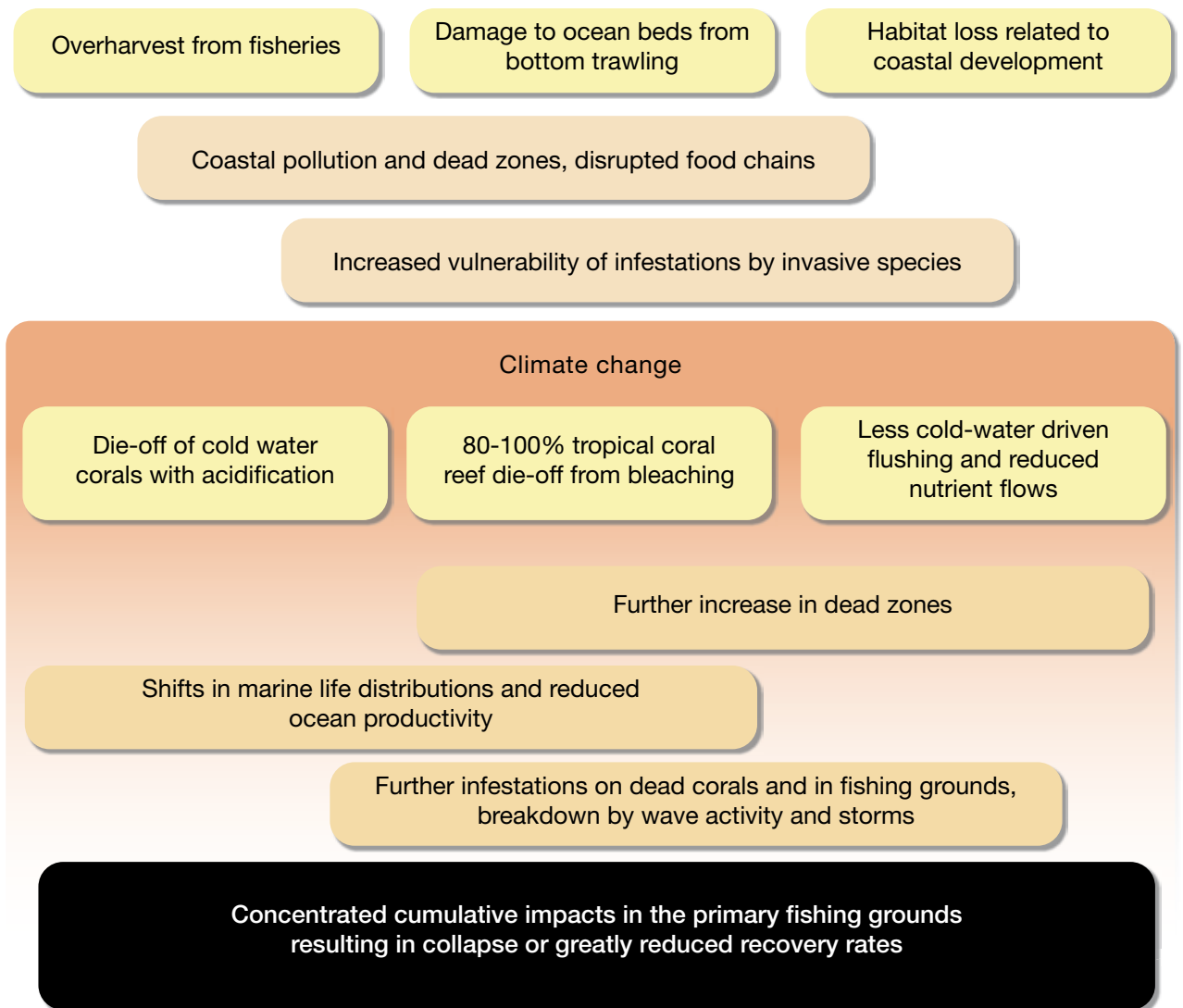
The combined effects of the 'Big Five' environmental threats provide a grim outlook to the sustainable future of the World's oceans, and the billions of people who depend on marine resources. Many marine areas and species may be exposed and impacted simultaneously by all or several stressors, often acting in synergy and thereby amplifying their effects and impacts (Harley and Rogers-Bennett, 2004). Climate change will

provide numerous changes in oceans. It will affect physical parameters such as temperature, strength of currents and the chemistry of the oceans, which, in turn, will invariably impact fisheries (MacKenzie *et al.*, 2007). Climate change is increasingly likely to put substantial strain on the productivity of the World's oceans, along with pollution, over-harvesting and unchecked coastal development. Disease and infestations often follow in the wake of the other stressors.

However, of perhaps even greater concern, is the fact that in the light of the accelerating climate change, the natural resilience of the oceans, such as their capacity to act as natural buffers, is likely to diminish in future. Heavily harvested fish stocks and populations will be even further reduced by impacts on their vulnerable spawning grounds from other activities. As long as deep-water seamounts and the continental shelves remain nearly completely unprotected, their important roles as nursery grounds is threatened by the expansion of fishing and mineral resource exploitation (Thrush and Dayton, 2002; Pusceddu *et al.*, 2005; Tillin *et al.*, 2006; Hixon *et al.*, 2007). Projections show that the coral reefs of the World are likely to meet, in the worst case, biannual bleaching events within a few decades. Healthy reefs might be able to recover from these impacts, but reefs already stressed and degraded by other factors (e.g. coastal development and pollution, overfishing etc.) will most likely succumb. It is critical that the areas with projected high risk to coral bleaching become







**Figure 31.** Climate change may, *inter alia* through effects on ocean currents, elevated sea temperatures, coral bleaching, shifts in marine life, ocean acidification, severely exacerbate the combined impacts of accelerating coastal development and pollution, dead zones, invasive species, bottom trawling and over-harvest. These impacts will be the strongest in 10–15% of the World’s oceans, which harbour the most productive fishing grounds today, responsible for more than half of the marine landings globally.



priority zones for reductions in coastal pollutions to prevent a collapse of the reefs and the associated loss of their functions.

Similarly, it is also evident that the majority of the World's most damaging marine infestations have taken place in areas with large stresses and diminished resilience due to human activities (e.g. in heavily harvested fishing grounds with extensive trawling/dredging). Hence, building resilience and strengthening the natural buffers of marine (eco)systems has to become an essential element and consideration in the conservation, protection and sustainable management/use efforts at all levels, such as in the creation of system of marine protected areas spanning from coastal waters to the high seas.

Of critical concern is the current lack of policies and protected areas covering deeper waters on the continental shelves and the high seas, including seamounts (Davies *et al.*, 2007; Mossop, 2007). On average, around 70% of the waters under national jurisdiction (e.g. within the EEZs of coastal states) are deeper than 200 meters, rising to over 95% in some island states. However, few countries are aware of their deep-waters and the need to explore, protect and manage the important services and resources these areas provide.

Biodiversity hotspots form the basis of the World's fisheries, but have currently no basis in either marine protected areas or in specific management. It is absolutely crucial that the management of these hotspots becomes an international environmental priority with regard to identifying areas where multiple stressors are likely to leave these water as death zones, lost fisheries and lost recre-

ational and tourist income regions. While there are projections of collapse in the World's fisheries alone as a result of over-harvest, it is far more likely that such collapse may arise even earlier as a result of the rapid growth of multiple stressors, including climate change, acting in combination. Unless these interlinked and synergistic processes are seen and addressed together, the environmental and socio-economic impacts, particularly for impoverished coastal populations, may become severe. Building resilience by giving climate impact hot-spots priority with regard to reducing other stressors should become focus for future environmental programmes.

The impacts of climate change on the marine environment are growing rapidly, and are likely to become much severe in coming decades. The lack of marine information and easy observation by man as a land-living organism has permitted these and other pressures to progress much farther than anything we have yet seen or would have permitted without intervention on land, in spite of the fact that the oceans are crucial for life on Earth and represent a significant share of global economies and basic food supply.

Unless other pressures are reduced in some of the primary fishing grounds, including bottom trawling and pollution, the impacts may become catastrophic, resulting in wide-spread death or strongly depleted fishing grounds, with severe impacts on countries, coastal economies, livelihoods and food supply. There are currently no international or widespread implemented national policies in place to ensure that such disaster is prevented. The urgency and relation to the continental shelves is critical, given the short time frame, severity and catastrophic nature of the already emerging impacts.

# CONTRIBUTORS AND REVIEWERS

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