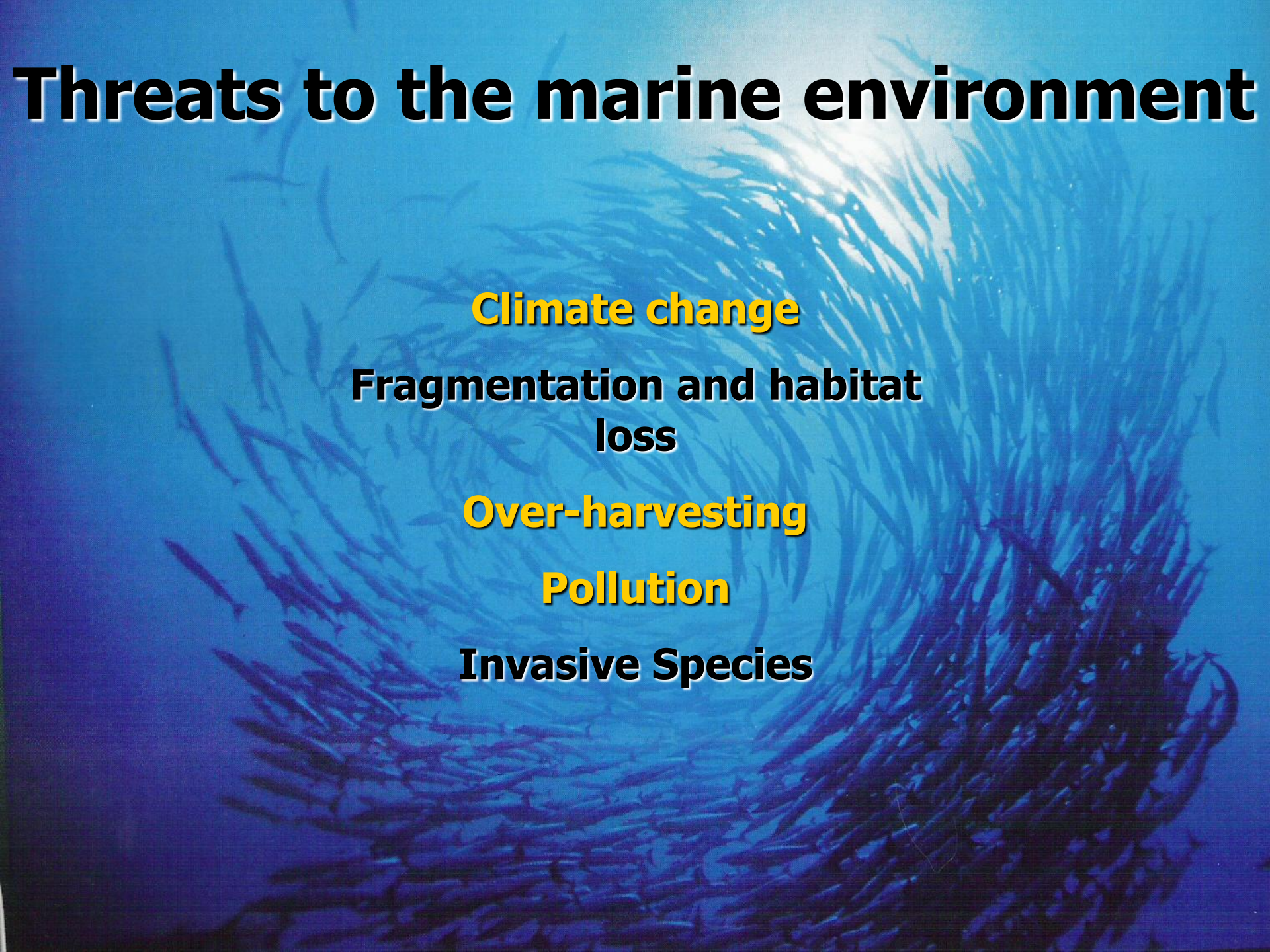


Threats to the marine environment



Climate change

**Fragmentation and habitat
loss**

Over-harvesting

Pollution

Invasive Species

The Carbon Cycle and Climate Change in the Marine Environment

A person wearing a red hat and a dark jacket is walking away from the camera on a snow-covered path. The path is next to a body of water, and there are some rocks or debris visible in the water. The background is a snowy landscape with some trees in the distance.

Carbon Dioxide

- Greenhouse gas
- Flux between ocean, land and the atmosphere:
 - Land – living biota; decaying organic material
 - Ocean – dissolved CO₂; small creatures
- Deep ocean largest reservoir:
 - 40,000 Gt C cf. 2,000 Gt C on land, 1,000 Gt C in upper ocean and 750Gt C in atmosphere

Global Carbon Cycle

1. Terrestrial Cycle

- Photosynthesis
- Soil carbon – respiration
- Varying carbon sinks
- Human activity effects
- 1950's – fossil fuel emissions exceed land use change

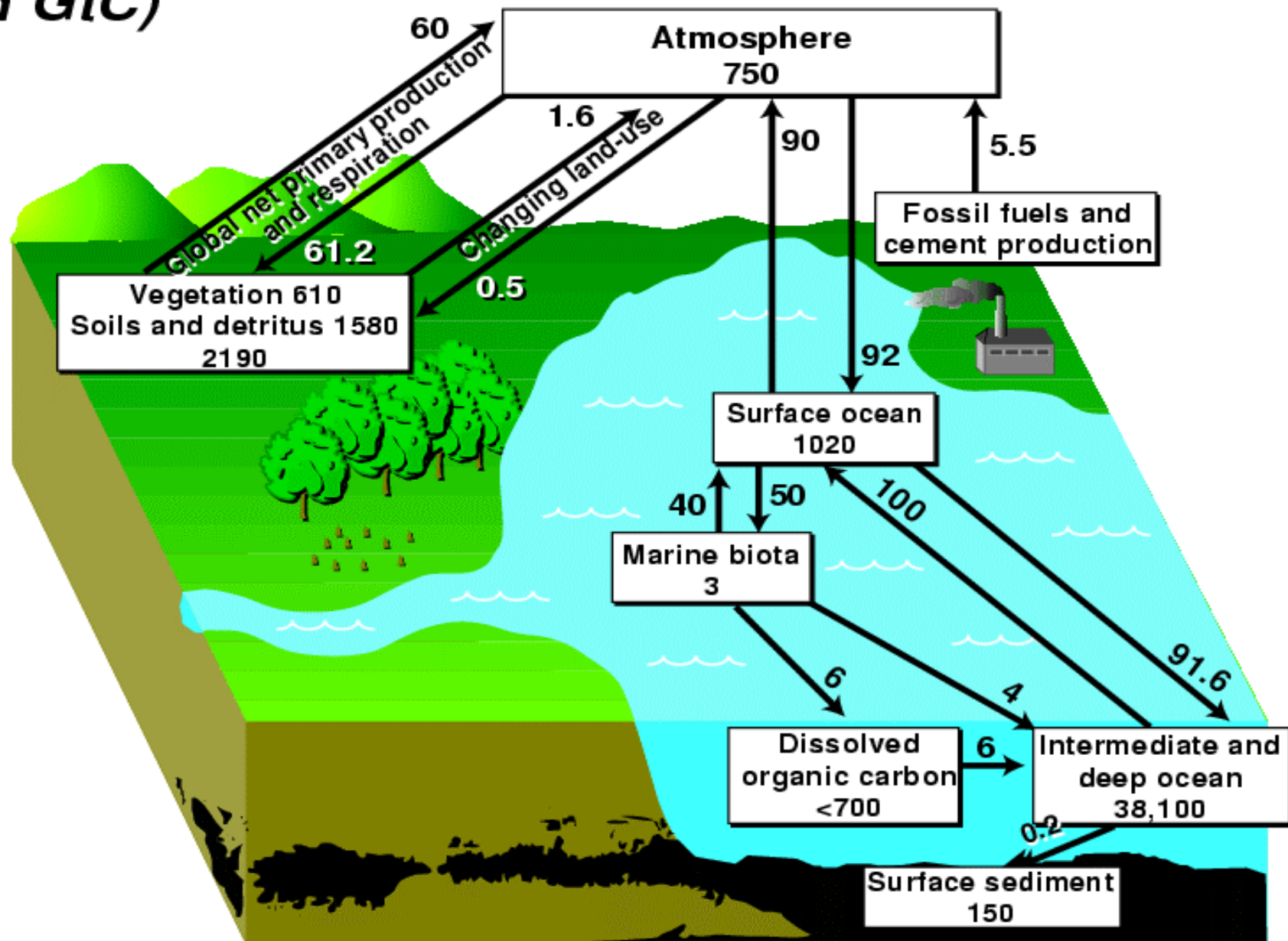


Global Carbon Cycle

2. Oceanic Cycle

- Dissolved Inorganic Carbon (DIC)
- Solubility Pump – CO_2 transferred from air to sea as DIC – distributed by ocean currents (500 yrs 'locked away')
- Biological Pump – CO_2 fixed by photosynthesis is transferred to the deep as organisms & faecal material
- Carbonate Pump – skeletal transfer

Global Carbon Cycle (in GtC)



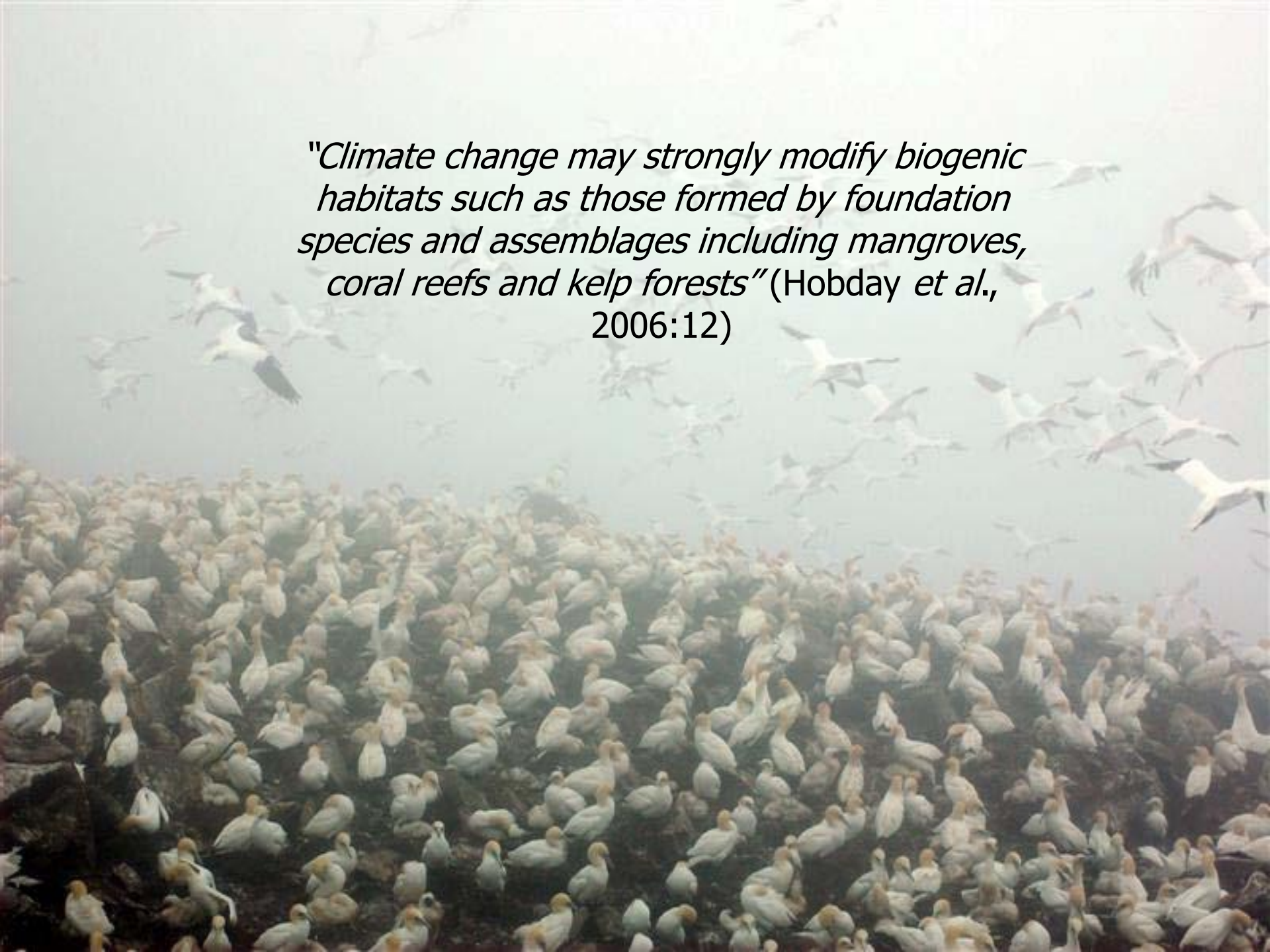
(NOAA, 2003)

Changing Oceans: Physical and Chemical Changes

- 1-3°C increase in 50 yrs
- Translated into warmer seas
- Changes not uniform
- Some cooling may be experienced
- Salinity variation



"Climate change may strongly modify biogenic habitats such as those formed by foundation species and assemblages including mangroves, coral reefs and kelp forests" (Hobday et al., 2006:12)



Impacts of Climate Change

- **Physical and Chemical Effects of Climate Change**

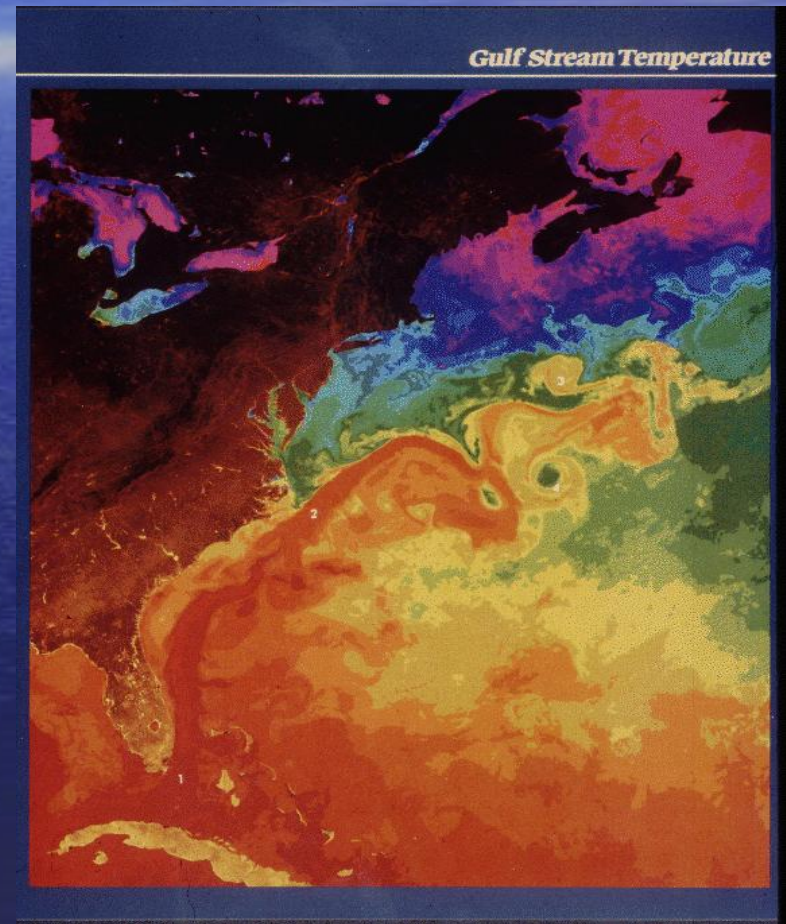
- Physical Effects of Ozone depletion and enhanced UV radiation
- Effects on biodiversity
- Effects on important ecosystems

- Deep ocean circulation patterns
- Wind patterns
- Ocean stratification
- Chemical composition
- ENSO and NAO

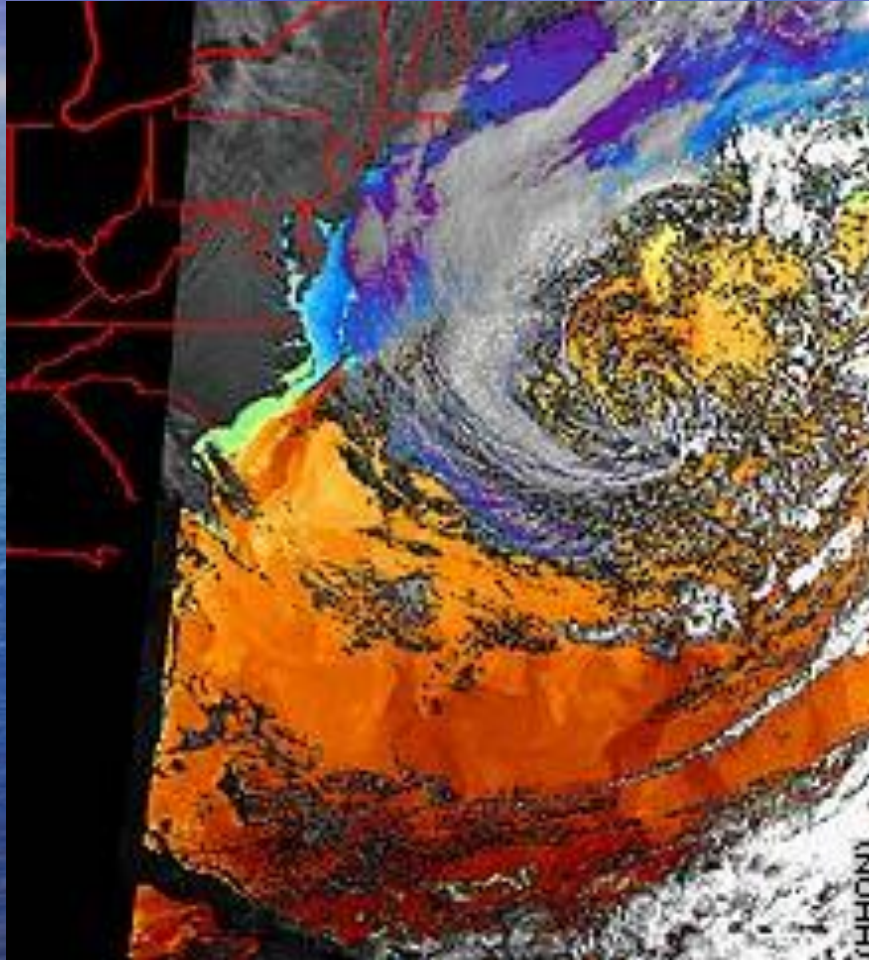
- Stratospheric ozone levels
- Plankton
- Fish
- Seabirds
- Mammals
- Polar Regions
- Deep Sea

Changing Oceans: deep ocean circulation patterns

- ❖ Glacial melt – reduces salinity
- ❖ Density reduced - reduces strength of thermohaline circulation
- ❖ Limits transport heat around ocean
- ❖ Warmer waters in Tropics – less dissolved CO_2 – positive feedback



Gulf Stream slowing



(Simms *et al.* , 2004)

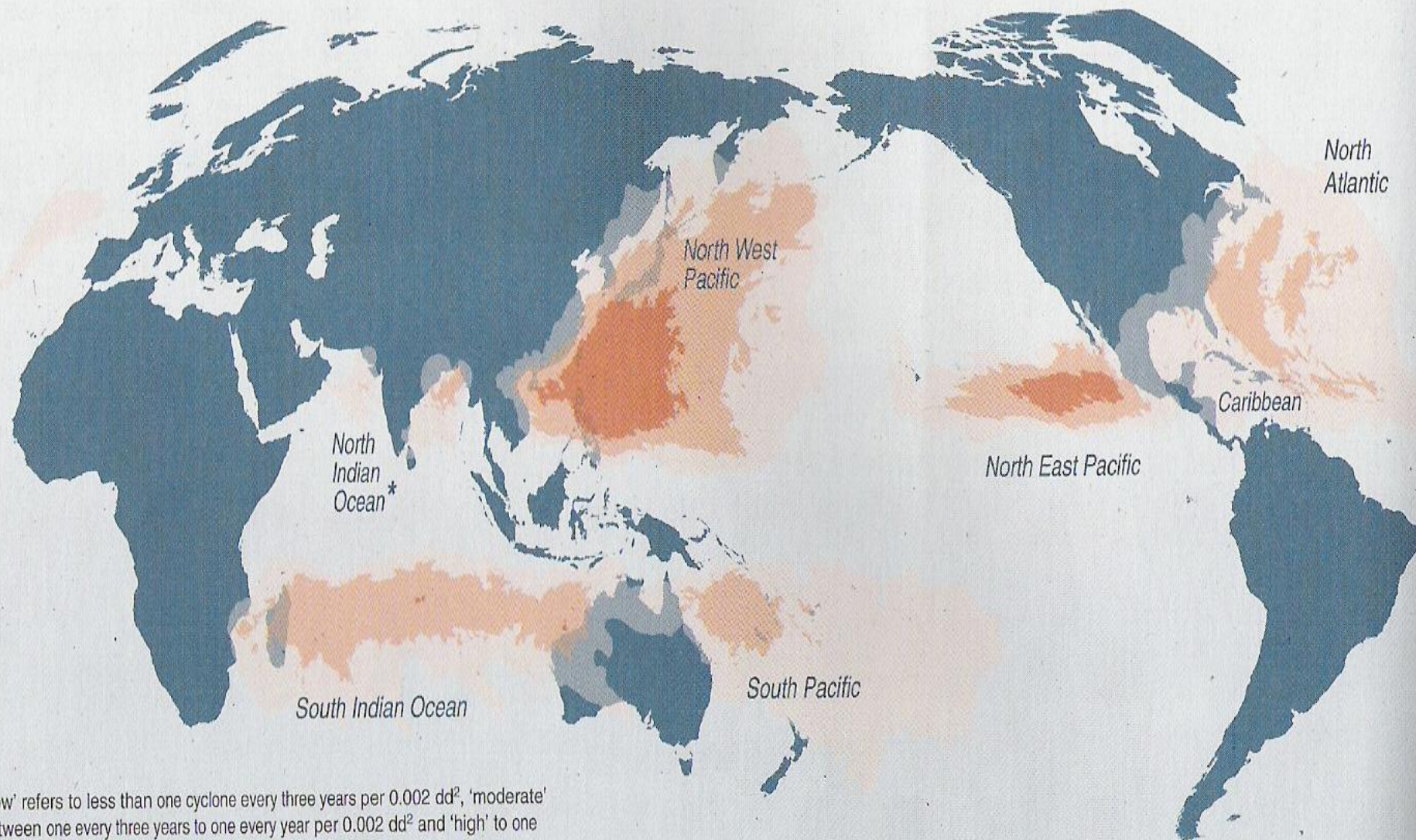
Changing oceans: wind patterns

- Sea surface temp affects patterns in atmospheric pressure – wind generation
- Stronger winds in some areas
- Frequency of extreme events
- Tropical storms – sea temp above 27°C
- Alteration to upwelling patterns



Average number of cyclones:
(1980-2000)

low moderate high

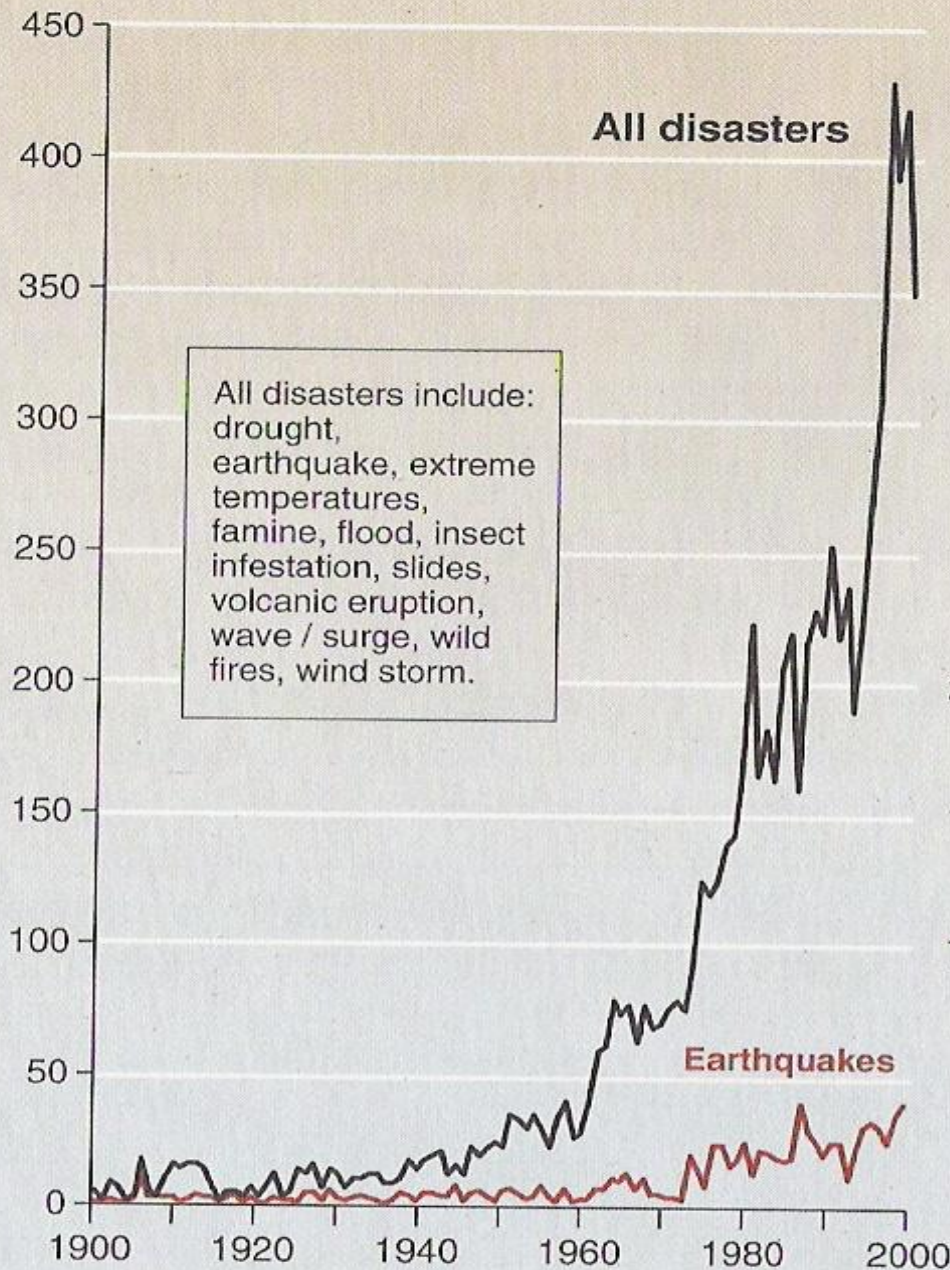


'Low' refers to less than one cyclone every three years per 0.002 dd², 'moderate' between one every three years to one every year per 0.002 dd² and 'high' to one to three cyclones per year per 0.002 dd². The unit '0.002 square decimal degree (dd²)' is equivalent to 25 km² on the equator, diminishing as latitude gets higher.

* average based on eight years only.

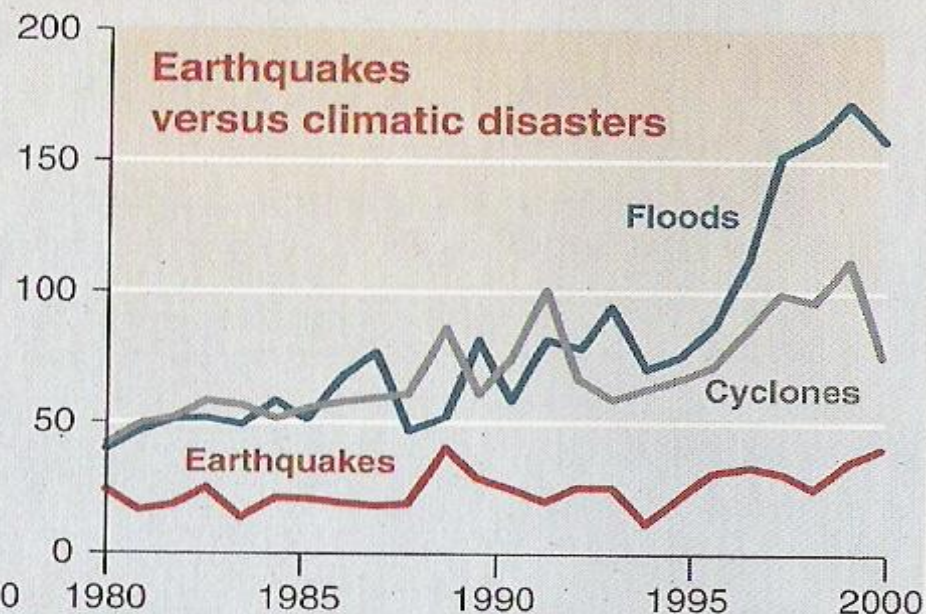
Sources: PREVIEW Global Cyclone Asymmetric Windspeed Profile, UNEP/GRID-Europe.

Number of events
per year



Trends in number of reported events

Much of the increase in the number of hazardous events reported is probably due to significant improvements in information access and also to population growth, but the number of floods and cyclones being reported is still rising compared to earthquakes. How, we must ask, is global warming affecting the frequency of natural hazards?





Changing oceans - stratification

- Warm, calm conditions – stratification intensified
- Resistance to mixing
- Winter winds may be less able to mix layers



Changing oceans: chemical composition

- Naturally alkaline – pH 8.2
- Warmer water – reduced concentration dissolved gases
- Exacerbate temperature rise
- However, less saline water can hold more CO_2 – glacial melt
- Aragonite reduction

Ocean Acidification



- Under saturated with calcium carbonate
- Coccolithophores - basis marine food chain (NASA, 2008)
- 2100, 75% cold water corals
- Changes could develop in decades not centuries (Orr *et al.*, 2005)
- 0.5 change in average pH by 2100 (c.f 0.1 over 200yrs)

Tropical Corals

- **Globally – between 1 and 9 million species**
- **Economic, and habitat relevance**
- **Bleaching – 1-2°C warming**
- **Acidification**
- **Distributional change**







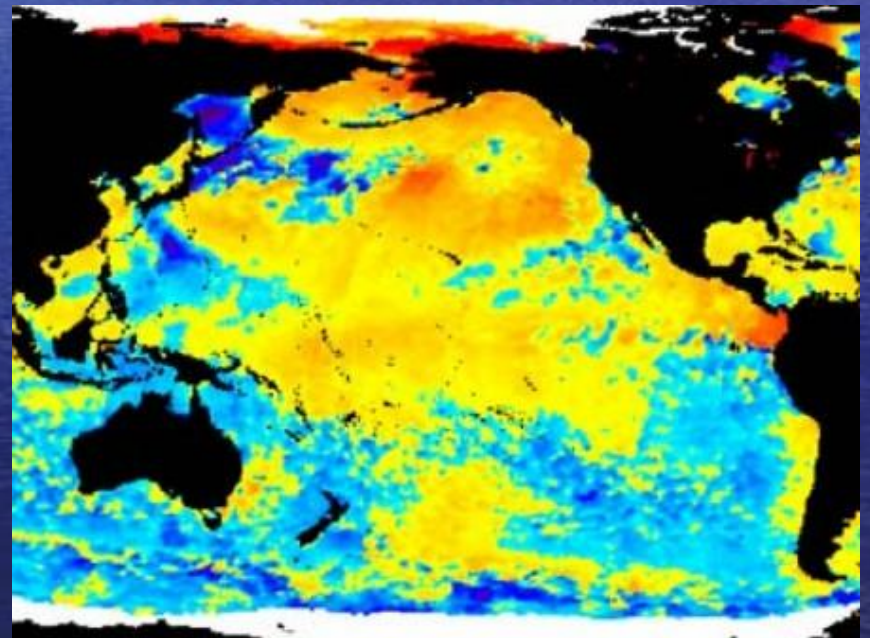
Cold water corals

- Seamounts and continental rise
- Hotspots of biodiversity
- Slow growing
- Depth of aragonite saturation horizon
- 75% affected by 2100



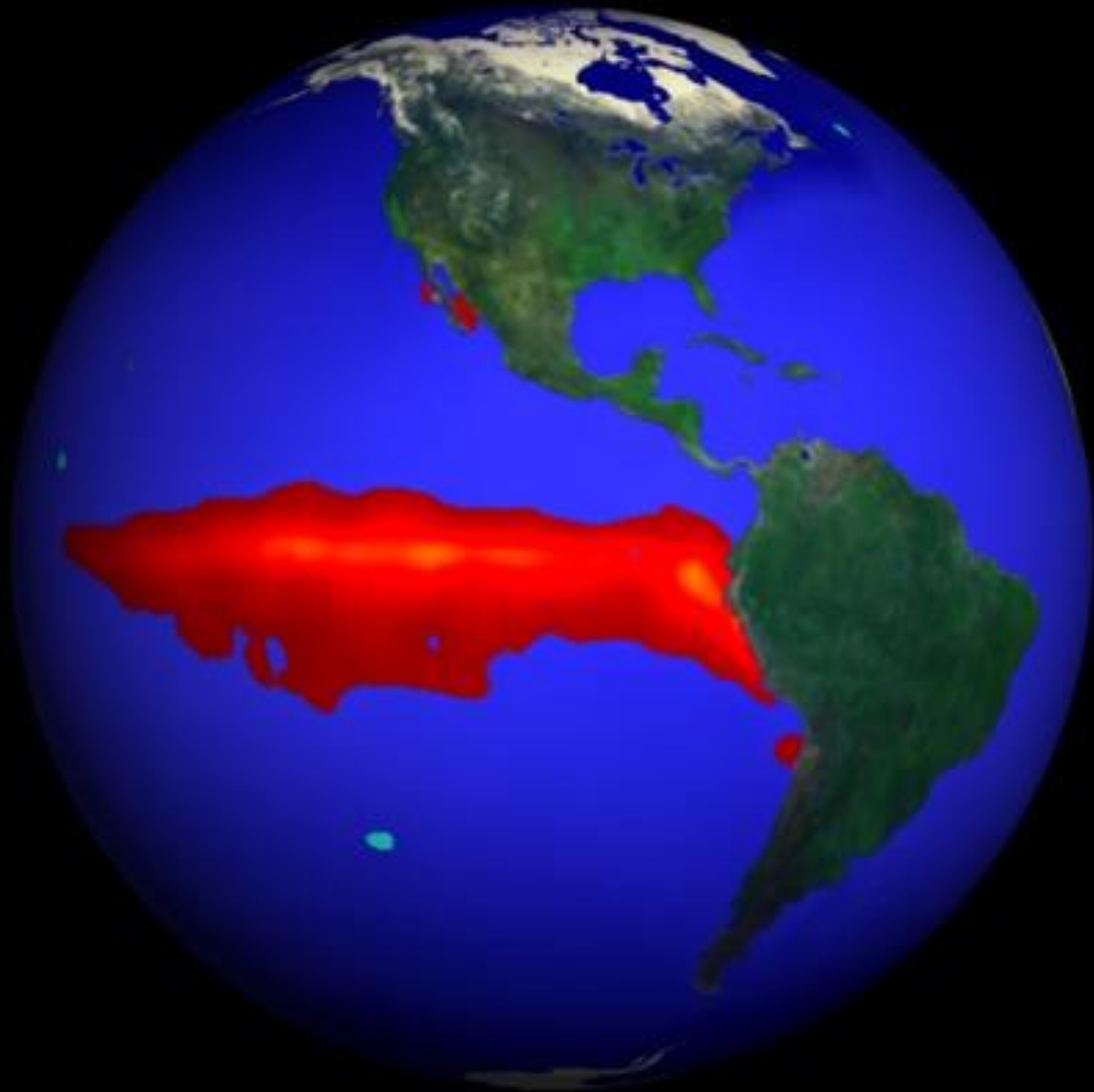
Changing Oceans: ENSO/NAO

- El Nino Southern Oscillation – naturally occurring fluctuation of atmospheric pressure in Pacific which weakens Trade Winds
- 2-8 year cycle – frequency and duration appear to have increased recently
- North Atlantic Oscillation – positive and negative phases
- Currently positive phase – stronger winter storms





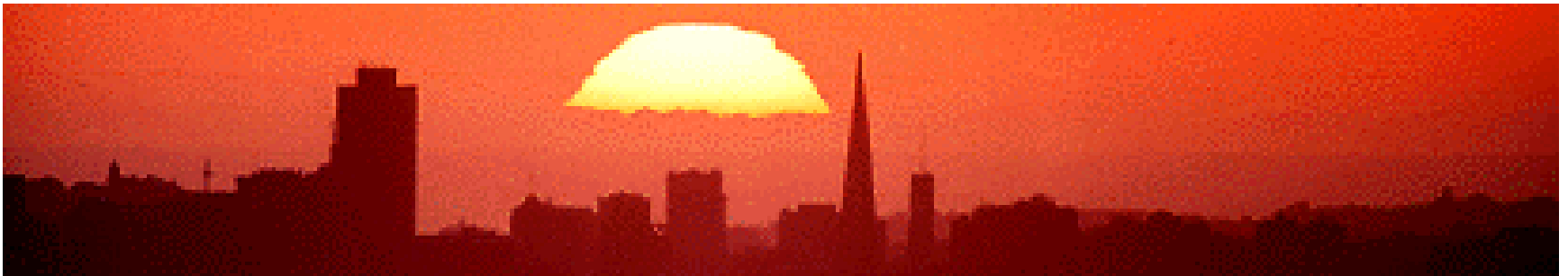
- The clearest sign that an El Niño event is underway is the appearance of unusually warmer water (up to 5°C) between the Equator and coasts of Ecuador and Peru



3D View of the El Niño Phenomenon

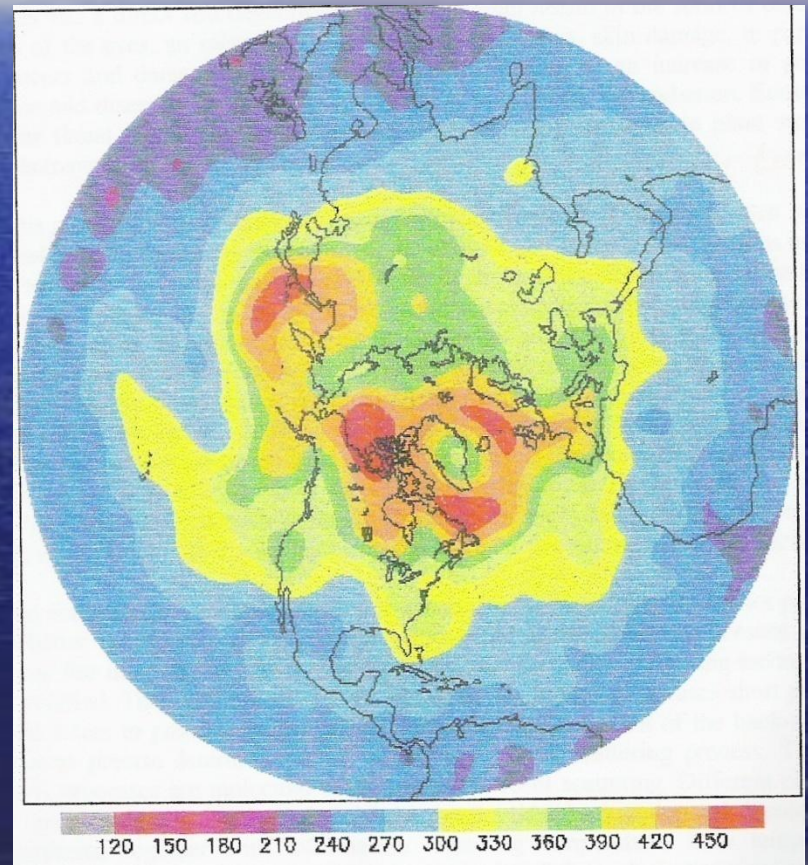
Ozone Depletion: UV radiation

- 90% ozone found in stratosphere
- 10% troposphere
- Filter mechanism
- Stratospheric O₃ – lowest levels since measurements began
- CFC's
- Ozone hole may have peaked

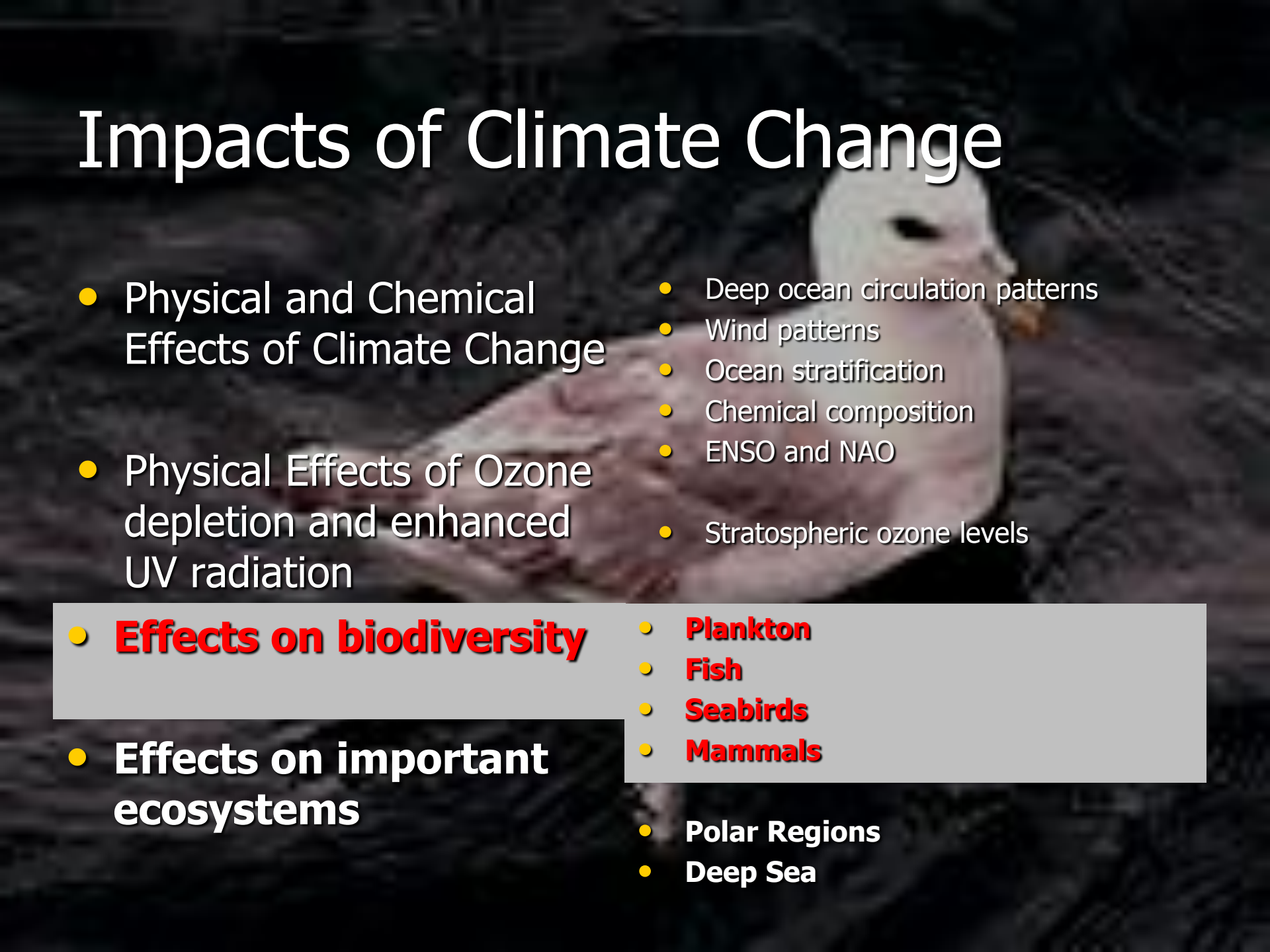


Ozone Depletion: UV radiation

- A beam of UV radiation can travel up to one and a half kilometres through pure water before all the harmful rays are completely absorbed.
- Dissolved oxygen – degree of shielding
- 1987 Montreal Protocol on Substances that Deplete the Ozone Layer
- Long-term effects



Impacts of Climate Change



- Physical and Chemical Effects of Climate Change
- Physical Effects of Ozone depletion and enhanced UV radiation
- **Effects on biodiversity**
 - **Plankton**
 - **Fish**
 - **Seabirds**
 - **Mammals**
- **Effects on important ecosystems**
 - **Polar Regions**
 - **Deep Sea**
- Deep ocean circulation patterns
- Wind patterns
- Ocean stratification
- Chemical composition
- ENSO and NAO
- Stratospheric ozone levels

Impacts of climate change on marine organisms

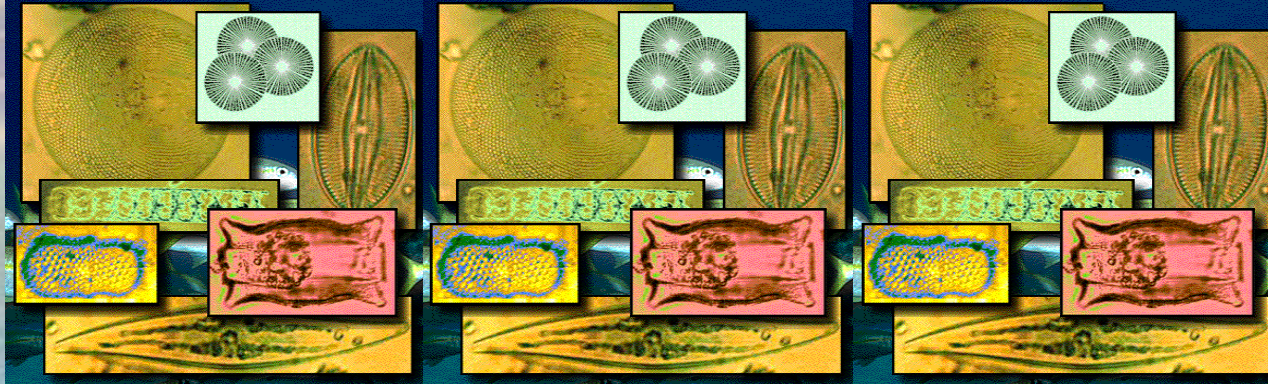
- 450ppm of CO_{2[atm]} - threshold beyond which irreparable damage may be done
- At current rates – 2040
- Loss of coral reefs and ice-covered polar seas by 2040

Biodiversity: Plankton

- Transfer of carbon from atmosphere to other trophic levels
- Vital for deep ocean organisms
- Future predictions largely unknown
- Changing wind patterns and stratification → ↓ primary productivity → ↓ CO₂ sequestration
- Deep sea affected by reduction in carbon input



Biodiversity: Plankton



- Changes to phytoplankton composition
- Carbon absorption varies per species
- Affect on food chain → Californian zooplankton
- UV radiation – affects photosynthesis, growth, reproduction and enzyme functioning

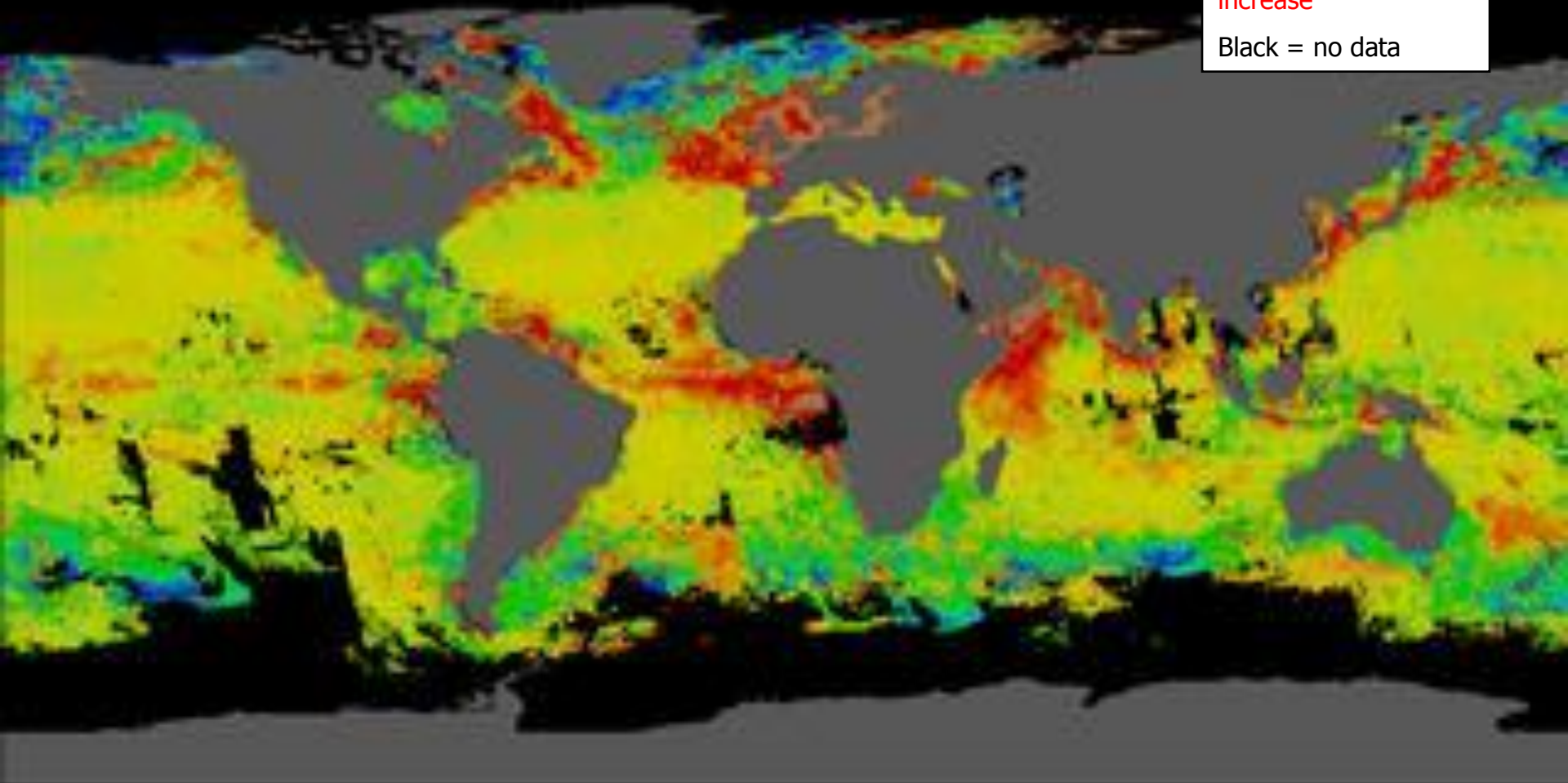
Phytoplankton changes

Blue = greatest loss

Yellow = no change

Red/orange/brown = increase

Black = no data

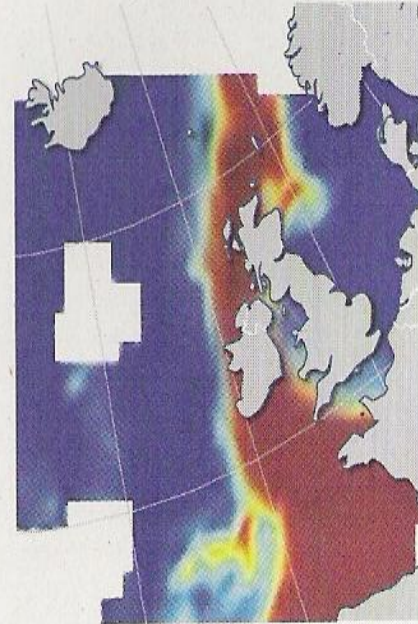
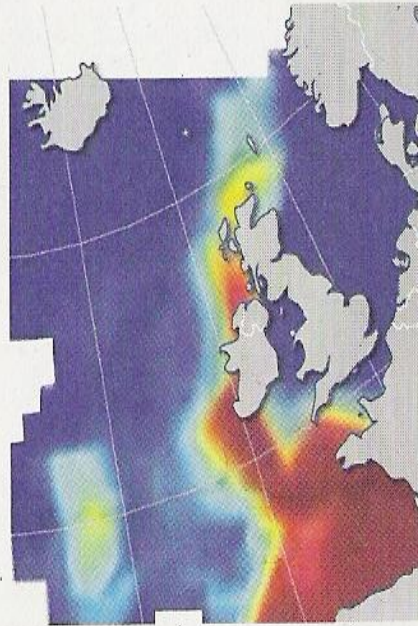
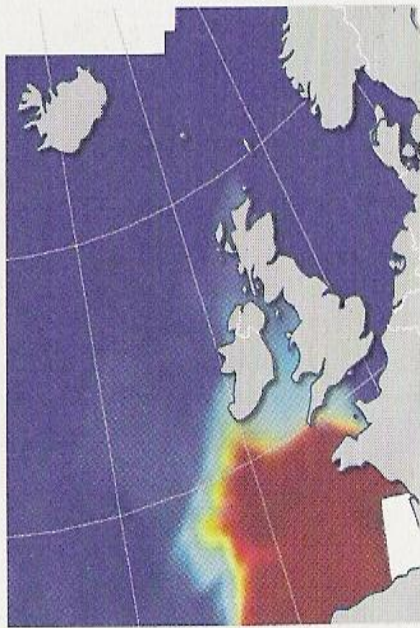


Summer Phytoplankton Levels
(NASA 2002)

1958–1981

1982–1999

2000–2002



Mean number of species per CPR sample



- Poleward movement of warm water species of plankton, fish and intertidal organisms in last 50 yrs
- Continuous Plankton Recorder (CPR) survey
- Copepods (crustacean) moved northwards by 10° Latitude (~ 1000km) in 40 yrs (up to 1999) – trend continues

Cold/warm indicator species

- **Calanus finmarchicus**
70% ↓ since 1960s

- **1000km northwards shift**

- **Seasonality of blooms**

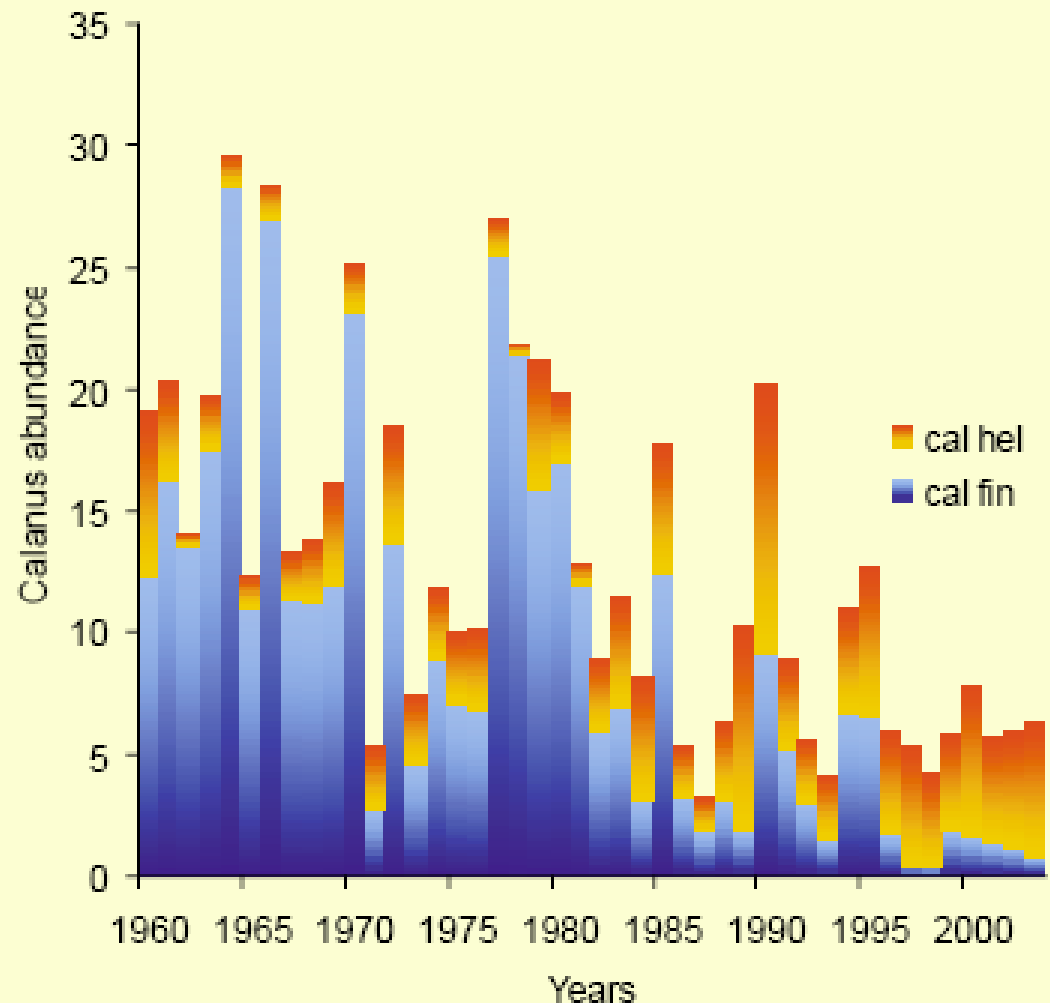


Fig. 4. The abundance of *Calanus* populations in the North Sea from 1960 to 2003. The percentage ratio of *Calanus finmarchicus* (blue) and *Calanus helgolandicus* (red) are shown in relation to total *Calanus* abundance in each annual bar.

Zooplankton

- Short generation times – sensitive to environmental change
- Alterations to species composition
- Decoupling with lower trophic levels and fish yields
- Jellyfish swarms



Biodiversity: Fish

- ↓ Plankton – less food for predators
- Polewards shift in distribution – level migration unclear
- Change in species composition
- Economic impact
- ENSO – impact on fish
- Eggs and larvae sensitive to UV radiation



Fish yields

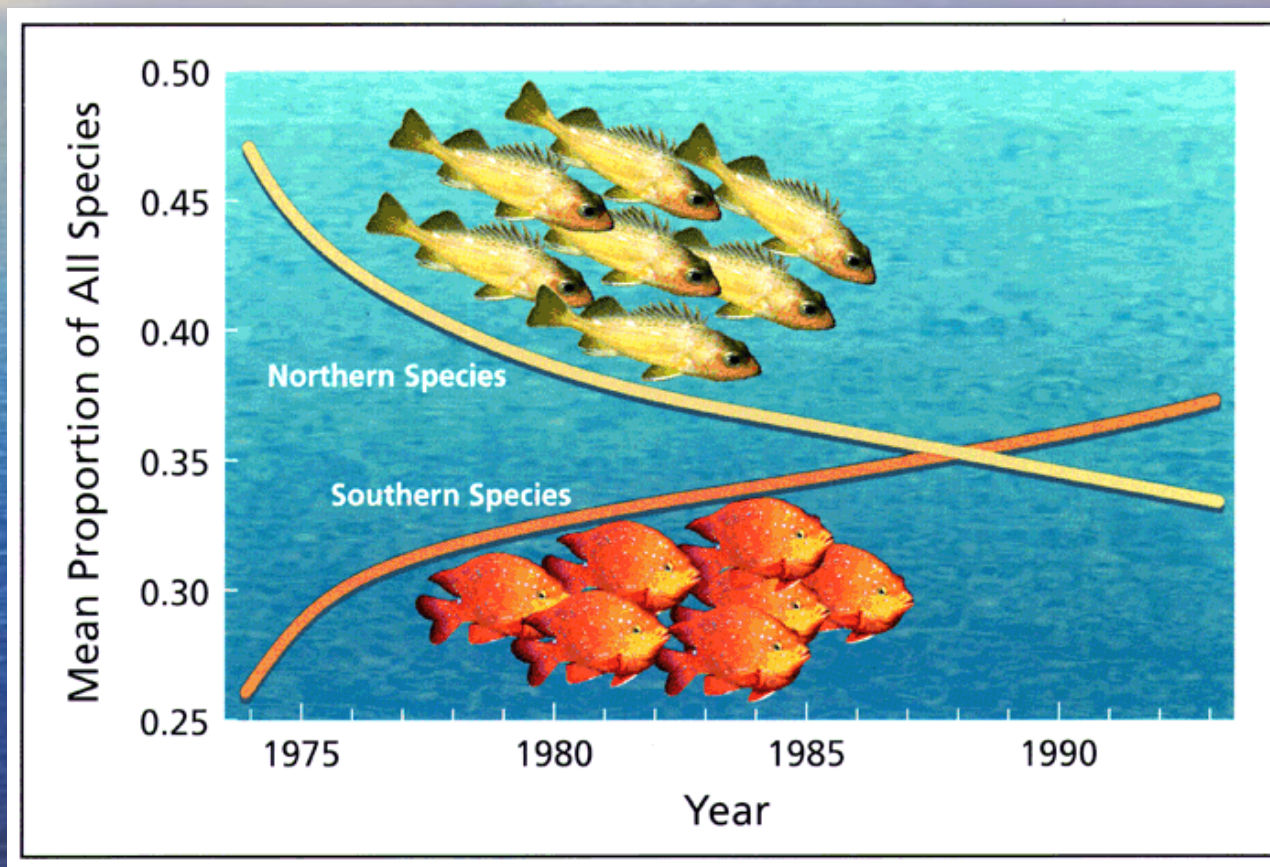


1963 – North Sea



2001 – North Sea

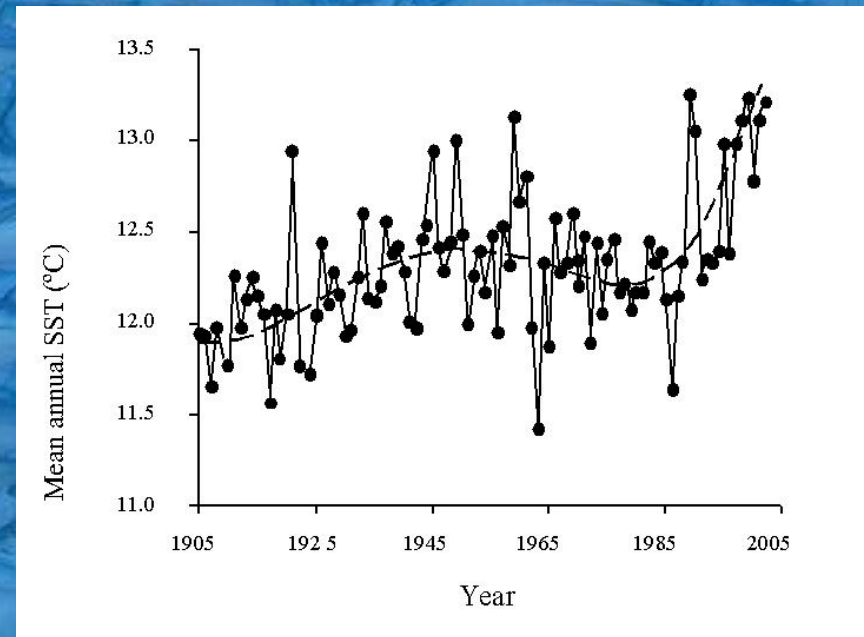
Reduced abundance Zooplankton and temperate fish off Southern California



NOAA (2000)

Response to climate change: Fisheries

- Trawls between 1913 and 2002
- Correlation between climate-linked temperature shifts and species composition and abundance
- Poor cod *Trisopterus minutus*, Butterfly blenny *Blenius ocellaris* responded positively to warming
- Southern species such as skate and rays have declined steadily



African fisheries

- **2.6 billion people – 40% world's population – fish make up a fifth of their protein intake**
- **In Pacific El Nino conditions could become near permanent**
- **Badly managed – Nigeria, Senegal, Vietnam, Angola**
(Pearce, 2009)



Atlantic Cod *Gadus morhua*

Marine Turtles

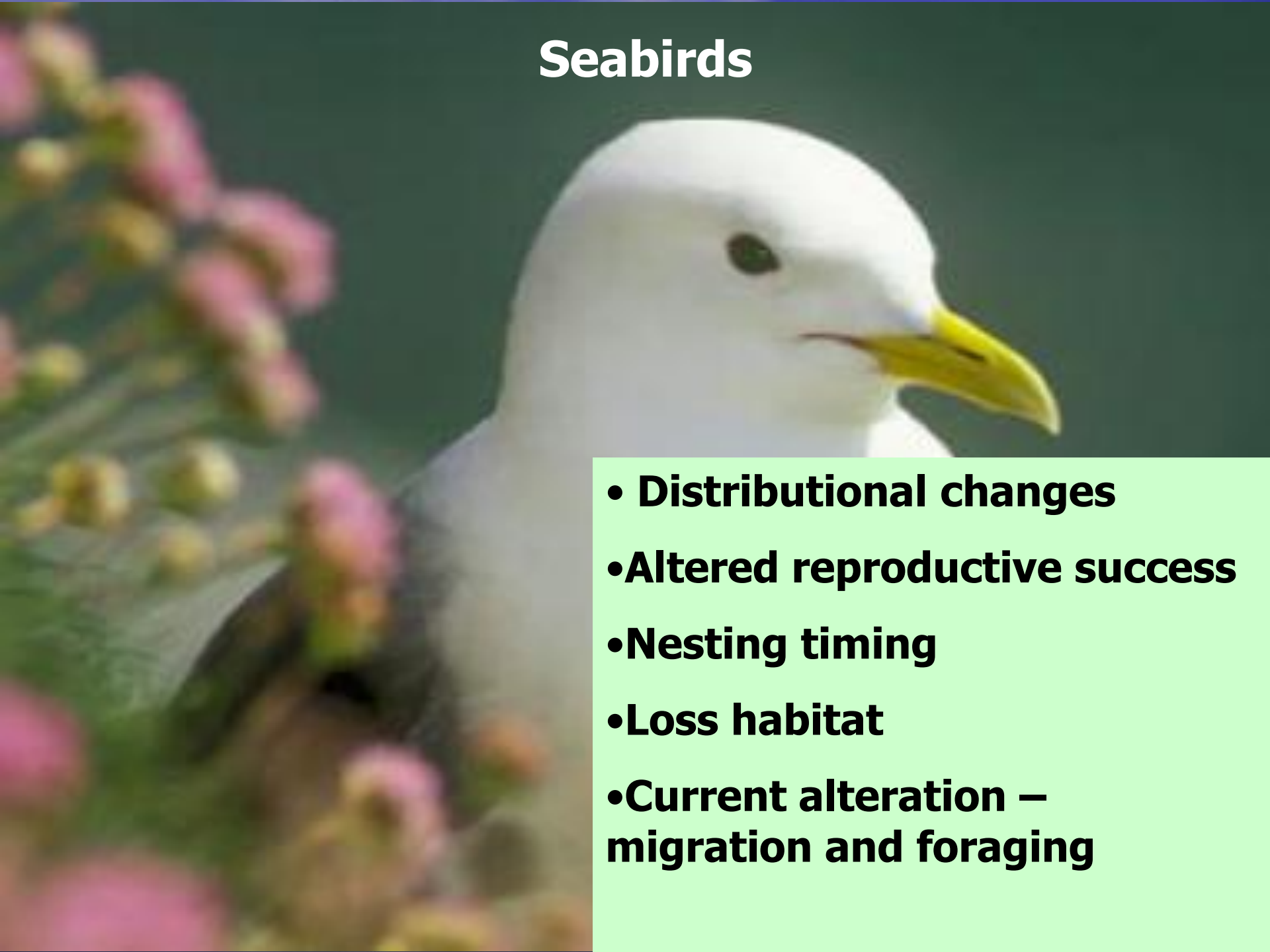
- **Slow growth rate**
- **Life history characteristics**
- **Changes to critical habitats**
- **Skewing of sex ratio**
- **Wave energy and storminess**
- **Alteration to timing of egg laying**







Seabirds



- **Distributional changes**
- **Altered reproductive success**
- **Nesting timing**
- **Loss habitat**
- **Current alteration – migration and foraging**

Biodiversity: Seabirds

- Starvation – Alaskan shearwaters
- Not a simple cause effect relationship – Leach's storm petrel
- Shift in prey preference
- Reproductive success – Cassin's auklets
- Increased storm activity
- Mobility



Biodiversity: Mammals

- Reduction in abundance of prey
- Energy expenditure – seals and seal lions
- Open water species thriving
- Polar species suffering consequence of diminishing ice sheets
- Cetaceans – changes in distribution
- Collisions and noise pollution!



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Ecosystems : Polar Regions

- Most productive seas
- Food for humans, endemic and migratory species
- Greatest overall temperature changes
- Decrease in coverage and thickness Arctic sea-ice
- Bloom of coccolithophores



Ecosystems : Deep Sea

- Limited knowledge
- Diversity in ocean muds
- Predictions – uninformed guesses
- Reduction in thermohaline circulation – ↓
O₂
- Warmer water - ↓ primary productivity - ↓
organic matter

Documented changes?

- Arctic Sea ice $\downarrow 2.8 \pm 0.3\%$ per decade 1973-1996
- Antarctic sea ice not replicated over same period
- Land precipitation $\uparrow 2\%$ since 1990
- Snow cover $\downarrow 10\%$ since 1966 in northern hemisphere

Global Sea Level Rise

- Can we use sea level rise as an indicator of climate change?

.....Difficult because:

- Many individual changes
- Range of uncertainties are large

Sea Level Rise

- Tide gauge system relative to land-based benchmark
- Problem?
- Vertical movements:
 - Isostatic effects
 - Sedimentation
- Filter these movements
- Land movements
- Wave climate

Sea-level impacts

- Global average risen by 10-20cm over past 100yrs
- Models project further increases 9-88cm by 2100
- Vulnerability small islands and coastal zone
- Flooding and coastal erosion
- Damage to key economic sectors
- Threats to human health
- Coastal ecosystems at risk
- Mitigation – protection, accommodation, planned retreat

Coastal Zone

- Accelerated coastal erosion – 17% UK
- 23% Welsh coastlines impacted currently
- Seawater intrusion into fresh groundwater
- Encroachment of tidal waters into estuaries and river system

Coastal Zone

- Coral reefs, mangroves and salt marshes vulnerable
- In England, 40-100 hectares saltmarsh lost annually (Eccleston, 2008)
- Vertical accretion rates and space or horizontal migration
- Ecosystem resilience reduced where there are also human influences

Seagrasses

- **Vital role in carbon and nutrient cycling**
- **Buffer**
- **Biodiversity**



- **Increase in productivity**
- **Temperature & UV radiation**
- **Storm regimes**

Mangroves

- **Buffer**
- **Sediment**
- **Filtering**
- **Habitat**
- **Nutrient and carbon cycling**



- **Increase productivity**
- **Threat of sea level rise**
- **Shift in distribution**
- **Growth rate changes**

Kelp Forests

- **Shifts in distribution and decline**
- **Storminess**
- **Changes in rainfall**
- **Species compositional change – herbivores**



Rocky Shores

- Species distributional movements – Acorn barnacle *Bifurcaria bifurcata*
- Changes to abundance and community composition
- Alteration to timing of reproduction and larval or spore release









