**Summary by region**

**Arctic:**

Physical changes:

* 5 C increase in air temperature;
* 6 percent increase in precipitation;
* 15 cm rise in sea level;
* 5 percent increase in cloud cover;
* 20 day reduction in sea ice duration;
* 20 percent reduction in winter ice with substantial ice-free areas in summer.

Ecological consequences:

* primary production increased two to five times over present conditions;
* reduced ranges of cold water fish and benthic species, but expanded ranges of Atlantic and Pacific species northwards;
* long-lived Arctic species with narrow temperature tolerances and late reproduction are likely to disappear from southerly habitats;
* changes to migration timing and increases in growth rates;
* non-native species are likely to increase in Arctic waters;
* extinction of any present Arctic fish species unlikely.

**North Atlantic**

Northeast Atlantic

Physical changes:

* future climate change impacts in the North Atlantic are likely to continue to vary with the state of the North Atlantic Oscillation;
* sea temperatures in the North Sea, Nordic seas and Barents Sea are likely to increase by 1 to 3 􀁯C over the next 50 years, with largest changes in the northernmost regions;
* increased wind-induced fluxes of warm Atlantic waters into these northern regions; increased vertical stratification;
* reduced ice cover.

Ecological changes:

* primary production likely to increase in the Barents Sea;
* zooplankton production likely to decrease as production by Arctic zooplankton declines;
* northward shifts in the distributions of all species;
* increased biomass production of species in Arcto-boreal regions;
* fish species from south of the North Sea likely to appear in the North Sea;
* spawning areas for capelin in the Barents Sea likely to shift eastwards;
* North Sea dominated by pelagic species such as herring and mackerel in the north, and sardine and anchovy in the south, although the total system productivity may not be too different than today;
* Baltic Sea is predicted to become warmer and fresher, with significant increases in its vertical stratification;
* in the Baltic, exclusion of marine-tolerant species in favour of species more tolerant of low salinities;
* non-native species may enter the Baltic, but few are expected to be able to colonise because of the salinity stress.

**Northwest Atlantic**

* predictions of distributions and migration changes similar to Northeast Atlantic;
* populations at their range limits will be most affected;
* in some locations and at some times, decreased temperatures may occur as a result of increased glacial melting in Greenland. This may provide refuges for some cold
* water species, or may provide lethal cold shocks to other species such as Atlantic cod;
* species adapted to cool and narrow temperature conditions, such as Atlantic salmon, may be extirpated from their present habitats.

Atlantic cod:

* cod survival in simulations of Gulf of Maine declined with increasing temperatures
* which offset their increases in growth;
* in middle range in the Northwest Atlantic, capelin (*Mallotus villosus*) are important prey of cod, but spawning times for capelin are susceptible to delays due to cold water from melting glaciers;
* in Northeast Atlantic, model simulations suggest increasing temperatures in North Sea will cause declines in cod populations.

**North Pacific**

* anthropogenic warming in 30 to 50 years likely to be as large as natural climate variability today;
* climate-ecosystem-fisheries relationships developed during the latter half of the twentieth century may not be resilient to the new conditions in the twenty-first century;
* Pacific Decadal Oscillation pattern of decadal variability will continue into the twenty-first century, but will occur on top of persistent upward trend in sea surface temperature;
* changes in mixed layer depths (shoaling) and temperature (increasing);
* subpolar planktonic system change from strong variability and winter lows to more constant annual values and decreased yearly-averaged primary productivity;
* other areas (e.g. coastal) may experience higher growth rates as temperatureswarm;
* in the North West Pacific, expect warmer conditions to cause changes in seasonal patterns of primary production;
* northward shifts of fish populations are predicted for west coast of NorthAmerica;
* Pacific sockeye salmon may be restricted to Bering Sea;
* Bering Sea: extensive retreat of sea ice, losses of cold-water species and increasing abundances of species from the North Pacific;
* North Pacific is sensitive to the effects of increasing acidification, and likely to become under-saturated in aragonite from the surface to bottom;
* various species are negatively impacted by low pH concentrations.

**Wind-driven coastal upwelling systems**

* responses to global warming of coastal wind systems that drive upwelling ecosystem are contradictory;
* if alongshore wind stress increases coastal upwelling, this would offset in these regions the global trend of increasing water temperatures and increasing vertical stratification;
* other model studies predict decreasing upwelling-favourable winds;
* global models of primary production responses to warmer conditions are contradictory. In the Pacific, the model of Sarmiento *et al*. (2004) showed no
* consistent global response of upwelling regions to climate change;
* intensified Benguela upwelling may increase nutrient inputs, primary production and low-oxygen events. Such may also occur in other upwelling systems;
* there is considerable local variability among systems which makes generalizations difficult.

**Tropical and subtropical seas**

* highly diverse habitats and biology; poorly studied;
* not resolved whether tropical Pacific will become more “El Nino-like” (east-west gradient in SST is reduced), or more “La Nina-like” character (increased east-west SST gradient);
* primary production in the tropical Pacific expected to decline because of increased stratification and decreased nutrient supply;
* combined effects of changes in circulation, temperature, nutrients, primary production cascade up the food web to influence prey availability and habitat conditions for tuna;
* tuna habitat conditions east of the date line could improve, similar to El Ninoevents;
* for waters of Australia and New Zealand, greatest impacts likely on coastal species and subtidal nursery areas, temperate endemic species rather than tropicals and coastal and demersal species rather than pelagic and deep-sea species;
* models for Australia predict physical changes similar to other regions: ocean warming, increased vertical stratification, strengthening of poleward coastal currents, increasing ocean acidification, sea level rise and altered storm and rainfall regimes;
* warming and increasing stratification will alter plankton community composition, alter their distributions polewards and change the timing of their bloom dynamics so that transfers to higher trophic levels may be impaired;
* benthic and demersal fishes will shift their distributions southward and may decline in abundance. Pelagic species will also shift their distributions southwards and some species may benefit from increased local wind-driven upwelling (e.g. anchovies).

**Coral reef systems**

* at risk from climate change impacts related to increasing temperatures, acidity, storm intensity and sea levels and non-climate factors such as overexploitation, non-native species introductions and increasing nutrient and sediment loads;
* risks to coral reefs not distributed equally: increasing temperatures significant issue for warm-water systems; increasing acidity and decalcification a significant issue for both warm- and cold-water systems; direct human impacts a significant issue in more populous regions;

three different time scales can be identified for climate change-related impacts to coral reef systems:

* years: increased temperature effects on coral bleaching;
* decades: increasing acidification and dissolution of carbonate structures of reefs;
* multidecades: weakening of structural integrity of reefs and increasing susceptibility to storms and erosion events.
* increasing acidity (decreasing pH) is a significant and pervasive longer-term threat to coral reefs. Potential for coral reef systems to adapt to these environmental stresses is uncertain: symbiotic zooxanthellae may adapt to be more tolerant of high temperatures.
* Migrations of corals to higher latitudes is unlikely;
* declines in corals had negative impacts on reef fish biodiversity in at least one study, however, to date there is little evidence for a link between climate warming and bleaching events with impacts on coastal fisheries.

**Freshwater systems**

* freshwater lakes and their ecosystems are highly vulnerable to climate change;
* paleo records show the shapes and distributions of lakes can change and they can disappear entirely with shifting dynamics among precipitation, evaporation and runoff;
* anticipated response is for cold-water species to be negatively affected, warm-water species to be positively affected and cool-water species to be positively affected in the northern, but negatively affected in the southern parts of their range;
* general shift of cool- and warm-water species northward is expected in North America and likely the rest of the Northern Hemisphere;
* responses of particular lake ecosystems to climate change depend on size, depth and trophic status of the lake;
* modelling studies concluded cold-water fish would be most affected because of losses of optimal habitats in shallow, eutrophic lakes;
* growth conditions for cool- and warm-water fishes should improve in well-mixed lakes, small lakes and those with oligotrophic nutrient conditions;
* rates of change of freshwater systems to climate will depend on ability of freshwater species to “move across the landscape”, i.e. use of dispersal corridors;
* most affected are likely to be fish in lowland areas that lack northward dispersal corridors, and cold-water species generally;
* river ecosystems are particularly sensitive to changes in the quantity and timing of water flows, which are likely to change with climate change;
* changes in river flows may be exacerbated by human efforts to retain water in reservoirs and irrigation channels. The role of dams in blocking fish migrations is considered by some to be the largest single threat to inland fisheries (Dugan 2008; Ferguson et al. 2011; Baran and Myschowoda 2008);
* abundance and species diversity of riverine fishes are particularly sensitive to these disturbances, since lower dry season water levels reduce the number of individuals able to spawn successfully and many fish species are adapted to spawn in synchrony with the flood pulse to enable their eggs and larvae to be transported to nursery areas on floodplains.

**Aquaculture systems**

* direct impacts include changes in the availability of freshwater, changes in temperature, changes in sea level, and increased frequencies of extreme events (such as flooding and storm surges);
* indirect effects include economic impacts, e.g. costs and availability of feed;
* negative impacts include (Table 4):
* stress due to increased temperature and oxygen demands;
* uncertain supplies of freshwater;
* extreme weather events;
* sea level rise;
* increased frequency of diseases and toxic events;
* uncertain supplies of fishmeal from capture fisheries.
* positive impacts of climate change on aquaculture include increased food conversion efficiencies and growth rates in warmer waters, increased length of the growing season, and range expansions polewards due to decreases in ice;
* increased primary production would provide more food for filter-feeding invertebrates;
* may be problems with non-native species invasions, declining oxygen concentrations, and possibly increased blooms of harmful algae;
* local conditions in traditional rearing areas may become unsuitable for many traditional species;
* temperature stress will affect physiological processes such as oxygen demands and food requirements;
* increased food supplies are needed for aquaculture activities to realise benefits from increased temperatures;
* freshwater aquaculture activities will compete with changes in availability of freshwater due to agricultural, industrial, domestic and riverine requirements, as well as changes in precipitation regimes;
* increases in precipitation could also cause problems such as flooding;
* sea level rise also has the potential to flood coastal land areas, mangrove