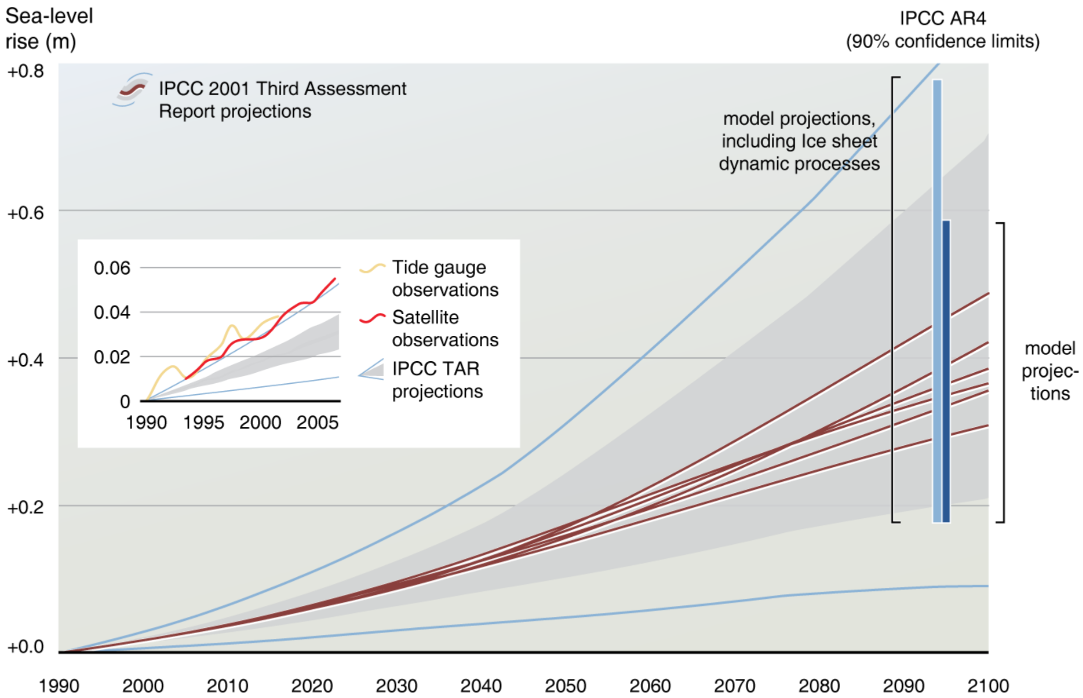
Strengthening Adaptive Capacities to the Impacts of Climate Change in Resource poor Small-scale Aquaculture and Aquatic resources-dependent Sector in the South and South-east Asian Region - AquaClimate

Potential impacts of Climate Change on aquaculture



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Current estimates of aquaculture productivity around the globe show that it is increasing and the number of people employed by aquaculture have also increased in the past decades. More and more developed and developing countries are becoming highly dependent on meeting their animal protein demands through aquaculture production. The necessity to assess the impacts of climate change and the strategies needed to be employed to mitigate and prepare for vulnerabilities is therefore wise and timely. The study of climate change, though fraught with uncertainties due to the scale of models employed to predict the changes being analysed is inextricably linked to our fisheries and aquaculture sector. This is not only to predict changes that will happen but to also prepare and mitigate any changes needed to be done. Despite the fact that many studies have already been published on the impact of climate change on marine fisheries and the ecosystem in general, there is currently a dearth of knowledge on the direct and indirect impacts of climate change on the aquaculture sector for lack of direct studies e.g. physiological impact of warming temperatures on larvae of various cultured organisms e.g. tilapia, milkfish, mud crabs, seaweeds, abalone and sea-urchins. Most of the technical briefs discussed have concerned themselves on general effects of climate change that does not take into account any technical studies done directly on cultured organisms. While we bereave this lack in the aquaculture sector, various isolated studies of fish, crustaceans, molluscs and ecosystems on climate change and fisheries are available though on different spatial scales and temporal observations varying from a few days to a few years and to decadal observations.

It could be that the lack of direct studies on impacts of climate change on aquaculture and organisms involved have made the community reluctant and cautious to accept the significance of changes that are occurring to the environment. However, as evidence for global warming and the changes that accompany it are increasing every year, the aquaculture and the fisheries sectors of many countries, especially in the tropics will have to do their own assessments. Global change or the industrial era did not start until the steam engine was invented and the discovery of oil facilitated the distribution of goods and increased travels to and within countries. Though these changes were remarkable progress for the human economy, it also brought unforseen consequences and impacts to the environment.

It increased the catch per unit efforts of fishermen using motorized boats and ships until it became an industrial scale. It is believed today that about 6million artisanal fishermen from various developing countries and industrial fleets of many developed countries are directly involved in extractive activities of both the capture and inland fisheries, including aquaculture. The global carbon footprint, for example, of capture fisheries is) and this contributes to the release of greenhouse gases that affects our climate. Though the convenience offered by fossil fuels are obvious, the destruction that it has brought through various pollution mechanisms such as power generation, transport and creation of goods have also emitted massive amounts of CO_2 into the atmosphere and in the oceans for the past decades .This has the effect of not only facilitating the demise of various rare organisms in the planet but also the destruction of their habitat through the fishing gears used that ploughed the bottom of the ocean and hunted schools of fishes as if the resources were without limit. The Fisheries and aquaculture resources are therefore sectors that remain vulnerable to the effects of climate change due its various ecological impacts. As the projected increase of temperature in the globe continue to be reached in the coming decades and countries ignore the effects of global warming, this ultimately affects not only the fisheries and aquaculture sector but the whole economy could be paralyzed due to inability to mitigate the combined and worsening effects of environmental changes. Many of these stressors may rarely work in isolation but could work in synergy or in additive combinations (Przeslawski et al. 2005, 2008). Some of these projected changes in the aquaculture sector are the effects of temperature on various organisms, changes in weather patterns, water quality fluctuation, sea-level rise and salt-water intrusion, outbreaks of diseases, and decrease in primary productivities. This paper aims to review the present knowledge on the above mentioned effects of climate change with a view on the aquaculture sector (both inland and marine).

CLIMATE CHANGE CHALLENGES TO AQUACULTURE AND FISHERIES

The Intergovernmental Panel on Climate Change (IPCC), defined climate change as any change in climate over time, whether due to natural variability or as a result of human activity (Hoegh-Guldberg, 1999). A greater concern than the change in atmospheric carbon dioxide (CO_2) and temperature are the rates at which change is occurring, or what is referred to as abrupt climate change. Abrupt changes in the climate is defined as large-scale change in the climate system that takes place over a few decades or less, persists for at least a few decades, and causes substantial disruptions in human and natural systems (USCCSP, 2008b). Recent increases in global temperature and CO_2 concentration have occurred 70 times faster and an astounding 1050 times faster, respectively, than mean rates of change for the past 420000 years as calculated from ice core data (Hoegh-Guldberg, 1999).

The most recent assessment made by IPCC (2001) provided evidence that 'an increasing body of observations gives a collective picture of a warming world and other changes in the climate system'. In addition, past records of climate and environmental change derived from archives such as tree rings, ice cores, corals and sediments indicate that global and regional climate has experienced abrupt changes, many occurring over a time span of decades or less (USCCSP, 2008b).

According to IPCC (2001), the observed warming could not be explained alone by natural variability. The most important cause is the increase of GHGs, initiated in the 19th century, and particularly rapid since 1950. The maximum CO_2 levels during the last one million years of 280 ppmv are already exceeded by 34% (Hoegh-Guldberg, 1999). Also, methane (CH_4) and nitrous oxide (N_2O) increased by 153% and 17%, respectively. The present concentrations of CO_2 of 375 parts per million (ppm) and CH_4 of 1772 parts per billion (ppb) are unprecedented high; the present N_2O concentration of 317 ppb has most likely not been exceeded in the past 1000 years (Leemans & van Vliet, 2004; USCCSP, 2008a).

In 2005, reports indicate that concentration of CO_2 exceeded the natural range that has existed over 650000 years. Evidence from observations of the climate system show an increase of $0.74^0C \pm 0.18^0C$ in global surface temperature during the 20th century and an even greater warming trend since 1950 ($0.13^0C \pm 0.03^0C$ per decade). Another manifestation of changes in the climate system is a warming in the world's oceans. Warming causes seawater to expand and thus contributes to sea level rise. Thermal expansion has contributed to approximately 1.6 mm per year to global average sea level since 1990 (Hoegh-Guldberg, 1999).

Aside from these, evidences of abrupt climate change is also seen in the rapid change at the edges of the Greenland and West Antarctic ice sheets where flow and thinning is accelerated with the velocity of some glaciers increasing more than twofold. Glacier accelerations that cause this imbalance have been related to enhanced surface melt water, production penetrating to the bed to lubricate glacier motion, and to ice-shelf removal, ice-front retreat, and glacier ungrounding that reduce resistance to flow.

These evidences and results of continuing observations of the climate system led IPCC to conclude that, “there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities” (Leemans & van Vliet, 2004; USCCSP, 2008a). Human activities such as the burning of fossil fuels and changes in land cover are modifying the concentration of atmospheric constituents and properties of the Earth’s surface that serve to absorb and scatter radiant energy (USCCSP, 2008a; USCCSP, 2008b).

IPCC (2001) also concluded that “recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems.” The ecological impacts of climate change are now observed everywhere and some unexpected changes occurred. Climate change has already had a considerable impact on species and ecosystems, and on human health and society. Many ecological impacts of climate change can and have occurred naturally in the past, some even during times not considered to be globally warm periods (Leemans & van Vliet, 2004).

The following are the summary of changes in the key parameters of climate change. These changes would be the basis of understanding the various impacts of climate change on the aquatic ecosystems of different regions.

Seasonal Patterns

Warmer atmospheres bring about greater numbers of heat waves but fewer extreme cold events. The climatological record of the past several decades offers evidence for these trends. Recent winters in North America and Asia have been mild but in a number of countries record heat waves have been experienced. A more recent case is the heat wave in 2002 which claimed over 600 lives in India as temperatures soared to 50^0C. A global rise in temperatures increases the possibility that more deadly heat waves will occur, as more evaporation could occur.

It was also observed that winter and night time minimum temperatures are continuing to increase faster than summer and daytime maximum temperatures, respectively, reducing seasonal and diurnal temperature ranges. New record high night time minimum temperatures are shortening the frost season in many mid-and high latitude regions (Leemans & van Vliet, 2004).

Extremes of warm temperature have increased in most regions, whereas the number of frost days and daily cold extremes has generally decreased (Flitner & Herbeck, 2009). In North America, since the record hot year of 1998, six of the last ten years (1998-2007) have had annual average temperatures that fall in the hottest 10% of all years on record. In addition, the number of heat waves (extended periods of extremely hot weather) also has been increasing over the past fifty years, while there have been fewer unusually cold days during the last few decades. The last 10 years have seen fewer severe cold snaps than for any other 10-year period in the historical record, which dates back to 1895 (USCCSP, 2008a).

In the United Kingdom, a significant shift in the seasonality of precipitation has been observed. Of the total amount of rain and snow falling in the UK, the proportion that falls in winter relative to summer has changed over time. Winters have been getting wetter and summers have been getting drier. (Pinnegar, *et al*., 2006). In the last 100 years, northern

Europe has become 10-40% wetter and southern Europe up to 20% drier and this is attributable to fewer cold extremes, more heat waves, smaller diurnal and seasonal ranges, heavier precipitation. Similar trends have been reported for other regions in the world (Leemans & van Vliet, 2004). In Mexico, it was observed that the monsoon season begins 10 days later than usual. In general, for the summer monsoon in southwestern North America, there are fewer rain events, but the events are more intense (USCCSP, 2008a).

Another change in seasonal pattern observed is the occurrence of severe droughts. Drought is one of the most costly types of extreme events and can affect large areas for long periods of time. Over the continental U.S. and southern Canada the most severe droughts occurred in the 1930s and there is no indication of an overall trend in the observational record, which dates back to 1895. In Mexico and the U.S. Southwest, the 1950s were the driest period though droughts in the past 10 years now rival the 1950s drought. There are also recent regional tendencies toward more severe droughts in parts of Canada and Alaska (USCCSP, 2008a).

The analysis of climate model scenarios of future hydroclimatic change over North America and the global subtropics indicate that subtropical aridity is likely to intensify and persist due to future greenhouse warming. This projected drying extends poleward into the U.S. Southwest, potentially increasing the likelihood of severe and persistent drought in the future (USCCSP, 2008b). The emphasis up to now has been on the semi-arid to arid Western United States as it is here where the late-20th century drought began and persisted (USCCSP, 2008b).

Precipitation patterns

One of the most important physical consequences of a warmer atmosphere is an increased in capacity to hold moisture. The projections for the 21st century suggest that the global mean precipitation is going to grow, however strong regional differences are expected (Flitner & Herbeck, 2009). General trends observed in the late 20th century are projected to continue. Moreover, increases in the amount of precipitation in high latitudes are very likely to experience a further decline of up to 20% until 2100. On the average, precipitation is likely to be less frequent but more intense and precipitation extremes are very likely to increase (USCCSP, 2008a).

Between regions, there is a significant difference on the observed changes in precipitation. The precipitation in temperate regions has generally increased from 1900 to 2005. Meanwhile, precipitation in the tropics shows a persistent decline from the mid-1970s onwards. An increasing frequency of drought events had been ascribed to those changes (Flitner & Herbeck, 2009).

For instance, the Sahel in Africa has become drier over the past several decades, accelerating desertification and placing an even greater premium on already-stretched water supplies. In Europe, annual precipitation trends for the period of 1900-2000 show a contrasting picture between northern (10-40% wetter) and southern (up to 20% drier) regions. Changes have been greatest in winter in most parts of Europe. The IPCC (2001), states there has likely been a widespread increase in every heavy rain in regions where total precipitation has increased. In some regions, increases in heavy rainfall have been identified where the total precipitation has decreased or remained constant, such as East Asia. This is attributed to a decrease in the frequency of precipitation (Leemans & van Vliet, 2004). On the other hand, extreme precipitation episodes have become more frequent and more intense in recent decades over most of North America and now account for a larger percentage of total precipitation. Intense precipitation in the continental U.S. increased by 20% over the past century while total precipitation increased by 7%. The monsoon season is beginning about 10 days later than usual in Mexico. In general, the summer monsoon in Southwestern North America, there are fewer rain events, but the events are more intense (USCCSP, 2008a).

Severe storm (cyclones, hurricanes, typhoons and monsoon flooding patterns)

A warmer atmosphere results in a greater number of tropical storms, extreme heat waves, floods and droughts. Based on Oxfam reports (2007), the number of climate-related disasters, particularly floods and storms, is rising faster than the number of geological disasters, such as earthquakes. Between 1980 and 2006, the number of floods and cyclones quadrupled from 60 to 240 in a year while the number of earthquakes remained approximately the same, at around 20 a year (OXFAM, 2007).

Extreme weather events are consistent with general warming trends. Tropical storms show clear upward trends with regard to storm intensity and duration since the 1970s, leading to a rising destructiveness of storm events. However, strong regional differences in the total number of storms have to be considered, with highest growing rates in the North Pacific, Indian and Southwest Pacific oceans. Since the 1960s, storms have also increased in mid-latitude regions, although in the late 1990s, levels have gone back to normal in the Northern Hemisphere (Flitner & Herbeck, 2009).

Atlantic tropical storm and hurricane destructive potential has increased substantially since about 1970 and is likely to have been substantial since the 1950s and 60s, in association with warming Atlantic sea surface temperatures (USCCSP, 2008a). There have been fluctuations in the number of tropical storms and hurricanes from decade to decade and data uncertainty is larger in the early part of the record compared to the satellite era beginning in 1965. Even taking these factors into account, it is likely that the annual numbers of tropical storms, hurricanes and major hurricanes in the North Atlantic have increased over the past 100 years, a time in which Atlantic sea surface temperatures also increased (USCCSP, 2008a). Observations show that hurricanes have become more destructive in both the Atlantic and the Pacific. In 2005, a study showed that tropical cyclone wind speed and duration over the last 30 years had increased by 70%. In another study in 2006, results show a 60% increase in the destructiveness of tropical storms from 1958-2001.

These study results find support in the disastrous effect of Hurricane Katrina in 2005. Hurricane Katrina caused a loss of 338 square kilometers of coastal wetlands, leeves and islands. During this time, 1800 people died, 300,000 homes were destroyed and total economic losses are estimated at $100 billion. Another supporting evidence is the deadly tsunami in December 2004 which resulted from an earthquake in the Indian Ocean. The tsunami left 150,000 dead and missing people and millions of homeless in eleven different countries.

In Europe, there seems to be little sign of long-term changes in storm intensity and frequency, but inter-decadal variations are pronounced. In Ireland, the increased sea surface temperature may lead to more intense cyclones increasing the probability of severe weather events such as heavy precipitation and strong wind storms. In this case, Western Europe could be affected by a larger number of transitioned tropical cyclones (Semmler, *et al.*, 2006).

Increased evaporation brings more rains and consequently, an increase in the frequency or intensity of floods. Perhaps no country is more vulnerable than Bangladesh when it comes to flooding. Intense floods will put at risk over 17 million people in Bangladesh who lives at an elevation of less than 3 ft (1m) above sea level. Past floods have displaced millions and turned out to have tragic results. Other countries such as China and Vietnam have also experienced catastrophic floods in the past few years. Exacerbated flooding had been experienced in countries as far apart as UK, Vietnam, South Africa, Mexico and India (OXFAM, 2007).

Over the 20th century, there has been considerable decade-to-decade variability in the frequency of snow storms. Regional analyses suggest that there has been a decrease in snow storms in the South and Lower Midwest of the U.S. and an increase in snow storms in the Upper Midwest and Northeast. This represents a northward shift in snow storm occurrence, and this shift, combined with higher temperature, is consistent with a decrease in snow cover extent over the U.S. In northern Canada, there has also been an observed increase in heavy snow events over the same time period. Changes in heavy snow events in southern Canada are dominated by decade-to-decade variability. The pattern of changes in ice storms varies by region (USCCSP, 2008a).

Projections for storms show reduced total numbers of tropical as well as extra-tropical storms, but the intensity of storms is expected to rise with regard to wind speed and precipitation (Flitner & Herbeck, 2009).

Sea level rise

Sea level rise has been relatively constant during the last 2000 years, but in the 20th century, there was a gradual change seen of this stability. From 1961 to 2003, sea level rose with an average of 1-1.8 mm per year, with a clear acceleration during the period from 1993 to 2003 (Flitner & Herbeck, 2009; Hoegh-Guldberg, 1999).

Other estimates indicate that the global average sea level rose at a rate of ~1.7 ± 0.5 mm per year over the last century. However, the rate of global sea level rise for the period 1993 to 2003 accelerated to 3.1 ± 0.7 mm per year, reflecting either variability on decadal time scales or an increase in the longer term trend (USCCSP, 2008b).

There may have been varying estimates on global sea levels, as sea level change is difficult to measure, but a clear trend emerges that sea level is indeed rising. However, there are regional and temporal differences observed. Regional differences arise not only from changes in land height, but from local differences in ocean heat content and the pattern of winds and currents. Over the past 50 years, sea level has risen faster across the subtropical belt, particularly the northern Pacific and Caribbean (Hoegh-Guldberg, 1999).

The major causes of this increase are thermal expansion of the surface waters and melting of glaciers and snow on land and the Greenland ice cap (Leemans & van Vliet, 2004; Flitner & Herbeck, 2009; USCCSP, 2008b). Relative to the period 1961-2003, estimates of the contributions from thermal expansion and from glaciers and ice sheets indicate that increases in both of these sources contributed to the acceleration in global sea level rise that characterized the 1992-2003 period (USCCSP, 2008b).

In the 20th century, the average level of the UK seas rose by some 14 cm. The IPCC Fourth Assessment Report projected that global mean sea level will rise by 18 to 59 cm during the 21st century through a combination of thermal expansion of the seawater and melting of glaciers and ice sheets. Because the rate and magnitude of ice sheet melting is highly uncertain, the IPCC also included a higher upper limit of 79 cm, but they ascribed no likelihood to this projection and could not discount significantly higher changes (Pinnegar *et al.*, 2006).

Based on IPCC AR4 report, sea level is projected to rise by 0.28 ± 0.10 m to 0.42 ± 0.16 m in response to the additional global warming, with the contribution from thermal expansion accounting for 70-75% of this rise. Recent studies allow the assumption that these estimates are rather conservative. The rate of Antarctic ice mass losses has been dramatically higher during the years from 1992 to 1996 (with an average thickness loss rate of 1.6 meter p.a.), compared to the average rate of the last 5000 years (between 2.3 and 3.8 cm thickness p.a.). Although it is unclear whether the unexpectedly high loss rate reflects a general trend or fluctuations are of temporary nature, the dramatic increase of ice losses could indicate an even faster rise of the sea level that as expected from the last IPCC report (Flitner & Herbeck, 2009).

Paleorecords demonstrate that there is a strong inverse relation between atmospheric carbon dioxide (CO_2) and global ice volume. Sea level rise associated with the melting of the ice sheets at the end of the last Ice Age ~20000 years ago averaged 10-20 mm per year with large “melt water fluxes” exceeding sea level rise of 50 mm per year and lasting several centuries clearly demonstrating the potential for ice sheets to cause rapid and large sea level changes (USCCSP, 2008b).

Observations show that it is extremely likely that the Greenland Ice Sheet is losing mass and that this has very likely been accelerating since the mid-1990s. Greenland has been thickening at high elevations because of the increase in snowfall that is consistent with high-latitude warming, but this gain is more than offset by an accelerating mass loss, with a large component from rapidly thinning and accelerating outlet glaciers. The mass balance for Antarctica is a net loss of about 80 Gt per year in the mid-1990s, increasing to almost 130 Gt per year in the mid 2000s. Observations show that while some higher elevation regions are thickening, substantial ice losses from West Antarctica and the Antarctic Peninsula are very likely caused by changing ice dynamics (USCCSP, 2008b).

Oceanic currents

There is very little information regarding the impact of climate change on local or regional current regimes, but changing wind and precipitation conditions allow the assumption that currents already change on this scale. Climate change impact on global current regimes and circulation is a matter of considerable debate. So far, there is no clear evidence of ocean circulation changes, although temperature variations have been documented in Southern Ocean mode and deeper circulation waters, as well as the Gulf Stream in the North Atlantic and North Pacific (Flitner & Herbeck, 2009).

For local changes of ocean currents, uncertainties in projections are high, but expected growth of strong wind and heavy precipitation events might influence local regimes. During the 21st century, the Atlantic Ocean Meridional Overturning Circulation (MOC) is very likely to slow down, but estimated range from virtually no changes to a reduction up to 50% by 2100 (Flitner & Herbeck, 2009).

In Australia, the southward flow of East Australian Currents are found to have strengthened pushing warmer and saltier water 350 km further south as compared to 60 years ago. On the other hand, the southward flow of Leeuwin current has slightly weakened since the 1970s (Hoegh-Guldberg, 1999).

Temperature patterns

Surface temperature has risen over the last 100 years, with a total temperature increase on 0.76^0C since 1989. The second half of the last century showed a warming rate of 0.10^0C to 0.16^0C per decade, almost twice as high as the average warming rate for the whole century. The 12 years from 1995 to 2006 saw eleven of the warmest years since the instrumental record of surface temperature (Flitner & Herbeck, 2009; USCCSP, 2008a).

An increase in global temperature was observed to have occurred in two periods, from about 1910 to 1945 and since 1976. Furthermore, most of this warming occurred on land, which tracks temperature change faster than large water bodies, although the oceans have also warmed significantly in the last 50 years, especially in the upper 300 meters. Since the late 19^{th} century, the global average sea surface temperature has increased by 0.6^0C, consistent with the increase in global air temperature. The Baltic and North seas and the western Mediterranean show a warming of about 0.5^0C over the past 15 years. Sea surface temperatures in the North Atlantic have been rising since the mid-1980s, which could have been part of a fluctuation over several decades. This is however, unlikely because the warming has accelerated over the last five years. This contributed to the rapid parallel increases of surface air temperature in much of Europe (Leemans and van Vliet, 2004).

Europe has warmed more than the global average, with a 0.95^0C increase since 1900. The warming has been greatest in north-west Russia and the Iberian Peninsula. (Leemans and van Vliet, 2004). Over the last 100 years, the UK climate has also experienced marked changes over the same period. Central England air temperature rose by almost 1ºC during the twentieth Century, and 2003 was the hottest year since records began in 1659. Warming over land has been accompanied by an equally dramatic warming of UK coastal waters (Pinnegar, *et al*., 2006).

Projections for 2100 show large variations, most optimistic projections expect global temperature rise of 1.1^0 to 2.9^0C whereas under non-mitigation scenarios temperatures are expected to rise from 2.4 to as much as 6.4 ^{0}C.

Acidification of open waters

The oceans are substantial carbon reservoir with an estimated daily uptake of 22 million metric tons of CO_2 (Feely, *et al*., 2008; The Royal Society, 2005). The pre-industrial oceanic carbon reservoir has been estimated at about 38000 Gt, compared with about 700 Gt in the atmosphere and somewhat less than 2000 Gt in the terrestrial biosphere. Oceans act as an important carbon sink, absorbing 2 Gt per year, more CO_2 than they are releasing into the atmosphere (The Royal Society, 2005).

Anthropogenic carbon is observed to penetrate in areas of deep and intermediate water formation, such as the North Atlantic, and the Southern Ocean, 40-50^0C. Anthropogenic CO_2 can be found in depths of up to 2500 m in certain areas, although newer studies in the North Atlantic have revealed large changes in CO_2 concentrations in deep-water masses between 3000 and 5000 meters depth, indicating that CO_2 might already have penetrated to this depth in certain locations (Tanhua, *et al*., 2007). Depending on the location and ocean currents, CO_2 can be retained in deep waters for several hundred years 16 (IPCC, 2005; Chisholm, 2000). This means that the equivalent CO_2 content is temporarily removed from the atmosphere for this time period.

Oceans act as major buffers of anthropogenic CO_2 emissions (Fernand & Brewer, 2008) The burning of fossil fuels has increased CO_2 in the atmosphere from about 275 ppm to 378 ppm since the Industrial Revolution began in the 1800s. The extra CO_2 has contributed to the observed rise in global temperatures of 0.6^0C via the greenhouse effect. The oceans have absorbed 48% of all the CO_2 emitted since 1800 (Sabine *et al*., 2004; ACECRC, 2008; Fernand & Brewer, 2008; Turley *et al.,* 2009; Flitner & Herbeck, 2009). This only demonstrates the integral role that oceans play within the natural processes of cycling carbon on a global scale or simply the carbon cycle (The Royal Society, 2005).

When CO_2 dissolves into the ocean, it creates carbonic acid. Oceanic uptake of CO_2 has led to a perturbation of the chemical environment, primarily in ocean surface waters associated with the increase in dissolved inorganic carbon (Fernand & Brewer, 2008). Ocean uptake of anthropogenic CO_2 has buffered climate change by reducing the atmospheric concentration of this greenhouse gas. However, when CO_2 reacts with seawater, the concentration of bicarbonate ions (HCO_3) increases while the amount of carbonate ions CO_3 and pH of the surface ocean waters decreases. This alters the ocean chemistry (Turley *et al*., 2009).

Ocean acidification is a global phenomenon. However, regional and seasonal influences, combined with the biological, chemical and physical factors influence the uptake of CO_2 and result to a variable pH and magnitude of ocean acidification across the global oceans of ± 0.3 units from about 7.90 to 8.20. Larger variations can be observed from 7.3 inside deep estuaries to 8.6 in productive coastal plankton blooms and 9.5 in tide pools (The Royal Society, 2005).

Before the Industrial Revolution, pH of the ocean surface waters ranged from 8.0 to 8.3. Ocean pH has dropped a full of 0.1 units since then, to the 7.9 to 8.2 range. Unless significant cuts in CO_2 emissions are realized in the next few decades, the pH will fall another 0.14-0.35 units by the year 2100 as the oceans continue to acidify, according to the IPCC 2007 Synthesis Report (Flitner & Herbeck, 2009).

In a report of ICES (2008), estimates of the changes in ocean pH is believed to have occurred in surface ocean waters over the past 650,000 years. The study revealed that the change in pH has been cyclical and associated with the glacial periods, with the transition from low to high values occurring every 50,000 years. From a historical perspective, the current levels of CO_2 are already high, and anthropogenic emissions are exacerbating this issue. The only factor which balances out high CO_2 levels in the oceans is the alkaline flux from the weathering of silicate rocks which happens on a time-scale of hundreds of thousands of years (Fernand & Brewer, 2008).

A 2005 report of the Royal Society of UK projects the decrease by 2100 will be 0.5 pH units, and notes that it will take more than 10,000 years for the ocean to return to its pre-1800 acidity level (ACECRC, 2008; Fernand & Brewer, 2008; The Royal Society, 2005). Southern ocean surface waters will be specially exposed to a decreasing calcium carbonate saturation, although low-latitude regions will be affected as well. Furthermore, the penetration of atmospheric CO_2 into the deep sea is expected to change the chemistry down to several thousands of meters (Flitner & Herbeck, 2009; The Royal Society, 2005).

Although studies into the impacts of high concentrations of CO_2 in the oceans are still in their infancy, evidence indicates that reduced ocean carbon uptake is starting to occur and that this poses a serious hazard because this is likely to speed up global warming , as occurred when this type of feedback was initiated during the early warming stages of previous interglacials (The Royal Society, 2005).

Availability of Freshwater

The world's rivers are fed with water from precipitation. Run-off results from the balance between precipitation, groundwater recharge, groundwater discharge and evaporation. There are many delays in the system. Precipitation can be stored in winter as snow and ice and is only released during the melting season. Some water slowly infiltrates the soil, flows as groundwater and re-emerges in spring. These storage processes often buffer water sources and determine water availability for human use, even when there is little precipitation (Leemans & van Vliet, 2004).

The declining glaciers and snowfields in the Himalayas , for example, strongly affect run-off and water availability in the Indo-Gangetic plains regions of India and Bangladesh, which is very important for the food security of South Asia. Although temperature and precipitation has somewhat increased in the region, the river data indicated an overall decrease in discharge. The decreasing trends of stream flow were more significant during the low-flow months when most of the water originates from snow-melt permitting a constant supply of water throughout the year. All these factors make the society of the Indo-Gangetic plains region one of the most vulnerable in the world to changes in climate (Leemans & van Vliet,2004).

Across Europe, annual river discharge has changed over the past few decades. In some regions including Eastern Europe, annual river discharge has increased, while in some areas such as Southern Europe it has significantly decreased. Some of these changes can be attributed to observed changes in precipitation. The combined effects of projected changes in precipitation and temperature will in most cases amplify the changes in annual river discharge. Annual discharge is projected to decline strongly in Southern and Southeast Europe but to increase in almost all parts of Northern and Northeast Europe, with consequences for water availability (Leemans & van Vliet,2004).

EXPECTED IMPACTS OF CLIMATE CHANGE ON AQUATIC ENVIRONMENTS

Climate variability can have an enormous impact on aquatic ecosystems, as well as those industries which strive to operate in this challenging environment. Long-term climate change may well affect the physical, biological, and biogeochemical characteristics of oceans and coasts, modifying ecosystems and the way that they function (Hoegh-Guldberg, 1999).

At present, the most documented impacts of climate change on natural systems have been ecological in nature. Observed ecological responses to local, regional and continental warming include changes in species' distribution, changes in species' phonologies, and alterations of ecosystem functioning. Most phenological changes focus on terrestrial plants and animals. However, changes in the timing of life-cycle events are also taking place in aquatic ecosystems (Leemans & van Vliet, 2004).

Freshwater

Freshwater environments in the form of natural and artificial bodies of water, water courses, watersheds and freshwater wetlands are affected by various climate change parameters such as acidification, rising temperatures, sea level rise and increased precipitation patterns.

Acidification

Acidification is not limited to seas and oceans, bodies of freshwaters are not spared from this climate change impact. Freshwater acidification was first identified in Scandinavia during the early 1970s at which time many scientific studies were initiated. Natural acidification of freshwater environments has been taking place since the last ice age. However, the recent rapid acidification of many of lakes throughout the world cannot be attributed to natural causes, but instead to the effects of acidic pollution from the burning of fossil fuels. Areas that are more susceptible to acidification have an unreactive geology such as granite and a base-poor soil. Lakes and streams that are generally regarded as acidified are very nutrient poor waters draining unreactive geology.

Acidification takes place most readily in areas where the natural geology is slightly acidic. Upland regions that have been subject to land-use changes over the last few decades are showing the signs of acidification. There are several factors affecting acidity such as action of atmospheric carbonic acids, formation of organic acids by humus podzolisation, podzolisation, land-use changes such as livestock introduction into the catchment, use of nitrogen fertilizer, increased efficiency of drainage, dry deposition of air pollutants, and wet deposition of sulphuric and nitric acids. The combination of these factors will lead to freshwater acidification.

Both the lower pH and higher aluminum concentrations in surface water that occur as a result of acidification causes significant damage to biodiversity. Soft bodied animals such as leeches, snails and crayfish are early victims, often being one of the first signs of the commencement of acidification. Few insect species are very resistant to acidification and species such as mayfly disappear even under moderate acidification. Salmon, trout and roach are particularly at risk from freshwater acidification, pike and eel being relatively resistant. It also affect all the life stages of fish; the reproductive ability of adults and survival of eggs and young fry (Flitner & Herbeck, 2009).

Temperature variations

Freshwater habitats are highly fragmented and include smaller and genetically more subdivided fish populations. Therefore the biodiversity of freshwater ecosystems and related food production from fisheries face specific challenges from climate change. In combination with other anthropogenic pressures, climate change has already caused faster biodiversity declines than in terrestrial or marine ecosystems over the past 30 years. Mean while, approximately 20% of the world’s freshwater fish species have been listed as threatened, endangered or extinct (Flitner & Herbeck, 2009).

Generally, freshwater species in both lotic and lentic systems will be exposed to rising water temperatures, due to global temperature increase. Growth, reproduction and activity of freshwater fish are affected by rising temperatures. This indicates changes in the species metabolism, food consumption and reproductive successes. Fish populations exposed to rising water temperatures limit levels of dissolved oxygen. Although depending on a high number of other local factors, rising water temperatures are likely to cause decreased dissolved oxygen in at least some systems, which can lead to an “oxygen squeeze” when decreased oxygen levels in the water cannot meet increased oxygen demand of fishes (Flitner & Herbeck, 2009; Watson *et al.,*2000).

Sea level rise
Through repercussions on freshwater aquifers, sea level rise will add on changing hydrologic regimes and thereby contribute to alterations of freshwater habitats and associated biodiversity losses (Flitner & Herbeck, 2009).

Precipitation patterns
In lotic systems, changed precipitation patterns and increased evaporation can affect water regimes and alter water availability (Flitner & Herbeck, 2009). While 70 % of the world's rivers are projected to experience increased water availability, the remaining 30% of the rivers will be negatively affected by climate change. Fundamental changes in water regimes might cause the loss of a significant share of species in these basins by 2100. Recent studies show that up to three quarters of local fish species in rivers with reduced water flow are threatened with extinction by 2070. Climate change plays a crucial role in reducing river discharge, while interlinkages with human water withdrawal and other additional anthropogenic pressures are projected to exacerbate regime changes and lead to even higher extinction rates (Flitner & Herbeck, 2009).

Freshwater and estuarine environments are often very sensitive to changes in meteorological conditions and, as a result, freshwater organisms may be greatly impacted by predicted future climate change (Pinnegar *et al*., 2007).

Change in temperature and precipitation
Temperature rise and less frequency of precipitation cause die-offs in flooded forests which depends largely on constant inundation. One of the largest flooded forest is the Amazon, which is projected to shrink to as much as 85% with 4^0C increase in temperature and even a modest temperature rise of 2^0C will still result to 20-40% die-off in 100 years (www.guardian.co.uk, 2010). In a span of 12 years, the Amazon have already experienced three extreme dry spells in 1998, 2005 and 2010. Among the consequences of the drought are extremely low flows on many of the region's rivers. Long dry spells in the Amazon wither crops and worsen air pollution and cut off whole towns from the rest of the world, when rivers turn to mud. In addition there are uncontrollable forest fires and at the same time, several species are affected particularly at the Pacaya Samiria National Reserve in the Peruvian Amazon (www.guardian.co.uk, 2010).

Changes in temperature and precipitation
With the expected long-term changes in rainfall patterns and increasing temperatures coupled with an onslaught of extreme events, climate change is expected to significantly affect the Greater Mekong Region's agricultural productivity. Although annual flooding of the paddy fields is required for the rice crop to succeed, unusually heavy flooding or severe droughts cause farmers to lose their entire crop and cut access to markets and possible coping strategies, through damage to infrastructure.

Sea level rise
Sea level rise will lead to salt-water intrusion and land loss affecting the lives and livelihoods of people in the coastal areas of Thailand and Vietnam. By the end of the century, higher sea levels in the Mekong Delta, where nearly half of Vietnam's rice is grown, may inundate about half (~1.4 million ha) of the delta's agricultural lands.

Brackishwater
Lagoons are highly productive coastal features that provide a range of natural services that society values. Their setting within the coastal landscape leaves them especially vulnerable

to profound physical, ecological, and associated societal disturbance from global climate change. Expected shifts in physical and ecological characteristics range from changes in flushing regime, freshwater inputs, and water chemistry to complete inundation and loss and the concomitant loss of natural and human communities. Therefore, managing coastal lagoons in the context of global climate change is critical. (Anthony *et al.,* 2009*).*

Climate change impacts on estuaries, lagoons and other brackishwaters in coastal zones come from extreme weather events such as storms and hurricanes, increased precipitation affecting runoff and sea level rise.

Extreme weather events and increased precipitation
Estuarine environments are affected by short-term natural events that are primarily weather related such as hurricanes, tropical storms or northeasters. These extreme weather events have major impacts on estuarine ecosystems' structure and function. These powerful weather systems damage habitats through direct wind or wave action and alter habitats by loading freshwater, nutrients, and pollutants into the estuary (Litaker & Tester, 2003).

The freshwater input during and after major storms, particularly hurricanes, determines the mortality among sessile organisms as well as displacement and mortality of mobile species. The mesohaline region of the estuary is generally most impacted by runoff during these events. Prolonged periods of reduced salinity results to extensive mortality among benthic organisms such as sponges, tunicates, bryozoans, coelenterates and mollusks. Some species may also be eliminated particularly species with limited dispersal capacity. Further, if the salinity stress coincides with the breeding season of a particular organism, fecundity and survival will be affected. The closer the storm occurs to the peak breeding season, the greater the chances of severe population impacts (Litaker & Tester, 2003).

Apart from salinity stress, nutrient loading is another problem being brought about by extreme weather events on estuaries. More than 50% of the annual nutrient loading can occur during a single, large runoff event. Nitrogen and Phosphorus in the runoff play a direct role in stimulating phytoplankton growth. In addition, most hurricanes and tropical storms occur in the warmer months when the phytoplanktons are actively growing. Under these conditions, phytoplanktons take up the inorganic N and P and grow rapidly. These same results occur during smaller storm events that also contribute nutrients into the estuary. The biomass increase generally occurs within a week following nutrient input and lasts for a few weeks up to three months, depending on the extent of loading. In estuaries where flushing rates are high, excess nutrients and cells may be transported out of the system, resulting in a smaller bloom than found in the lagoonal systems that efficiently trap nutrients. Phytoplankton blooms contain a large quantity of carbon, the base of food chain. Zooplankton grazing communities would generally be major consumers of this increased productivity. However, zooplankton biomass is often significantly decreased following major runoff events. This further favors the development of phytoplankton blooms and subsequent bacterial use of newly-produced carbon that would otherwise have been consumed by the zooplankton community (Litaker & Tester, 2003).

Studies of salt wedge estuaries that have experienced a runoff event and bloom during warmer months indicate that if both the carbon supply from sinking phytoplankton and temperatures are sufficiently high, extensive bacterial respiration will cause the lower salt wedge to become hypoxic or anoxic. Transient hypoxic or anoxic events similarly occur in shallow estuaries when the primary production is sufficiently high so the biological oxygen demand (BOD) consumes all or most of the oxygen in the water column. Sometimes these hypoxic or anoxic zones can be quite large and lead to additional fish kills or the decimation of the benthic microfauna. Though anoxia tends to slow down remineralization of organic compounds in the benthos, significant amounts of ammonium and phosphate can be released.

Runoff from tropical storms and hurricanes can load more than a year's worth of sediment into an estuary within several weeks. Sedimentation affects the benthic community directly by burying many benthic organisms so they cannot feed effectively. Indirectly, the sediments represent a large source of organic carbon, exacerbating the BOD problem during the warmer months. The initial anoxic or hypoxic conditions produced by storm runoff are often not the result of bacterial action on increased algal production, but rather the immediate metabolism of organic material in the sediment (Litaker & Tester, 2003).

The increased productivity following runoff events can have both positive and negative effects. On the positive side, the increased productivity can result in a rapid increase in the abundance of certain invertebrates. On the other hand, certain parts of the estuary, with fairly low flushing rates and high recycling rates, may experience nuisance algal blooms when there is little wind. These blooms greatly reduce the recreational value of the estuary and can supply enough carbon for the bacterial community to create anoxia and related fish kills (Litaker & Tester, 2003).

The extent to which hurricanes load toxicants into estuaries depends largely on upstream sources. Large amounts of water coming into the system often dilute dissolved toxic compounds below levels of detection. Given sufficient outflow from the estuary during the event, they can be largely eliminated from the estuary. In that respect, the runoff can cleanse the estuary. If the upstream sediment is contaminated with heavy metals, pesticides, or other harmful chemicals, these substances can be retained in the system. After reaching the benthos, they either remain inertly attached to the particle or are mobilized to enter the food chain (Litaker & Tester, 2003).

Sea level rise

Accelerated sea level increase is a particular threat to low-lying, shallow-gradient coastal ecosystems. Most barrier-lagoon systems respond naturally to sea level increase by migrating landward along undeveloped shorelines with gentle slopes; the retreating shore face profile can remain essentially unchanged as the shoreline retreats landward and upward in response to moderate sea level increases. However, with accelerated sea level increase, landward retreat of barriers may not be rapid enough to prevent inundation. Hardened shorelines on developed coastlines impede this natural migration and increase the vulnerability of coastal structures to inundation and storm damage.

Mangroves

Mangrove ecosystems are affected by sea level rise and extreme weather events. Due to these climate change impacts, mangroves are one of the forest ecosystems which are expected to experience the most significant losses of biodiversity and most serious reduction of ecosystem services, together with boreal forests, dry forests, tropical forests and cloud forests (Flitner & Herbeck, 2009).

Sea level rise

Sea level rise which brings about increased salinity levels and more frequent flooding, will greatly affect coastal forest ecosystems. Regeneration periods will be reduced and trees, including mangroves, will suffer from salt water intrusion.

Extreme weather events
Hurricanes, tropical storms and particularly northeasters are also notable for the physical damage they cause to mangroves. Vascular plant communities surrounding estuaries are most visibly affected by major storms. Mortality and damage occurs from uprooting, stripping leaves and limbs and salt spray damage. The periodic damage inflicted by hurricanes, therefore, plays a crucial role in the structure of these plant communities (Litaker & Tester, 2003).

In addition, hurricanes open space in mangroves by destroying trees, removing peat deposits, and by bringing poisonous anoxic sulfide rich sediments to the surface. The sulfide released from the mud kills weakened trees and saplings. Despite the damage, the mangrove and other plant communities gradually respond with increased productivity after the storm and generally recover until the next storm produces similar damage. The immediate effect of storms is the degradation of habitats for many vertebrate and invertebrate species. Storm surges also frequently disrupt littoral sand communities and deposit large amounts of sand onto existing marshes further inland, causing significant habitat destruction (Litaker & Tester, 2003).

Marine systems
The changing climate has been linked to a wide range of impacts on marine ecosystems, either directly (through changes in sea temperatures) or indirectly through the impacts on seasonality, distribution and abundance of species.

Direct drivers affecting marine ecosystems include ocean warming, sea level rise, increase in wave height and frequency, loss of sea ice, increased risk of diseases in marine biota and decreases in the pH and carbonate ion concentration of surface oceans. Climate change drivers impact marine ecosystems globally, with high cumulative impacts and with particular importance for offshore habitats. The different factors directly influence physiology, behavior, growth, reproductive capacity, mortality and distribution of fish stocks (Flitner & Herbeck, 2009).

Rising sea temperatures
Recent changes in global temperature have caused significant phenological and distributional changes everywhere in the world. These changes have altered and will further alter many interactions between species. Extreme events are expected to determine the future development of local populations and species (Leemans & van Vliet, 2004).

It is already evident that increasing sea temperatures already cause shifts in the movements of plankton, fish and other species in a pole-ward direction. Further changes in migration routes and in the productivity of fish stocks are expected with continuing warming, which might be responsible for a local loss of fish species. At the same time, range shifts through changing temperatures might also favor the extension of invasive species into new marine ecosystems, posing additional threats to biodiversity (Flitner & Herbeck, 2009).

Marine and freshwater biological invasions are increasingly recognized as a threat to biodiversity and industry, including fisheries. Future temperature increases could enable more species to invade and become established, replacing or displacing native species. Non-native species can have far-reaching and undesirable ecological consequences. The new conditions are likely to place additional stress on native species, which will be compounded by the introduction of invasive non-native species, either through direct effects or indirect influences (Marcos-Lopez *et al*., 2010).

Ocean Acidification

Acidification of the Earth's oceans have potential serious and far-reaching impacts within the 21st century, for the sustainability and management of many marine and coastal ecosystems and fisheries. The impact of ocean acidification is projected to vary regionally with varying rates of CO_2 uptake from the atmosphere and pre-existing variations in the chemical state of seawater.

It is reported that ocean acidification and its impacts will be seen first in the Southern Ocean, providing early signals of what is likely to follow elsewhere. Progressive ocean acidification in temperate and tropical seas may have significant ramifications for human communities dependent on coastal resources in Australia, the Indian Ocean and South Pacific regions (ACECRC, 2008).

Acidification will have impacts on key Australian marine ecosystems such as those of the Southern Ocean, marine protected areas of the Australian continent and, eventually the Great Barrier Reef (ACECRC, 2008).

Ocean acidification creates problems for a number of organism. Corals and other creatures that build shells out of calcium carbonate are particularly vulnerable, since they cannot form their shells if the acidity passes a critical level because their shells will dissolve. Several shell-building planktonic organisms such as coccolithophorids, pteropods and foraminifera, form an important basis of the food chain in the cold waters surrounding Antartica. The effect of ocean acidification is more pronounced at colder temperatures, and it is believed that these important micro-organisms will die out or be forced to move to warmer waters in order to survive (ACECRC,2008; The Royal Society, 2005).

Changing pH and reduced oxygen concentrations pose serious threats to marine animals with narrow temperature range such as the cod whose maximum growth rate spans a 5^0C range[6]. Increased CO_2 and decreased pH could have major effect on the respiratory gas exchange system of large marine animals. Increased CO_2 may result to 'hypercapnia', or the acidification of body tissues and fluids of marine animals (The Royal Society, 2005).
Increased CO_2 also has impacts on the lifecycle of multicellular animals. For example, decreasing pH from 8.5 to 7.5 units will result into a 40% reduction in the respiration rate of the steelhead trout (*Oncorhynchus mykiss*) and significant loss of sperm motility of about 40% in oysters (*Crassostrea gigas*) during large changes in pH from 8 to 6 units. Other experiments show potential impacts of increased pH on reproduction of gastropod mollusks (*Babylonia areolata*), silver sea bream (*Pagrus major*) and sea urchins. These indicate that the early life stages of the life cycle show the greatest sensitivity to climate change impacts.

The impacts of climate change on oceans and marine organisms are not at all bad. There are a number of species which benefit from high levels of dissolved CO_2 in the oceans. Many higher plants such as sea grasses use dissolved CO_2 directly to help them grow, and should prosper from higher CO_2 levels in the ocean, just as many plants on land are expected to benefit from higher atmospheric CO_2 levels. Some types of phytoplanktons will probably benefit as well, while some types will likely be unaffected. This was supported by a report of the Royal Society of the UK (2005) which concluded that "the increase of CO_2 in the surface oceans expected by 2100 is unlikely to have any significant direct effect on photosynthesis or growth of most micro-organisms in the oceans (ACECRC, 2008).

Any changes in the biological processes in the surface ocean waters will also affect the deeper water of the oceans. This is because organisms and habitats living at the lower levels of the oceans, which are far from sunlight, rely mainly on the products created by life in the surface waters. On a longer time scale, these organisms may also be vulnerable to acidification and changes in ocean chemistry as higher levels of CO_2 mix throughout the oceans (The Royal Society, 2005).

Changes in oceanic currents

Changes in oceanic currents might change migration routes of fish communities, lead to altered transport routes for egg and larvae, and generally be responsible for shifts of bioregional zones in the oceans. On a global scale, evidence grows that climate change could cause a slow-down of thermohaline circulation. Although little is known about critical thresholds causing abrupt and fundamental changes of Meridional Overturning Circulation (MOC), also slight changes could impact marine ecosystem productivity, ocean chemistry and cause shifts in ecosystem composition for fisheries (Flitner & Herbeck, 2009).

Extreme weather events and sea level rise

A higher frequency of extreme weather events and a rising sea level can lead to habitat degradation and eutrophication of coastal ecosystems and increased silt and algae coverage of corals, leading to the disappearance of ecological niches and important hatching grounds of marine biota (Flitner & Herbeck, 2009).

Coral Reefs and Seagrass Beds

Coral reefs and seagrass beds are apparently affected by several climate change parameters including ocean acidification, increasing sea temperatures, increased precipitation patterns, strong waves and currents, extreme weather events and sea level rise.

Coral Reefs

The tropical and subtropical corals are expected to be among the worst affected, with implications for the stability and longevity of the reefs that they build and the organisms that depend on them. Cold-water coral reefs are also likely to be adversely affected, before they have been fully explored (The Royal Society, 2005).

Coral reefs are the most diverse marine ecosystem and embrace possibly millions of plant, animal and protest species. Actually, coral reefs are referred to as the “tropical rainforests of the ocean” (Hoegh-Guldberg, 1999). They have become one of the clearest indicators of climate change’s ecological impacts. Threats to coral diversity include coastal development, global warming, ocean acidification from CO_2 emissions, human disturbance beyond sustainable limits and inadequate management (Hoegh-Guldberg, 1999).

According to the CORDO 2008 Status Report released by the Global Reef Monitoring Network, 19 % of the world’s coral reefs have already been lost and the remaining may disappear within 20-40 years if current trends in CO_2 emissions continue (Science Daily, 2009).

Ocean acidification

Coral reefs presently face threats from increasing concentration of carbon dioxide in the atmosphere. As atmospheric levels of CO_2 escalates, more of this gas are dissolved in the world’s oceans, causing a significant reduction in the ocean’s pH and alters the ocean chemistry. This has major corrosive effects on marine ecosystem and alters the calcification rates of coral, phytoplanktons and other species (Hoegh-Guldberg, 1999).

The increasing concentrations of CO_2 in the atmosphere spells “double trouble” for coral reefs. First, the trapped heat in the atmosphere causes ocean warming, which can cause extensive coral bleaching events and mass mortalities. Second, high CO_2 levels leads to ocean acidification, which reduces the ability of coral reefs to grow and maintain their structure and function (Hoegh-Guldberg, 1999).

Corals in tropical and subtropical waters will not dissolve in the more acidic waters, but the increased acidity will cause them to grow more slowly. When this additional stress tops off the impacts of coral bleaching from global warming, pollution and destruction due to dynamite fishing, the future of coral reefs is at risk. About one-third of the world’s coral reefs have already been damaged in the past century, with another one-third at serious risk of destruction by 2030.

Under most IPCC emission scenarios, corals are unlikely to remain abundant on reefs and could be rare on tropical and subtropical reefs by the middle of this century if CO_2 doubles or triples above present levels. Over long timescales, reef frameworks that are critical for the protection of coastlines across tropical and subtropical regions may start to disappear as the rate of erosion starts to exceed calcification rates.

Increasing sea temperatures

One of the potential impacts of warming sea temperatures on coral reefs is coral bleaching. Coral bleaching is the loss of dinoflagellate symbionts from reef-building corals. Rising global sea surface temperatures and increased episodic warming events such as El Niño are the main culprits behind coral bleaching. High sea surface temperature associated with strong El Niño event in 1997-1998 caused bleaching in every ocean basin (up to 95% of corals bleached in the Indian Ocean), ultimately resulting in 16% of corals dying globally (Hoegh-Guldberg, 1999). The mortality from bleaching has affected the world’s coral reefs with increasing frequency and intensity since the late 1970s (Leemans & van Vliet, 2004).

Reef regions around the world experience varying thermal environments but corals have adapted to the temperature range present at their specific location. While the western Indian Ocean and Caribbean are slightly cooler than the other ocean basins, which means that reefs there do not experience warmer temperatures to the same extent as other oceans, reefs “conditioned” to the cooler temperatures and tend to bleach at lower temperatures (above 30^0C). Conversely, Western Pacific reefs generally have a higher bleaching threshold (around 30.5^0C). Peak warming events took place in the Western Indian Ocean and North-western Pacific in 1997-1998, in the North of Australia and Central Pacific during the 2003-2004, and in the Caribbean in 2005 (Hoegh- Guldberg, 1999).

Mass bleaching events, which often cover thousands of square kilometers of coral reefs, are triggered by small increases (1 to 3^0C above mean maximum) in water temperature. The temperature regimes of corals used to be very stable, covering a range of 3^0C between minimum and maximum. During recent El Niño events, water temperatures in many tropical waters have increased by over 5^0C, which resulted in massive bleaching events of up to 95% in shallow waters off countries like Sri Lanka, India, Kenya, Maldives, and Tanzania. The loss of living coral cover is resulting in an unspecified reduction in the abundance of myriad species (Leemans & van Vliet, 2004; Flitner & Herbeck, 2009).

Further, increases in temperature push corals on the northern hemisphere to migrate to northern areas. It was observed that both the Staghorn Coral (*Acropora cervicornis*) and Elkhorn Coral (*Acropora palmata*) are now expanding their range northward along the Florida Peninsula and into the northern Gulf of Mexico.

Increased Precipitation
Coral reefs have low tolerance over changing salinity levels. Changes in precipitation, evaporation and river runoff affect the salinity of the upper ocean. Salinity trends over the past 50 years vary significantly across global reef regions. Ocean waters have become more fresh in South and Southeast Asia, the Northern Pacific and the Caribbean, where rainfall has increased from 1979-2009. On the other hand, the ocean has become saltier in the Southern Hemisphere, which is likely related to decreased rainfall over Africa and the Subtropical Pacific. Interconnections between salinity and hydrology also suggest that increased rainfall in Southeast Asia and the Amazon region generates river plumes that extend offshore into reef environments. Associated sediment loading and harmful nutrients have negative impacts on reef ecosystem health (Hoegh-Guldberg, 1999).

Changing winds and currents

Changes in winds and currents alter the water environment in terms of salinity, temperature, mixing and upwelling. Easterly trade winds have generally increased during the past 50 years across the Atlantic, Southern Indian and Northern Pacific oceans. The acceleration of trade winds in the Southern hemisphere, since 1980, corresponds with increased evaporation and salinity. Ocean currents have shown the most pronounced trends over the past 50 years along the Equator, exhibiting increased eastward currents across the Indian and Pacific Oceans, while the Atlantic has experienced increased westward currents. The westward North Equatorial Current of the Pacific has increased, consistent with the observed change in wind (Hoegh-Guldberg, 1999).

Changes in currents can affect coral reefs through a reduction (or increase) in mixing between surface and deep waters (with follow-on effects of changes in nutrient levels) modified advection of waters (which can influence connectivity between reef systems, particularly in the open ocean) and potential changes in lagoonal flushing rates (Hoegh-Guldberg, 1999).

Waves and currents also significantly influence the location and diversity of coral assemblages. Some coral species are better suited than others to high-wave environments. Waves generated during tropical cyclones can exceed normal conditions on all parts of the reef, however, overturning colonies can break coral branches, causing extensive reef damage. A build-up of rubble and excess sediment can also occur, reducing the availability of suitable substrate (Hoegh-Guldberg, 1999).

Sea level rise
Sea level rise over coral reefs provides corals with greater space to grow upward. While corals are growing, however, and have not yet fully occupied this new space, there is the potential for increased wave action, which can damage corals. Of greater potential importance for corals is increased sedimentation due to erosion from land areas that are newly exposed to seawater. The greatest impact is likely to be on human communities living adjacent to coral reefs, however, through loss of land, including that used for agriculture, due to saltwater intrusion, and increased flooding and exposure to waves (Hoegh-Guldberg, 1999).

Extreme weather events
Tropical cyclones are not at all destructive, they can on one hand benefit coral reefs by alleviating thermal stress. As the upper ocean warms during summer, corals may experience thermal stress and bleaching. TCs can mitigate thermal stress through three mechanisms. First, heat energy from surface waters is transferred into the atmosphere through evaporation. The amount of heat transferred is related to the intensity and extent of the tropical cyclone. Second, surface water temperatures are cooled via increased mixing of deeper waters, the magnitude of which depends on wind speeds and water temperature variations with depth. Third, the ocean surface is shaded by clouds of the tropical cyclones, which allows further cooling of the water and reduces light stress (Hoegh-Guldberg, 1999).

Seagrass Beds

Seagrasses appear to be declining around many coasts due to human impacts, and this is expected to accelerate if climate change alters environmental conditions in coastal waters. Changes in salinity and temperature and increased sea level, atmospheric CO_2, storm activity and ultraviolet irradiance alter sea grass distribution, productivity and community composition.

Increased temperature
Too much warming exposure will make seagrasses susceptible to other stresses leading to mortality. The warm waters alter their growth rates and physiological functions as well as change distribution and patterns of reproduction.

Increased CO_2 levels
The increased concentrations of atmospheric CO_2 will also enhance primary production for carbon limited seagrass areas. Impacts of high CO_2 concentrations will vary among species but will most likely disrupt competition among species and between seagrass and algal population. Increases in the amount of dissolved CO_2 and, for some species, HCO_3 present in aquatic environments, will lead to higher rated of photosynthesis in submerged aquatic vegetation, similar to the effects of CO_2 enrichment on most terrestrial plants, if nutrient availability or other limiting factors do not offset the potential for enhanced productivity. An increase in epiphytic or suspended algae would decrease light available to submerged aquatic vegetation in estuarine and lagoonal systems.

Sea level rise
Sea level rise will lead to increased water depths, tidal variation, water movement alterations, and increases seawater intrusion into estuaries and rivers. These would also reduce light in seagrass beds decreasing their productivity.

Oceanic current patterns
Ocean current patterns enhanced by erosion alter near shore seagrass areas and affect breeding as well as the ecosystem's nursery functions.

Salinity changes
The changes in salinity levels will result to alterations of plant distribution, changes in seed germination, propagule formation, photosynthesis, growth and biomass of seagrasses.

GLOBAL AND REGIONAL IMPLICATIONS OF CLIMATE CHANGE VARIABILITY ON AQUATIC ECOSYSTEMS

Global climate change has different effects on different regions of the Earth. The polar regions of the world are showing the most rapid responses to climate change. As a result of a strong ice–ocean influence, small changes in temperature, salinity and ice cover may trigger large and sudden changes in regional climate with potential downstream feedbacks to the climate of the rest of the world. A warming Arctic Ocean may lead to further releases of the potent greenhouse gas methane from hydrates and permafrost. The Southern Ocean plays a critical role in driving, modifying and regulating global climate change via the carbon cycle and through its impact on adjacent Antarctica. The Antarctic Peninsula has shown some of the most rapid rises in atmospheric and oceanic temperature in the world, with an associated retreat of the majority of glaciers. Parts of the West Antarctic ice sheet are deflating rapidly, very likely due to a change in the flux of oceanic heat to the undersides of the floating ice shelves.

Africa (Central, East, North, Southern and West)

Climate change has great implications on the various aquatic ecosystems found in the African Region. In Africa, reduced precipitation if accompanied by high interannual variability, could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socioeconomic activities. In particular, the freshwater supply from the African Great Lake wetlands will be greatly affected. Consequently, the decreasing freshwater discharge from rivers, overharvesting and increasing land-based pollution cause adverse impacts on the health of mangroves in Africa (Watson, *et al*., 2000).

Sea level rise put at risk the coastal nations of west and central Africa (e.g., Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola) which have low-lying lagoonal coasts that are susceptible to erosion, particularly because most of the countries in this area have major and rapidly expanding cities on the coast (Watson *et al.,* 2000).
Corals and seagrass aquatic ecosystems are not spared from climate change variabilities and extremes. In Africa, sea level rise and climatic variation may reduce the buffer effect of coral and patch reefs along the east coast, increasing the potential for erosion. In Kenya, coral reefs suffered severe mortality in the 1998 bleaching event while in Tanzania and Mozambique, the degradation of the coral reef resources due to increasing population pressures and coral bleaching is an important management issue (Obura, 2004). Bleaching has caused the decline of 30% of the reefs, and the threats posed by a growing population are probably slowing their recovery. In Mozambique and southern Tanzania, there have been increased rates of reef erosion, due in part to the bio- erosion of dead coral tables and plates (Watson *et al.,* 2000). The loss of living coral cover is resulting in an unspecified reduction in the abundance of myriad species (Leemans & van Vliet, 2004; Flitner & Herbeck, 2009).

Seagrass beds in Africa have declined at an alarming rate and have even disappeared in the Indian Ocean (Watson *et al*., 2000). This is attributed to warming of seas and reduced oxygen levels. The potential loss of seagrass ecosystems will have major impacts on the world's fishery and aquaculture production.

Latin America/Caribbean (Central America, South America and the Caribbean)

In Latin America and in the Caribbean, the impacts of climate change are highly observable in the freshwater ecosystems, marine ecosystems, mangroves and coral reefs.

In this region, there is much concern on sea-level rise affecting the freshwater ecosystems. Sea level rise blocks the runoff of flatland rivers into the ocean, which increase the risks of flooding in their basins, particularly in the Argentine Pampas (Watson, *et al.,* 2000).

Climate change affects the marine ecosystem of Latin America in the form of losses of coastal land and biodiversity , damage to infrastructure, and saltwater intrusion resulting from sea-level rise occur in low-lying coasts in countries such as those of the Central American isthmus, Venezuela, Argentina, and Uruguay (Watson *et al.,* 2000).

The coral reefs in the area suffers from bleaching particularly in 2005, when high sea surface temperatures in the Tropical North Atlantic resulted to one of the worst coral bleaching episodes on record in the Caribbean, as well as energizing one of the most active Atlantic hurricane seasons on record (www.guardian.co.uk, 2010). In some areas in the Caribbean, coral mortality due to bleaching reached 50% during this period.

Flitner & Herbeck (2009), noted that if sea level rise and extreme weather events will continue, mangrove ecosystems will be heavily affected. Local extinctions of mangrove species might occur in Antigua and Barbuda as soon as 2030.

Northern America

In northern America, increased runoff in winter and spring and decreased soil moisture and runoff in summer could be observed. These manifestations of climate change make the Great Plains and prairie regions particularly vulnerable. Heavy rainfall events and severe flooding accompanied by an increase in the length of dry periods between rainfall events and in the frequency and/or severity of droughts in parts of North America could affect water quality and cause a decline in minimum river flows (Watson, *et al.,* 2000). Further, there would be a reduction in habitat for cool water species, particularly fish and macroinvertebrates in Appalachian streams, expansion of subtropical species northwards, including several non-native nuisance species currently confined to southern Florida, expansion of wetlands in Florida and coastal Mexico, but increase in eutrophication of Florida lakes as a result of greater runoff from urban and agricultural areas; and changes in the flushing rate of estuaries that would alter their salinity regimes, stratification and water quality as well as influence productivity in the Gulf of Mexico (Mulholland *et al.,* 1997).

Freshwater shortage is also a serious problem in many small island states (i.e. Bahamas, the Maldives, Kiribati and the Marshall Islands) of northern America. These states depend heavily on rainwater as the source of water and the changes in the patterns of rainfall may cause serious problems to such nations (Watson, *et al.,* 2000).

In addition to freshwater ecosystems the brackishwater of North America is also heavily affected by climate change impacts. Sea level rise could inundate 8,500 to 19,000 km^2 of dry land, expand the 100-year floodplain by more than 23,000 km^2, and eliminate as much as 50% of North America's coastal wetlands (Watson, *et al.,* 2000).

The valuable mangroves of northern America particularly that of Florida Bay are also threatened by climate change. These mangroves protect the shoreline of Florida from erosion, storm surge, filter pollution, home to many unique species of animals and plants, and serve as nursery and feeding grounds for myriad fish, marine mammals and invertebrates. Excessive storm surge flooding and intense storms expected endanger the long-term health of Florida’s mangrove forests. The Tufts University study projects that

Florida will lose 99 percent of its mangroves by 2060, when sea level rise will likely convert them to shallow marine habitat or open water (WWF, 2010).

In the marine environment, it is expected that climate change will cause changes in the life cycle, nesting patterns and sex ratio of various marine species such as the Loggerhead Sea Turtles (*Caretta caretta*) on the Atlantic Coast of Florida (Leemans & van Vliet, 2004).

In the case of coral reef ecosystems, it was observed that increases in temperature push corals on the northern hemisphere to migrate to northern areas. It was observed that both the Staghorn Coral (*Acropora cervicornis*) and Elkhorn Coral (*Acropora palmata*) are now expanding their range northward along the Florida Peninsula and into the northern Gulf of Mexico. Aside from this, bleaching has also been a persistent problem in the coral reefs. Bleaching has occurred to some degree every year in Florida since 2005 (WWF,2010).

The extensive and highly productive seagrass meadows of Florida Bay is also greatly affected by climate change. The research work of SeagrassNet on the seagrass areas around the world indicated that the seagrass population in North America is on a steady decline (Science Daily, 2006).

Asia (Central, Eastern, Southern, South-Eastern and Western)
Climate change is seen to have great impacts on the aquatic ecosystems of Asia. Based on observations, acidification and acid rain is now emerging as major problem in the developing world, especially in parts of Asia and the Pacific region. In these regions, energy use and the use of sulfur-containing coal and oil, which are the primary sources of acid emissions, has surged to very high levels. An estimated 34 million metric tons of SO_2 were emitted in the Asian region in 1990, over 40% more than in North America. Acid deposition levels are particularly high in Southeast China, Northeast India, Thailand and the Republic of Korea. This will affect the freshwater supply in small catchments and monsoonal wetlands of Asia.

In arid Western Asia, water shortage which is already a problem is likely to be exacerbated by climate change. Glacial melt is projected to increase under climate change-leading to increased flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear (Watson, *et al,* 2000).

In temperate Asia, runoff from glaciers in central Asia is projected to increase threefold by 2050, but by 2100 glacier runoff would taper to two-thirds of its present value. Studies also show that northern part of China is quite vulnerable to climate change, mainly as a consequence of changes in precipitation in spring, summer, and autumn, especially during the flood season. On the other hand, in tropical Asia, the projected increases in evapotranspiration and rainfall variability are likely to have a negative impact on the viability of freshwater wetlands, resulting in shrinkage and desiccation. Increased temperatures and increased seasonal variability in precipitation are expected to result in increased recession of glaciers and increasing danger from glacial lake outburst floods. A reduction in average flow of snow-fed rivers, coupled with an increase in peak flows and sediment yield, would have major impacts on hydropower generation, urban water supply, and agriculture. Availability of water from snow-fed rivers may increase in the short term but decrease in the long run. Runoff from rain-fed rivers may change in the future. A reduction in snowmelt water will put the dry-season flow of these rivers under more stress than is the case now (Watson, *et al.,* 2000).

In tropical Asia, densely settled and intensively used low-lying coastal plains, islands, and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front, and seawater intrusion into freshwater lenses. Especially at risk are large delta regions of Bangladesh, Myanmar, Viet Nam, and Thailand, and the low-lying areas of Indonesia, the Philippines, and Malaysia (Watson *et al.,* 2000).

One of the unique ecosystems in Asia that suffers from climate change impacts is in the form of flooded forests. In tropical Asia, Thailand, for instance, the area of tropical forest could increase from 45% to 80% of total forest cover, whereas in Sri Lanka, a significant increase in dry forest and a decrease in wet forest could occur. Warmer temperatures and altered precipitation patterns may shift or shrink suitable habitat for rare, threatened and endemic species, alter availability of fruit resources, change forest types and cause floods (Blate,2009).

The agricultural wetlands of Asia are also likely to experience the impacts of climate change. The changes in temperature and precipitation coupled with an onslaught of extreme events, is expected to significantly affect the Greater Mekong Region's agricultural productivity. Although annual flooding of the paddy fields is required for the rice crop to succeed, unusually heavy flooding or severe droughts cause farmers to lose their entire crop and cut access to markets and possible coping strategies, through damage to infrastructure. In addition, sea level rise will lead to salt-water intrusion and land loss affecting the lives and livelihoods of people in the coastal areas of Thailand and Vietnam. By the end of the century, higher sea levels in the Mekong Delta, where nearly half of Vietnam's rice is grown, may inundate about half (~1.4 million ha) of the delta's agricultural lands. In the Mekong region, there was an observed 10% decline in rice yield with 1^0C increase in minimum temperature (Blate, 2009). This decline would spell huge decreases in the volume of rice exported by Vietnam and Thailand.

In terms of mangrove ecosystems, it was observed that across Asia mangrove loss has exceeded 60 percent, on the average, in recent decades while the total area has decreased to less than 15 million hectares worldwide from estimated 32 million hectares originally. Thousands of hectares of mangrove forests in Asia have been cleared for shrimp farming and other forms of coastal development (Watson *et al.,* 2000). Sea level rise which leads to decreased precipitation and run-off and increased salinity results to a lesser mangrove production. Climate change disrupts the balance between fresh and saltwaters in mangrove areas and the prolonged warming may affect the reproductive patterns of associated flora and fauna.

Rising sea temperatures and its consequences are reported to cause local extinctions and intense species invasions in the marine ecosystems of tropical Asia invasions (Flitner & Herbeck, 2009). On the other hand, in temperate Asia, sea level rise threatens certain coastal areas. For example, the Japanese coastal zone, on which 50% of Japan's industrial production is located (e.g., Tokyo, Osaka, and Nagoya) and about 90% of the remaining sandy beaches in Japan are in danger of disappearing (Watson *et al.,* 2000).

In tropical Asia, coral reefs and seagrass beds are also affected by climate change impacts. The seagrass population in the Asian region is reported to be on a steady decline (Science Daily, 2006). On the other hand, coral reefs of tropical Asia may be able to keep up with the rate of sea-level rise but still suffer bleaching from higher temperatures (Watson *et al.,* 2000). High sea surface temperature is believed to be the major cause of bleaching in Asia coinciding with the El Niño occurrence and aggravated by other factors such as solar irradiance, current, wave energy, tidal fluctuations, and reef morphology resulting to greater susceptibility (Capili *et al.,* 2005). Massive bleaching events of up to 95% in shallow waters off countries were observed in Asian countries like Sri Lanka and India. The loss of living coral cover is resulting in an unspecified reduction in the abundance of myriad species (Leemans & van Vliet, 2004; Flitner & Herbeck, 2009).

Europe (Eastern, Northern, Southern and Western)

In cool temperate and boreal regions such as Europe, a warmer climate cause initial reduction in freshwater species diversity. Ecosystems in southern Europe would be threatened mainly by reduced precipitation and subsequent increases in water scarcity. Temperature increases in this region is larger than the global average which significantly affects water supply and coupled with problems of flooding and drought. Expected changes in snow and ice will have profound impacts on European streams and rivers. Up to 95% of Alpine glacier mass could disappear by 2100, with subsequent consequences for the water flow regime-affecting, for example, summer water supply, shipping, hydropower and winter tourism (Watson, *et al.,* 2000).

In Europe, some coastal areas already are beneath mean sea level, and many others are vulnerable to storm surges. Areas most at risk include the Dutch, German, Ukrainian, and Russian coastlines; some Mediterranean deltas; and Baltic coastal zones (Watson *et al.,* 2000).

In Europe's marine environment, there are phenological changes observed in marine species in relation to climate change. Examples of these are changes in the timing of life cycle events of amphibians in UK and Poland, changes in the fish-spawning dates of Pike (*Esox lucius)* and Bream (*Abramis brama*) in Estonia, significant increase in phytoplankton, and changes in the seasonal timing of decapods larvae or zooplanktons (Leemans & van Vliet, 2004). In addition to phenology, climate change also has impacts on the distribution area and population of marine species. Examples of these are the observed population increase of Scaldfish (*Arnoglossus laterna)* and the Lesser Weever Fish (*Echiichthys vipera*) not only in the Mediterranean Sea and Southern Scandinavia but also in the North Sea, fluctuations in the populations of autochthonous crabs and shrimps, mollusks and aliens in Belgium, observed northward shift of up to 1000 kilometers of zooplankton species , northward extension of the ranges of many warm-water fish species towards a warmer north-eastern Atlantic, and invasion of warm-water species into the temperate areas of the north-east Atlantic (Leemans & van Vliet, 2004).

Another aquatic environment in Europe that is affected by climate change is the seagrass. The research work of SeagrassNet on the seagrass areas around the world indicated that the seagrass population in Europe is on a steady decline. The potential loss of seagrass ecosystems will have major impacts on the world's fishery and aquaculture production. This case had been proven in 1930 when 90% of the eelgrass in North Atlantic was wiped out by a disease outbreak, which resulted to the loss of the scallop fishery in mid-Atlantic (Science Daily, 2006).

Oceania (Australia and New Zealand, Melanesia, Micronesia, Polynesia)

In the Oceania region, climate change is seen to have adverse impacts on the freshwater ecosystems such as the monsoonal wetlands of Australia. Climate change impacts on freshwater ecosystems will primarily affect water availability and supply and flood occurrences in various areas. At the same time, the mangroves of Australia are also affected.

It is observed that in this area, the expansion of mangroves into salt marsh habitat in southeast Australia and into freshwater wetlands in northern Australia are driven by sea-level rise and soil subsidence associated with reduced rainfall (Hoeng-Guldberg, 1999). Sea level rise will also result to higher rates of erosion and coastal land loss in many small islands. In the case of Majuro atoll in the Marshall Islands and Kiribati, it is estimated that for a 1-m rise in sea level as much as 80% and 12.5% (respectively) of total land would be vulnerable. Low-lying island states and atolls also are expected to experience increased sea flooding, inundation, and salinization as a direct consequence of sea-level rise (Watson *et al.,* 2000).

In the marine ecosystems, it is seen that rising sea temperatures and ocean acidification will have impacts on key Australian marine ecosystems such as those of the Southern Ocean, marine protected areas of the Australian continent and, eventually the Great Barrier Reef (ACECRC, 2008). According to Watson *et al.,* (2000), the tropical coral reefs of Oceania, including the Great Barrier Reef, may be able to keep pace with sea level rise but will be vulnerable to bleaching and death of corals induced by episodes of higher sea temperatures and other stresses. Ocean acidification and increased thermal stress are the likely causes of more than 10% reduction in the growth rates of massive Porites corals on the Great Barrier Reef (Hoegh-Guldberg, 1999).

South America

Temperature rise and less frequency of precipitation will cause significant impacts on one of the largest flooded forests in the world, which is the Amazon rainforest. The Amazon is projected to shrink to as much as 85% with 4^0C increase in temperature and even a modest temperature rise of 2^0C will still result to 20-40% die-off in 100 years (www.guardian.co.uk, 2010). Climate change adds additional stress to the adverse effects of continued deforestation in the Amazon rainforest. This impact could lead to biodiversity losses, reduce rainfall and runoff within and beyond the Amazon basin (reduced precipitation recycling through evapo- transpiration), and affect the global carbon cycle.

Effects of temperature changes on organisms and ecosystem

While many of the Global Climate Models are being refined today to a finer resolution, at the regional or local level, these models cannot predict what the impact of high temperature may mean to the system. Prediction of the impact of temperature to various organisms in both the tropical and temperate areas need to be ground truthed by various lab and microcosm experiments to determine their accuracy and feed this information into functional models of the ecosystem. Temperature is known to be the most important factor that controls marine populations and has long been of interest to many biologists (Vernberg 1962; O'Conner & Mulley 1977; Pechenik 1987; Olive 1995) and most recently (Hays et al; O'Connor et al 2007) as the effects of increasing global warming on various marine biota are being examined.

Temperature affects physiological processes and many ecological interactions (Hochachka et al 2002;Dunson and Travis 1991). Thus temperature changes are equated with global climate change and are expected to alter species and communities (Southward et al 1995; Mieskowska et al 2007).Because global warming is expected to cause a disproportionate warming of the oceans and the marine biota living in them, it has been found that it not only affects the distribution but also the development of various marine species (Byrne et al 2009). Some are known to be more impacted by a high range of temperature such as their thermal tolerance limits (Ubaldo et al 2007). A study in tolerance limit of six intertidal echinoderms based on their righting response in a tropical rocky shore have shown that they can tolerate up to 35 deg Celsius but no more than 40 deg C for 12 h exposure (Ubaldo et al

2007).In addition, Byrne's study have documented the interactive impact of warming and acidification under various climate change scenarios on the development of sea-urchins (Heliocidaris erythrogramma) and found that high temperature not pH determines their development (Byrne et al 2009). Current investigations on impact of temperature on mussels in the rocky shores have shown that a 1 degree of simulated change in temperature have varied effects on mussels depending on geographic locations, vertical positions, and temperature remains variable (Gilman et al 2006).

In various tropical areas, it is expected to have reduced diversity, loss of species, increased coral degradation due to warming and bleaching and associated loss of reef fishes dependent on this habitat with consequent losses on ecosystem productivity (Worm and Lotze 2009). Changes in diversity that may accompany this warming and lead to changes in species range, decline of ice dependent species and contraction of cold adapted species, increased of warm adapted species range, eradication of some species and new invasions (Worm and Lotze 2009).Already, the habitat fragmentation and depletion of top predators (Hughes et al 2003; Pauly et al 1998) that has been occuring in various large marine ecosystems around the world is having deleterious effects on the productivity and biodiversity of the ecosystem (Worm et al 2006).This decrease in diversity and isolation of organisms may exacerbate due to warming and could render them susceptible to effects of global warming(Ayer and Hughes 2004).

A recent finding that examined the fundamental role of temperature or kinetic energy in structuring cross-taxon marine biodiversity have found that of the 11, 567 species across 13 different taxonomic groups examined, only temperature was found to strongly affect diversity across 13 taxa (Tittensor et al 2010). Although habitat availability and historical factors are also important for coastal species as warming reduces habitat suitability, while the net effects of harvesting, warming and destruction of habitats poses the most serious threat to a population as it leads to the largest decline of the population. Although each environmental stressors may affect the population individually, the combined effects of stressors indicates that all threats are equally capable of causing deleterious effects and that they all need to be simultaneously addressed if their effects are to be reversed (Mora et al 2007).

At ecosystem level, long term performance and thus fitness are key to survival and success of a species. Fishes for example may thermoregulate by escaping through various microhabitats that vary in temperature ranges. But eventually, fishes that are unable to adapt genetically have to move to an environment that is most beneficial to their survival or die (Nielsen et al. 1994; Brio 1998). However, as temperature in the environment and other stressors continue to rise, the growth, development and swimming ability of fishes will be affected (Fry 1971; Portner 2010).Thermal tolerance limits plus the effects of acidification may actually lower the physiological capacity of the organism to react to its environment. Initial findings suggest decreased growth and enhanced mortality of sensitive species like among molluscs or echinoderms in response to a doubling of CO_2 levels from pre-industrial to 560 ppm (Shirayama and Thornton 2005), a value which is likely exceeded during this century. Marine invertebrates are hypothesized to be among the organisms most sensitive to anthropogenic CO_2 accumulation, especially those with a hypometabolic mode of life and heavily calcified (Portner et al. 2004, 2005). Early life stages with an incomplete development of physiological capacities may be the most sensitive. Thereby, reduced reproductive success may be a key effect of ocean acidification. Furthermore, performance is also limited by temperature.

The width and limitation of thermal windows emerge as a basic character defining species success and survival in thermally stressed ecosystems (Portner and Knust 2007). This includes their capacity to interact with other species. This narrowing of thermal tolerance windows (Portner et al. 2005) may result in a narrowing of temperature range of the organism which affects their critical life stages and acclimation capacity (Portner and Farrel 2008). The physiological principles shaping performance are likely also involved in multi-step processes affecting marine food webs. Continued efforts on physiological investigations on the impact of climate warming in the marine ecosystem should complete our mechanistic understanding and quantify effects in relation to future scenarios of anthropogenic CO2 emissions and ocean warming.

Effects of temperature on pond effluents and toxicants

With the projected increase of warming that ranges from a low of 1.1-2.9 C and a high of 2.4-6.4 C in the coming years (IPCC 2007) toxicants and pollutants that remain at large in bodies of water and in sediments may become more lethal to fisheries and aquaculture production. This is because dissolved oxygen in water becomes scarcer under conditions of high temperature and may result to higher incidence of hypoxia or anoxia leading to fishkills. This has broad economic implications because aquaculture is dependent on outside supply of feeds and ambient amount of DO in the water. It is estimated that unused feeds and partially digested ones settle at the bottom of fish cages which accumulates and facilitates the growth of various anaerobic bacteria which depletes oxygen in the water. Holmer and others (2002) who studied fish cages of milkfish in Bolinao, Pangasinan found out that oxygen consumption in sediments near fish cages are faster than the control. In another related study (Bacaltos et al 1999) where fish ponds were located near tne river head, dry season which portends low precipitation rates greatly diminished flushing rate of nutrients which remained in pond canals. Draining of pond effluents, ammonia and domestic wastes only occurred during the wet season which increased the volume of flow and allowed flushing in the river (Bacaltos et al 1999).

A combination of high temperature and low dissolved oxygen concentration and a sublethal ammonia concentrations have been shown to cause gill necrosis in common carp (Jeney and Nemcsok 1992). And the increased uptake of exogenous toxicants due to poor environmental conditions such as high values of ammonia has the potential to reduce fisheries productivity in the wild, cause massive fish kills due to anoxic bottom waters and enhance algal blooms world wide. Although rivers and streams have the capacity to self purify from toxic effluents (Jenssen et al. 1994; Sandifer and Hopkins 1996), the overloading of fish operators of the carrying capacity of rivers, estuaries and embayments for fish culture could have detrimental effects on the health of fishes being cultured.

It is estimated that about 31% of nitrogen and 84% of phosphorus are retained in the sediments of shrimp ponds (Briggs and Funge-Smith 1994). Moreover in fish cultures, it is estimated that of the total input, about 51-68% of carbon and nitrogen is lost to the surrounding environment (Holmer et al., 2002) which is made readily available for microbial decomposition. With high microbial production, the energetics in the system may reverse and both the available energy and dissolved oxygen for predators such as fishes will be transferred to the microbial loop (Diaz and Rosenber 2008). This can lead to a condition called "oxygen squeeze" in fishes and in benthic fauna when very low levels of oxygen occur. In temperate countries severe environmental impacts were documented regarding net cage cultures (Holmer and Kristensen, 1992, 1994; Karakassis et al., 2000) and increase of oxygen minimum zones or dead zones occur due to eutrophication and high stratification in the water column (Diaz and Rosenberg 2008; Chan et al 2008). These changes in sediment &

water quality could be exacerbated by the projected increase in temperature causing massive fish kills, proliferation of algal blooms and spread of oxygen minimum zones in coastal areas (Justic et al 1995; Diaz & Rosenberg 2008; Middelburg & Levin 2009).

Climate change impact on water quality

In association with increased temperature, changes in precipitation and saltwater intrusion, water quality is expected to get worse as changes in precipitation affects the supply of freshwater in various rivers and lakes. Inland bodies of water and near coastal bodies of water are critical for human survival as these are used to supply most urban centers and populated areas for domestic water use as well as for aquaculture and other production uses. Water quality is dependent on measurements based on nutrient concentrations, with lower and ambient nutrients found to be oligotrophic system, a moderate nutrient concentration as mesotrophic and a high nutrient concentration to be eutrophic (Nixon 1995). Water quality is maintained by rate of loss (evapotranspiration), rates of replenishment (eg precipiation by rainfall or groundwater discharge), nutrients, rate of turnover. However, as economic growth continue and pressure for use of resource increases, this alters the trophic status of bodies of water (Daoji & Daler 2004). Most eutrophication cases of lakes, rivers and even coastal embayments arise from run-off of agricultural wastes and fertilizers and sewage discharge causing unpleasant sights and odors from these bodies of water.

A combination of warming and high nutrient inputs in bodies of water may cause explosion of macrophyte growth as observed in many systems. Artificial structures and alteration of the trophic status of a system may also facilitate invasive species into the area causing extirpation of native species unable to cope with pollution and change of habitat. IPCC simulation of enhanced impact of warming on freshwater organisms in the Mekong delta show that increased temperature, accompanied by anthropogenic impacts such as sewage discharge, urban run-offs and agricultural wastes not only enhanced eutrophication but increased the duration of stratification of water bodies. Because of low precipitation and high discharge of nutrients, current flow are altered and water bodies have reduced flushing times (Klapper 1991). With the increase of duration of water stratification in large lakes and coastal areas as well as in big rivers, hypoxia may develop in bottom waters due to highly anoxic sediments filled with Hydrogen Sulfide waiting to be released in the water column when strong currents stir the lake or river.

As macrophytes dominate a high nutrient system, this puts pressure on the habitat space of fishes and may reduce their range and ability to get oxygen. Macrophytes may produce oxygen during daytime but when they die and decompose, bacterial decomposition will consume oxygen and release nutrients into the water that could enhance toxic blooms (Klapper, 1991; Li & Zhang, 2002; Azanza et al., 2006). The phytoplankton composition of the water can also be altered in favor of species that thrives well on a eutrophic system (de Castro et al 2005; Azanza et al., 2006). The implication of this change of food composition to the fish population means that the diet of many of the fishes may not be optimal for their growth and reproduction. Recent studies examining the impact of nutrients and sedimentation have shown that these two factors will be enhanced by a changing climate. Multiple stressors and not single stressors will act in concert to affect macrophytes in the near future on their distribution and abundance as effects of human disturbance increases.

A mechanistic understanding of how this works have been carried out by few studies such as (Tasman and Crowe, 2010; Byrne et al., 2009; reviewed by Crain et al., 2008; Gray, 1997). Increased sediment loads due to high discharge from rivers, run-offs and human effects from sewages have been documented to affect the growth of macroalgae and structure their community. Extractive activities that removes herbivores may also affect the abundance and distribution patterns of macrophytes (Thompson et al., 2002). In Atalah and Crowe's study it has been shown that the algal communities were affected by the two stressors additively. Further, the low flushing times that accompany eutrophic lakes could endanger any aquaculture production in the system as these are vulnerable to effects of Hydrogen Sulfide realease when the water column will be stirred by a strong current or storm. Fish kills have occurred in many tropical lakes and coastal areas such as in the Taal lake and Lingayen Gulf in the Philippines, Lake Victoria and Lake Tanganyika in Africa because of sudden turn over of anoxic bottom water during windstress or storm (Ochumba, 1990; Verschuren et al., 2002; Azanza et al., 2005).

Effects on rivers and streams

Rivers and streams like lakes are dependent on precipitation, and evapotranspitaion (Wood et al. 2002; Jiongxin 2005). There are recent observed effects of changes in river hydrology due to changes in precipitation particularly in the Nile river and the smaller African rivers as well as in the Mekong delta. Rivers are known to have their own hydrologic regimes and therefore a specific set of biotic communities that are particularly adapted to the different magnitudes of river flows, interannual variabilities and regional changes. Fishes and other biotic communities that live on these systems are adapted to these specific conditions. For example in the Amazon river, fish are particularly adapted to thrive on fruits and leaves during peak flows but during drought periods or low flows, it hibernates and thrives on eating benthic organisms ().In the Mekong river, fish is only found in the flood plain but not up river. With the looming global warming these community regimes may change and could lead to extirpation of some species that are only adapted to a particular flow regime in the river. The pulse flow in most large rivers which occur during the wet season or high period of precipitation is also the period utilized by fishes for breeding and reproduction. When this flood flow is reduced, so will the spawning ground of fishes. Or if this flood flow will increase, great inundation of low lying areas will occur and may likely increase incidence of alien species invasion. Most fishes are known to be dependent on these seasonal pulse regimes for recruitment and success (Welcomme, 1979).The IPCC reports on decrease in precipitation for the Amazon basin (IPCC, 2007) is likely to translate to drastic reduction of stream flows (Meisner, 1992).

Climate change impact & sealevel rise & salt water intrusion

Global scenarios of sealevel rise show that low lying areas, archipelagic nations and small island nations are vulnerable to flooding (USGS) and coastal erosion as the sea expands into new areas (Scavia et al., 2002). The loss of wetlands and marshes and croplands found in the sea coasts will increase with concomitant loss in diversity and economic revenues. The rapid coastal developments and population build up during the 21st century near the coasts have made the society increasingly vulnerable to sealevel rise as demonstrated in New Orleans in 2005 (Graumann et al., 2005). Still, the relative sea-level rise will have a wide range of effect on many coastal areas; ground subsidence, salt-water intrusion into surface and ground waters may worsen.

The most vulnerable low lying areas such as the Bay of Bengal which experience past destructive cyclones and storm surge may well continue and worsen. It has been known that there were 23 surge events recorded in the Bay of Bengal, with over 10,000 people killed in each since 1737 (Murty et al. 1986; Murty and Flather 1994). One of the most severe occurred in 1991 in the Bay of Bengal region where about 140,000 people were killed and over 10 million made homeless and 1.5 billion USD of damaged properties in Bangladesh

(http://en.wikipedia.org/wiki/1991_Bangladesh_cyclone) and recently cyclone Nargis (2008) which also affected the same region and caused a death toll of 138,000 with damaged properties amounting to 10 billion USD in Mayanmar.
(http://en.wikipedia.org/wiki/Cyclone_Nargis).

In Europe, the storm surge of 1953 had a major impact, with the loss of over 1,800 lives in the Netherlands and 300 in southeast England (Wolf and Flather 2005) and in the US, the impact of hurricane Katrina combined with other anthropogenic effects destroyed properties worth in excess of 125 billion dollars and cause the loss of lives of 1800 people with thousands homeless (Graumann et al. 2005).Thus, coastal and low lying areas will become increasingly vulnerable to disasters as the sea moves into land and marshes, wetlands and mangroves that protects coastal communities could not cope with the rate of rapid rise. Storm surge will become common features as strong typhoons and hurricanes increase in frequency. Previous research on sealevel rise inidcate that it vary by 120m during the glacial and interglacial cycles and little has change over the past milleninia until the 19th and 20th century. Currently, sea levels are rising by over 3mm per year and this has been thought to be mainly due to ocean thermal expansion and the increased rates of melting of glaciers and ice caps (Church et al., 2008). Thus, rising sealevels are projected to cause massive flooding and severe loss of lives due to storm surge when no appropriate response measures or adaptation measures are put in place.

This makes essential the protective role afforded by coastal vegetations such as mangrove forests and seagrass beds which are known to dampen and reduce the impact of tidal waves. As the Asian tsunami in 2004 demonstrated, in areas where coastal vegetation are much reduced, destruction of properties and loss of human lives were unprecedented but in areas where coastal vegetations are thick and existing, villages were unharmed and few damages were recorded (Danielsen et al. 2005). In addition, mangrove and coastal vegetations are known to enhance fisheries production apart from attenuating destructive waves (Primavera 2005; Walton et al 2006). When these adaptive measures are put in place such as replanting of destroyed mangrove stands and putting up tree belts in coastal areas as defence and protective structures, these may also enhance fisheries production in the long run. However, if the projected warming continues, buffering the seacoasts with trees and vegetations could only be limited by human coastal developments. In most developing countries, the aquaculture sector may benefit in the short term for conversion of croplands into ponds for shrimp, tilapia and milkfish farms. Even seaweed cultivations may increase in many coastal areas as farmers change livelihoods from planting rice crops into fish & seaweed cultivation. However, established aquaculture areas especially in low lying deltaic regions such as the Mekong and Irrawaddy may still sufffer as caused by rapid sealevel rise and change of hydrologic regimes (Nguyen 2006; Aye et al 2007).Further, the projected severe storms that may impact the low lying coastal areas could pose serious threats to aquaculture, facilitate translocation of species as well as enhance biotic pollution as a result.

Increased salt-water intrusion

In addition to these issues, one serious threat that may endanger the well-being of populations living near and in the coastal areas include salt-water intrusion. As part of the consequence of rapid sea level rise, which ranged between 10 cm and 80 cm by 2100 according to IPCC scenarios (IPCC 2001), salt water intrusion may worsen not only food crop availability and aquaculture production but also fresh water supply for drinking and other domestic use. Though this rise would be partially attributable to the melting of glaciers and the polar ice caps, the majority of sea level rise would occur due to the thermal expansion of seawater (ACIA 2004).When the sea-level rises, low lying deltaic regions will not only be flooded but summer will also reduce the water flow of major rivers with dangerous consequences on potable water supply of many towns, cities and provinces dependent for domestic use on these resources.

This also changes the biotic community regime as saline waters move deep into estuaries and rivers affecting the distribution patterns of various organisms (Remane & Schlieper, 1971) and facilitating biotic fouling. Moreover, the combined effects of sea level rise and high incidence of salt water intrusion will not only affect a number of organisms and their distribution, but river runoff during periods of high precipitation (wet season in the tropics and spring in temperate) and pollution from ground sources could cause eutrophication of bodies of water where they drain. For example, both the Mekong and the Amazon rivers are extremely low gradient rivers. During periods of dry season, when the Mekong River's discharge drops below 1,500 m3/s, seawater penetrates the river system as far as 50 km from the coast (Hori, 2000). This greatly inhibits rice production where it is cultivated in the vast and productive area of 1.7–2.1 million hectares (Jacobs 1992). The Amazon River also has a very low slope (100 m per 4,000 km) (Salati and Marques, 1984), so the diminished water flow could profoundly affect its lowland and deltaic regions by altering the water chemistry and allowing more saltwater intrusion. Thus, the repercussions on freshwater aquifers and on rivers and estuaries are drastic changes in hydrologic regimes which will worsen associated biodiversity losses, destruction of habitat, coastal erosion and spread of diseases (MEA 2005c; Harvell et al. 1999).

Effects of climate change on biological invasions and outbreak of diseases
Climate change, which is largely driven by land use changes and alteration of the atmospheric composition will continue to be a strong driving force in the extirpation of species both in land and in water (Vitousek et al 1997). It is estimated that the global extinction rate is 100 to 1000 times greater than pre-human levels (Lawton et al., 1995; Pimm et al., 1995) and this has adversedly affected the functioning of ecosystem (Chapin III et a 1997; Worm et al., 2006). As the resilience of ecosystem is reduced due to lower diversity, its functional services and ability to cope with perturbations and ecological surprises is also compromised (Chapin III et al., 1997). The increases in temperature which is inherent to global warming and change will also be accompanied by changes in the distribution and range of tropical parasites and diseases as well as their hosts and vectors.

This will also enhance biological invasions in both the tropical and temperate areas which could endanger the local native and highly specialized species. Biological invasions are now being recognized as an important element of global change following observations on the dispersal and development of alien species in various parts of the world. As climate change effects continue to beset us due to increased eutrophication, pollutants, habitat modification and disturbance, both terrestrial and aquatic ecosystems can interact with biological invasions. Biological invasions have been implicated to cause the collapse and decline of several ecosystems (Stachowicz et al 2002; Frank et al., 2005) and are known to contribute on the prevalence of disease outbreaks (McMichael, Drake et al). Biotic pollution as a term that evolved from alien species invasion on their non-native communities requires constant monitoring on affected communities to predict future changes and allow management and to mitigate and manage them (Ambrogi 2007).

The social implications of increase in invasive species due to warming is wide-ranging as the possibility of local collapse of ecosystems will endanger livelihoods, facilitate spread of diseases and further increase poverty incidence in most developing countries dependent on subsistence farming. For example, the introduction of zebra mussel in the Hudson river has a dramatic effect on the phytoplankton composition of the river and preferentially reduced the cyanobacterial composition of the water column (Smith et al 1998; Strayer et al 1999).

This change brought about shifts in the diet and foraging range of open water and littoral fish species in the river as the mussel limited primary production and diet of the fishes (Strayer et al 2004). In addition, the near mass extirpation of hundreds of endemic species only found in lake Victoria due to the introduction of two exotic fish species, the Nile Perch (Lates nilotica), and tilapia (Orechromis niloticus), have caused dramatic changes in the food web and livelihood of the 30 million people dependent on native fisheries around the lake (Kaufman 1992; Goldschmidt et al., 1993). In another instance, the introduced grass carp (Ctenopharyngodon idella) in the U.S. reduces natural aquatic vegetation, while the common carp (Cyprinus carpio) reduces water quality by increasing turbidity. These have effects of causing the decline of some native fish species (Taylor et al., 1984). Introduction of other mollusc species had a major impact such as for example, the edible periwinkle (Littorina littorea) which was introduced to the east coast of America in the middle of the 19th century where it had a major impact on rocky shore communities and in some locations displaced the native mud snail (Ilynassa obsoleta) (Carlton, 1982, 1989). Other examples of introduced species in Europe include the slipper limpet and oyster drill from America and the marine alga Sargassum muticum from Japan (Carlton, 1989; Critchley et al., 1990; Southward, 1991). For plant species, the range of Sargassum is increasing dramatically and has been shown to have modified macroalgal assemblages in northern Spain and the Pacific coast of North America (Walker & Kendrick, 1998).

Other disruptions brought about by introductions of exotic species include toxic algal bloom species in many countries (Hallegraeff, 1993; Smayda 1997) from ships ballasts and can have massive devastating effects on local fisheries and aquaculture production as a result (Azanza et al., 2005). It is thought that nutrients regulate or control the the yearly occurrence of both toxic and non-toxic algal blooms (Hallegraeff, 1993; Justic et al., 1995; Hodgkiss & Ho, 1997) and the addition of temperature as an stressor may interplay with the already existing stressors in the community. For example, the projected warming may decrease the habitat and foraging range of some fish species which are cold adapted and cause these to move poleward. The increased duration of stratification in the water column may also expand the halocline of warm water thereby diminishing the possibility of turn over with surface water to replenish the oxygen levels and could also pose as a barrier for other migrating fish species. In addition to this, there were also reports of increased incidence of disease outbreaks due to warming.

The abalone (Haliotis tuberculata) aquaculture in France have been affected by mass mortalities during the summer which have been shown to be related to thermal stress and bacterial infections of Vibrio harveyi during elevated mean summer temp. (Travers et al., 2009). Studies of mollusc egg masses under different combinations of stressors showed complex interactions among climate change, stressors and microevolutions (Byrne and Davis, 2008). Thus, the introductions or translocation of species modify local ecological conditions by altering the reproduction, growth and development of native species, as well as hybridisation and introducing diseases and parasites (Latini & Petrere 2004). Already, the changing climate is allowing the rapid built up of introduced species in Antarctica never before known but could have been released from ballast water of ships, tourism and scientific expeditions in that place (Frenot et al 2005).

Some common underlying mechanisms for species introduction includes two pathways, unintentional (transport underneath ships, through ship's ballast water, opening up of navigable canals or coastal developments) and intentional (deliberate introductions, pets, baits, aquaria, gardens, and through aquaculture) (Crowe et al 2000;Kolar and Lodge 2002; Semmens et al 2004). There are far more species introductions found in freshwater and marine habitat probably due to faster rate of dispersal and rapid establishment of population (Truscot et al 2006; Richardson et al & Pysek 2006; Richardson et al 2007; Strayer 2010). Human made structures and coastal developments may also facilitate species introductions such as navigation canals from drainage basins to water ways and into the sea (Gido and Brown 1999).

Although not all species introduction carry diseases with them or becomes a dominant established species, the potential for a major and permanent collapse of ecosystem remains especially when pathogens are included in the transfer of species. The importance of an alien species is directly linked on its ability to affect the primary production of a system, disrupt the base of food webs and fishes that disrupt the apex of a food web and decapods that act as powerful omnivores and aquatic plants that have strong engineering effects and affect the quality and quantity of primary production, and diseases, which probably have been underestimated as an ecological force (Strayer 2010).

Higher incidence of disease outbreaks

With warming temperatures and continued land use changes, marine diseases have increased in frequency with higher temperatures being positively correlated as a major cause of range shifts among pathogens and vectors (Harvell et al 1999;Van Dolah 2000). Because climate change is primarily temperature driven, the warming up of higher latitude environments may produce an ambient temperature that could enhance the establishment and spread of vector borne parasites, anthropods and diseases (Parkinson & Butler 2005). In addition, stressed out functional groups in the marine ecosystems may have reduced or impaired their resistance and resiliesnce to different stressors (Myers & Worm 2003; Worm et al 2006) such that they become susceptible to pollution or bacterial infection as mediated by higher temperature. For example wide swaths of seagrasses, Thalassia testudinum, have been decimated and an additional 23,000 ha severely affected by an unknown agent in the Florida Keys (Gladfelter, 1982; Hughes 1994). Corals in the Great Barrier Reef, in the Carribean and in the Indopacific region have been affected by massive bleaching events (Hughes 1994) due to warming and Sea urchins in the Carribean have been eradicated by the long-spined disease (Hughes 1994).

The widespread occurrence of marine algal toxins in oceans, embayments,fjords and seas have also been positively correlated to global warming and pollution (Van Dolah 2000). A 30 year observation on the recent increase of diseases in the marine environment show that factors such as climate warming, pollution, harvesting, and introduced species can contribute to disease outbreaks in marine life but no single factor can be attributed to this increase (Ward & Lafferty 2004; Lafferty et al 2004). For instance, the increase in disease of Caribbean coral is postulated to be a result of climate change and introduction of terrestrial pathogens (Carlton & Richardson 1995; Diaz-Soltero 1999; Hoegh-Guldberg et al., 2007). Indirect evidence also exists that warming increased disease in turtles (Harvell et al 1999; Hawkes et al 2009); protection, pollution, and terrestrial pathogens increased mammal disease (Harvell et al 1999; ward & Lafferty 2004) aquaculture increased disease in mollusks (Dungan et al. 1982; Lafferty & Kuris 1993;Lafferty 2004) and release from top predators increased sea urchin disease (Lafferty 2004; Lessios 1988).

In fisheries, many unintended introductions of pathogens and diseases occurred through aquaculture which introduced pathogens became more pathogenic in local hosts than in their original exotic hosts (Gog et al. 2002, McCallum & Dobson 1995). For instance when the Caspian stellate sturgeon was introduced into the Aral Sea, it brought a monogene that infected gills of the native spiny sturgeon, leading to mass mortalities of this naive host (Dogiel & Lutta 1937). In the same way, when the European trout was introduced into North America, whirling disease spread from stocked trout to native trout, with severe consequences for the natives (Bergersen & Anderson 1997, Gilbert & Granath 2003).

A similar type of pathogen transmission can occur in cultured shrimps as well as fish culture due to the rapid expansion of commercial operations in the aquaculture industry causing the expansion of several viruses and bacteria that spread from cultured shrimps and fish to wild populations (Lightner 1996; de la Peña et al 2001; Tendencia 2002a, 2002b).These studies indicate the pervasive influence of climate change on the spread & emergence of diseases causing mass mortalities in both native populations and hosts with ecological consequences of which much remains unknown. These too carries serious implications as declining fisheries & aquaculture productions may reduce revenue and impair ecosystem functioning.

Additionally, the increase of projected extreme events such as storms and flooding may directly affect human health and often serve as catalyst for outbreaks of infectious diseases (Noji 2005). In general an ambient warmer temperatures and wetter climate will favor range shifts, affect the seasonality of diseases and the life cycle of vectors and hosts of pathogen.

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