

Effects of Climate Change on Marine Ecosystems

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Climate change will fundamentally alter the structure of oceans and directly impact marine ecosystems and human societies. Recent assessments of the global climate have concluded that ocean temperature, sea level and acidity have been increasing (IPCC report). Further, summaries of recent climatic data indicate that the intensity and frequency of ocean storms are increasing as well.

Climate induced changes and other less-understood anthropogenic changes will be superimposed on other impacts resulting from human activities such as over fishing, pollution, damming of rivers and habitat loss in coastal areas. Consequently, the fundamental characteristics of marine ecosystems, some already under stress, will be altered. Whether overall global yield from marine fisheries will decline due to climate change remains unclear; however, regime shift within individual marine ecosystems and trends in fish landing for certain species will likely occur. Calcareous plankton and coral are already suffering because of more acidic and warmer seawater. Combined with the potential loss of primary and secondary producers and important habitats, detrimental effects of climate change to fisheries are a matter of concern.

KEYWORDS climate change; ecosystem; fisheries; ocean acidification; coral

1. Introduction

Empirical data suggest that oceanic environments and marine ecosystems are changing as a result of natural or man-made variations in climate and river run-off (Turner and Rabalais 1994; Fogarty 2002; Rebstock and

Kang 2003; Lin *et al.* 2005; Gedney *et al.* 2006; Halpern *et al.* 2008). Any effects of such climate change on fisheries will compound the existing problems of massive over-capacities of usage, and conflicts between fishing fleets and among competing uses of marine ecosystems (IPCC 2001; Halpern *et al.* 2008). Increasing greenhouse gas concentrations

are expected to lead to substantial atmosphere warming during this century (IPCC 2007). As a consequence of atmospheric warming, we expect the warming of oceans and shifts in habitat ranges in addition to changes in algal, plankton and fish abundance in high latitude oceans to follow (IPCC 2007). In some locations ocean temperature has increased (e.g., Scranton *et al.* 1987; Freeland 1990; Bethoux *et al.* 1998); whereas, at other locations, oceans are cooling (Read and Gould 1992).

In marine ecosystems, slight changes in environmental variables, such as temperature, salinity, wind speed and direction, ocean currents, upwelling strength, UV-B radiation, pollution, diminishing wetlands and nursery areas as well as predation patterns, can sharply alter the food chain and the abundance of fish populations (IPCC 1996, 2001; Ji *et al.* 2007). Some of the effects of climate change-related warming on fisheries are summarized in Table 1 (IPCC 2001).

Of note is that the above mentioned changes impact the entire ocean water column. For example, Whitney *et al.* (2007) identified a warming trend and a concomitant decrease in oxygen in waters of the subarctic Pacific Ocean down to 370 ± 44 m (Fig. 1). Additionally, the bottom waters of

the Sea of Japan have increased in temperature and oxygen content has decreased (Fig. 2; Gamo *et al.* 1986; Kim and Kim 1996). Chen *et al.* (1999) suggested that bottom waters of the Sea of Japan might even become anoxic as early as 2200. Various organisms can adapt to a wide range of oxygen concentrations. However, a wide range of detrimental effects to marine animals occur as oxygen levels decline, progressing from slowed growth rates to metabolic impairment, and death. What follows concentrate on three types of effects of climate change on marine ecosystems.

2. Effects of Sea Surface Warming and Sea Level Rise

Variations in ocean temperatures will undoubtedly impact marine ecosystems and reduce fishery productions (IPCC 2001; Fogarty 2002). For example, the harvest of pink salmon off the Alaskan coast co-vary with the Pacific Decadal Oscillation Index, a measure of sea surface temperature in the North Pacific (Mantua *et al.* 1997). Temperature changes are expected to be greatest at high latitudes (IPCC 2001). For instance, warmed seawater and shifting winds have caused the Arctic ice pack to shrink such that

Table 1. Effects of climate change-related warming of fisheries (taken from IPCC 2007)

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- longer growing seasons and increased rates of biological processes—and often of production;
 - greater risk of oxygen depletion;
 - species shift to more tolerant of warmer and perhaps less-oxygenated waters;
 - redeployment or re-design and relocation of coastal facilities;
 - coastal cultures may need to consider the impacts of sea-level rise on facilities and the freeing of contaminants from nearby waste sites;
 - changes in precipitation, freshwater flows, and lake levels. Strong regional variations are likely;
 - introduction of new disease organisms or exotic or undesired species;
 - establishment of compensating mechanisms or intervention strategies;
 - a longer season for production and maintenance;
 - modification of aquaculture systems, e.g. keeping them indoors under controlled light, may be needed more often to protect larvae from solar UV-B. In addition, several of the above and other factors, such as competing demand for coastal areas, may argue for technological intensification in ponds and non-coastal facilities.”
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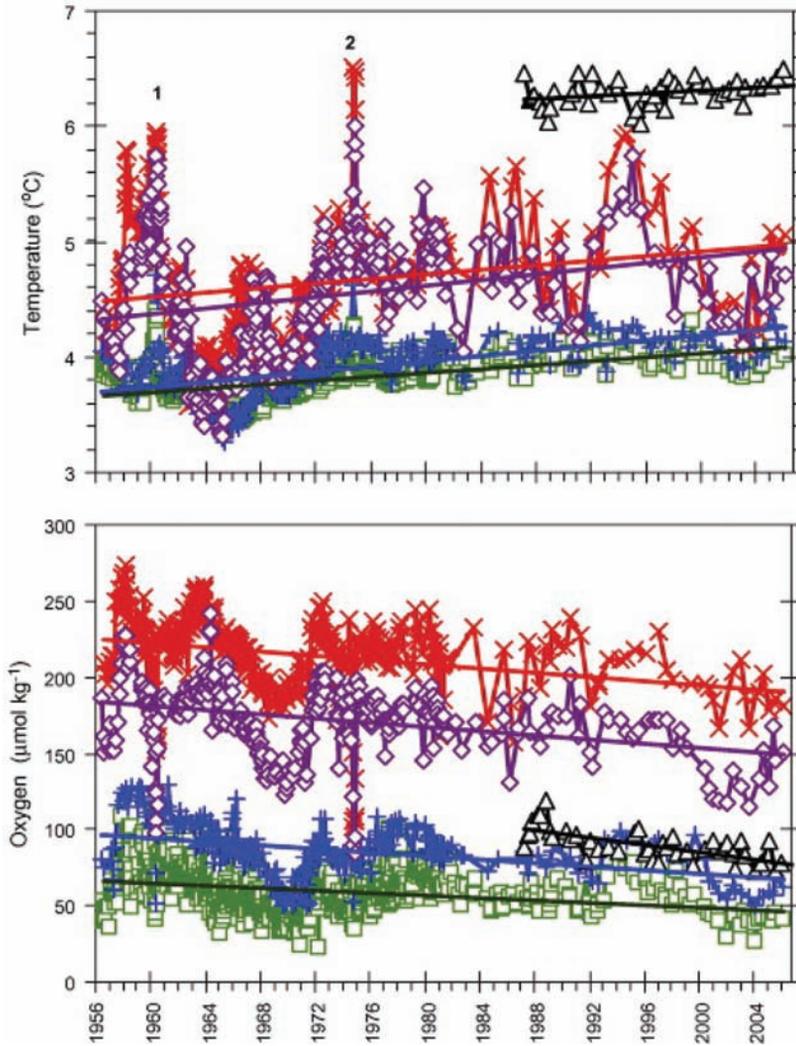


Fig. 1. Temperature and oxygen trends at Ocean Station P (50°N , 145°W) on the 26.5 (\times ; 140 ± 15 m), 26.7 (\diamond ; 168 ± 17 m), 26.9 ($+$; 278 ± 27 m) and 27.0 (\square ; 370 ± 44 m) isopycnal surfaces and at station P4 (Δ ; 48.66°N , 126.67°W) on the 26.7 surface. P4 is warming at $0.0084^{\circ}\text{C y}^{-1}$, with O_2 declining at $1.22 \mu\text{mol kg}^{-1} \text{y}^{-1}$. Two mesoscale eddies are labelled 1 and 2 (taken from Whitney *et al.* 2007).

the size and number of floating ice-bergs have declined to an extent unparalleled over a century (Revkin 2007). Consequently, 2.6 million km^2 of ocean has lost ice cover in the Arctic and Antarctic Oceans beyond the long term average since satellites first started measurements in 1979 (Fig. 3).

Since most marine species have particular thermal preferences with a well-defined optimal temperature range, important northern fish species, such as broad whitefish (*Coregonus nasus*), Arctic char (*Salvelinus alpinus*), Arctic grayling (*Thymallus arcticus*) and Arctic cisco (*Coregonus autumnalis*), are

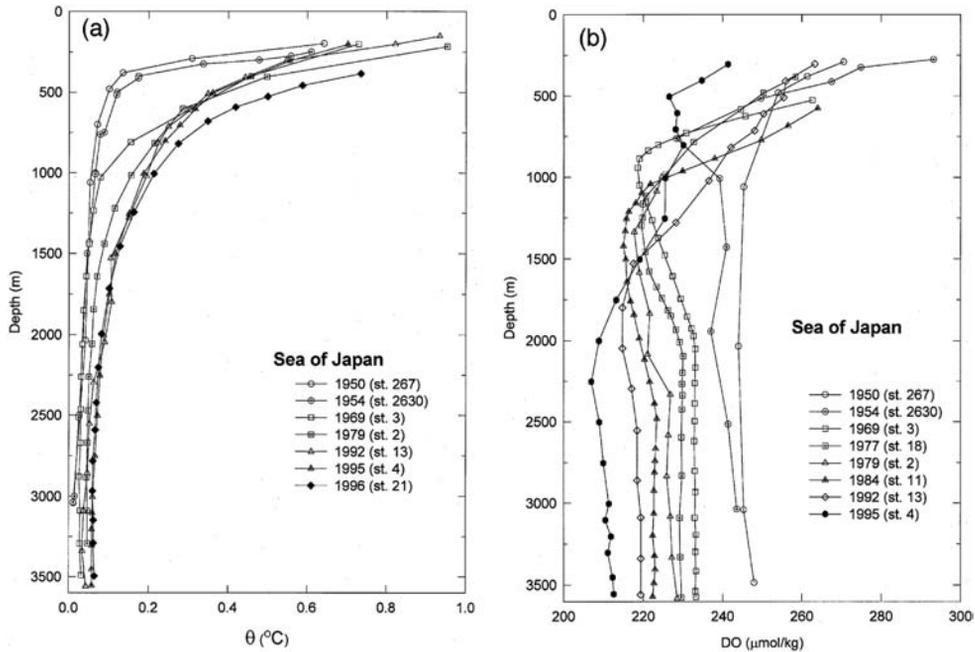


Fig. 2. Vertical distribution of (a) potential temperature and (b) dissolved oxygen in the Sea of Japan from 1950 to 1996 (taken from Chen *et al.* 1999).

likely to decline due to warming seawater and changing habitats (IPCC 2007). Predatory species in the Pacific and Atlantic Oceans, perhaps carrying new diseases, may move to warming Arctic waters as climatic barriers to species invasions are lowered (IPCC 2007). By the same token, with higher temperatures, invasion by non-native species is expected to occur, particularly on mid- and high-latitude regions (IPCC 2007).

Satellite data show phytoplankton biomass and growth generally decline as the oceans' surface waters warm up (Behrenfeld *et al.* 2006). Changes occurring in the expansive stratified low latitude oceans influence the availability of nutrients for phytoplankton growth, hence a prolonged decrease of net primary productivity of 190×10^{12} g C/yr since 1999. Such a decrease may be a harbinger of the future for marine ecosystems (Doney 2006a; Behrenfeld *et al.* 2006).

In the Southern Ocean, the decline in sea ice has been linked to a decline in krill populations, a keystone species in the Antarctic food chain (Loeb *et al.* 1997). Species that have adapted to life at the sea ice edge, such as crustaceans, may also experience population declines, thereby decreasing the available food sources for penguins, seals, polar cod and narwhals (IPCC 2007). Conversely, fishery production may increase in mid- to high-latitude regions due to increases in growth and survival of exploited species (Everett 1995; Fogarty 2002; IPCC 2007).

Open Arctic waters could experience a boon in fishing (Revkin 2007). However, as the Arctic ecosystem changes from ice-covered to ice-free, understanding how storm surges will affect coastal habitats, and how much of the fishery will be sustainable are questions yet to be answered. Increased fishing activities is likely from the modern industrial fishing fleet because of their ability to fish in harsh environments far from home.

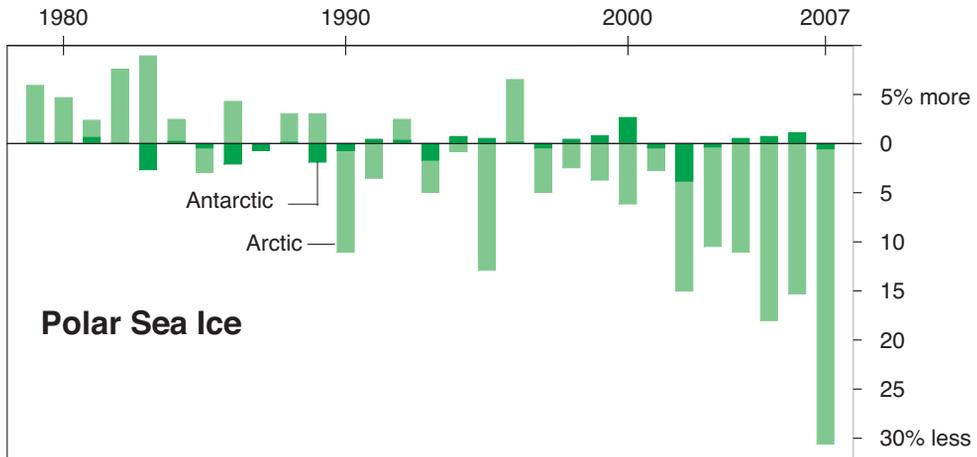


Fig. 3. Sea ice in the Arctic and Antarctic Oceans: Sea ice has declined in the Arctic in both summer and winter, and slightly increased around Antarctica in summer. Above is average deviation from August (taken from Revkin 2007).

It is speculated that developed nations will likely be the major players in the Arctic in the future, which is beyond the reach of most developing countries.

Many countries with extensive inhabited coastlines, especially island nations, are likely to suffer most from rising sea levels (IPCC 2007). Pressures will be greatest on developing countries as they are least able to afford mitigation measures. Rising sea levels may submerge important coastal habitats such as mangrove forests, sea grass beds and salt marshes, especially where they are constrained on their landward side, or starved of sediment because of construction of dams upstream which traps sediments. Approximately 30% of global coastal wetlands may be lost (Everett 1995; IPCC 2007). Further, warming surface oceans in the tropics will likely generate an increased number of hurricanes or tropical storms of increased magnitude (Emanuel 2005). As a result of increased coastal storms, damage to coastal cities and settlements and the submerging of coastal habitats may occur (IPCC 2007).

Habitats that have received the most attention as a consequence of climate change

are coral reefs. In 1998, El Niño and the concomitant failure of the Indian Monsoon resulted in bleaching and death of over three quarters of coral reefs in the Indian Ocean (Wilkinson *et al.* 1999). In fact, coral reefs elsewhere fared no better as they are vulnerable to thermal stress and have poor adaptive capacity (IPCC 2007).

Seawater has warmed by roughly 1°C over the past 50 years; thus, in El Niño years, temporary increases of a degree on top of this long-term temperature change may push ecosystems to their limits. The frequency and intensity of El Niño events have been predicted to increase (Steffen *et al.* 2002). These increases will adversely impact the Peruvian Anchovetta fisheries, and have other detrimental effects (Fogarty 2002). Fishery production is a critical issue of global food security as over 1 billion people are strongly dependent on fish as an integral component of their diet (FAO 2001). Yet, many of whom are poor and will adapt poorly to the decline or shifts in fish stocks (Sheppard 2001; Montaigne 2007). Effects of ocean acidification to be discussed below, are likely to compound the issue.

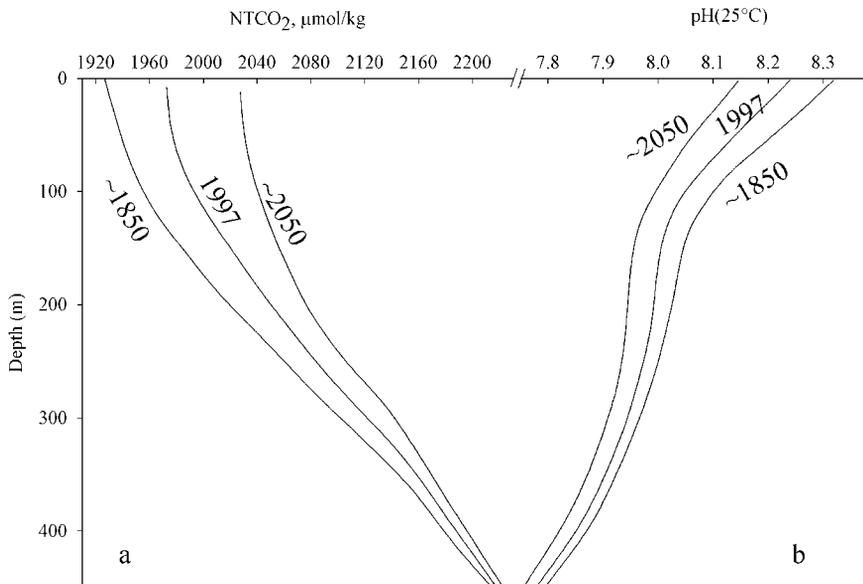


Fig. 4. Typical pre-industrial (~1850), present (1997) and projected (~2050) (a) NTCO_2 and (b) pH vertical profiles of seawater in the SCS (taken from Chen *et al.* 2006).

3. Effects of Ocean Acidification

In addition to increasing greenhouse gases in the atmosphere, a significant amount of CO_2 humans emit ends up in oceans. Figure 4 presents the typical pre-industrial (~1850), present (1997) and projected (~2050) normalized total CO_2 (NTCO_2 : total CO_2 concentration at a salinity of 35) and pH vertical profiles of seawater in the South China Sea. To date, anthropogenic CO_2 emissions have already decreased surface water pH by roughly 0.1 units of pH. By 2050, pH is predicted to decrease further by approximately an additional 0.1 unit. Of course, ocean acidification in addition to seawater warming will make CaCO_3 -based systems increasingly fragile (Sheppard 2001; Doney 2006b; IPCC 2007).

Predictions from ocean models suggest that ocean pH several centuries from now will be lower than at any time in the past

300 million years (Caldeira and Wickett 2003). Although these pH reductions may seem small, they provide ample cause for alarm. When oceans absorb CO_2 , they become increasingly acidic, and calcite and aragonite dissolve with increased ease. Beyond a specific acidity threshold, organisms using calcite and aragonite for shell and skeletal growth, such as coral, mollusks, crustaceans, zooplankton and phytoplankton, start to suffer (Doney 2006a, b). Mesocosm experiments have demonstrated that at expected CO_2 concentrations in 2150, calcification of species such as the single-celled plants coccolithophores, the most productive calcifying organisms on the planet, will be reduced to almost half of that at the current ambient CO_2 concentration (www.carboschools.org). Ocean acidification therefore threatens the survival of a whole suite of marine species and the entire ocean food chain (Doney 2006b).

4. Effects of Changing the Stability of the Surface Mixed Layer

Climate change-induced warming and freshening of seawater on the surface layer will stabilize the water column in the global oceans. For instance, the temperature of bottom water in the Sea of Japan has been rising (Fig. 2(a)) because the surface layer has warmed, and thus become increasingly stable. As a result of sea surface temperature increases, the ability of the oxygen-laden surface water to sink to the bottom to replenish bottom oxygen has become more difficult (Chen *et al.* 1999). Additionally, studies have determined that some parts of oceans may be seeing decreases in salinity due to increased river runoff (Gendey *et al.* 2006). Further, wind patterns may change, thereby altering upwelling; a principal source of nutrients that support new production (Everett 1995; Chen 2004).

Changes in upwelling patterns and decreases in salinity can be illustrated best in small seas. Take the Baltic Sea as an example, it has been demonstrated that mean annual sea surface temperatures may increase by 2–4°C by the end of the 21st century (BACC Lead Author Group 2006). Sea ice would then decrease by 50–80% along with a decrease between 8–50% in average salinity. All these changes may increase phytoplankton production and shift the phytoplankton community toward species, such as cyanobacteria, that favor high temperatures. Cold-water species may be eliminated from much of their present habitat while cool- and warm-water species expand northwards. Stratification of the water column may also lead to accelerated eutrophication, putting pressure on bottom-dwelling species and a loss of biodiversity in the Baltic (BACC Lead Author Group 2006).

Decreases in salinity in the Baltic Sea will alter the sea's ecology. A decrease in

marine fauna is predicted to occur first in the northern Baltic Sea because of increased predicted rainfall (BACC Lead Author Group 2006). As an example, the common starfish and shore crab are among the species expected to decrease when salinity drops to below 15–25 (BACC Lead Author Group, 2006). When the salinity drops to <11.5, buoyancy would be too low for cod eggs to remain floating (BACC Lead Author Group, 2006).

Even in larger seas such as the Sea of Japan, changes to temperature and salinity mixed layer depth have been observed. For example, the mixed layer there was thinner and less variable (18.2 ± 4.9 m) in 1961–1975 compared with those (26.1 ± 15.1 m) in 1976–1990 during the March–May period (Fig. 5). The shallower mixed layer depth in spring during the earlier period before the regime shift around 1976 resulted in higher chlorophyll a concentrations and zooplankton biomass (Kang *et al.* 2000). Responses of some fish species to these changes can be large. For instance, the catch of saury crashed after 1976, while the sardine catch skyrocketed (Fig. 6).

As mentioned above, climate change-induced warming and freshening of the surface layer will stabilize the water column in the global oceans. Examples given above for the Baltic Sea and the Sea of Japan may serve as a basis for further studies on climate changes in other oceans.

5. Conclusion

Climate change will exacerbate the stress on living resources already impacted by pollution, over fishing and other anthropogenic activities. Even if the net impact on fishery production is neutral, shifts in regional production are likely to alter local availability of preferred species and food supply, and may have significant local effects on fishery-dependent communities. Although climate change science has improved rapidly

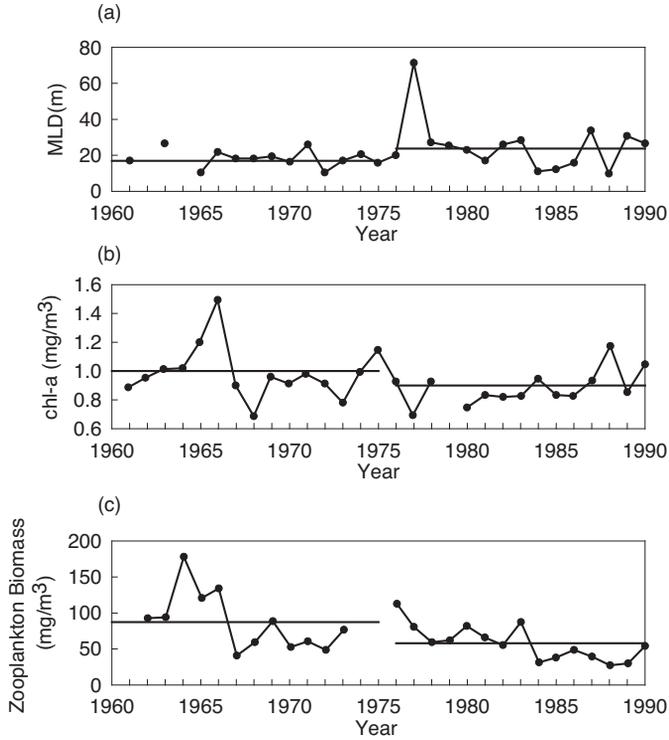


Fig. 5. Variations of (a) mixed layer depth, (b) chl-a concentration, and (c) zooplankton biomass in the Sea of Japan during spring (March–May, but mostly April) of 1960–1990 (taken from Kang *et al.* 2000).

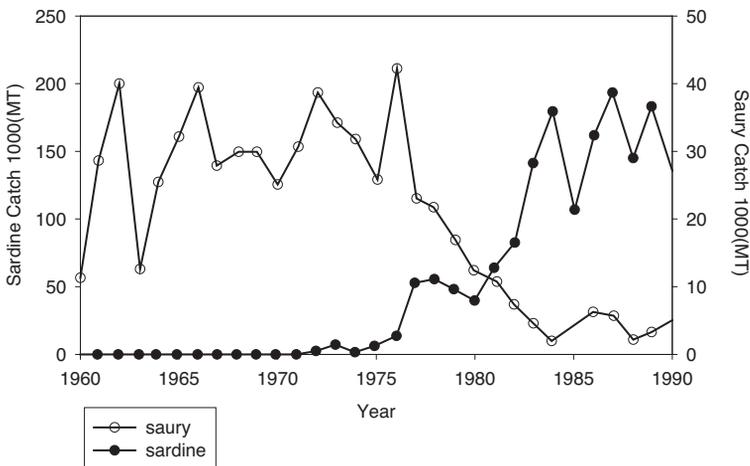


Fig. 6. Annual commercial catches for sardine and saury from the Sea of Japan (taken from Kang *et al.* 2000).

over the last few decades, the responses of marine ecosystems to the compounded effects of climate change and anthropogenic activities remain poorly understood. Consequently, little data for adaptation and mitigation measures are available. Further observations and research are clearly warranted.

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