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Impacts of climate change on ocean primary productivity

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Abstract
The changes in the statistics of average sea water temperature, average ocean water salinity, average sea level rise, average sea height, average water pH range *etc*. over the decades, years or even centuries called climate change. Human activities over land such as burning of fossil fuels, deforestation, agricultural activities *etc*. causes human induced climate change. Phytoplankton were the major source of primary productivity of oceans. The various reports on climate change and its impact on phytoplankton, stated that the increase in sea surface temperature and large amount of CO_2 diffusion in ocean water causes some of the serious effects on primary productivity and this ultimately posed thoughtful risks to fisheries as well as human population. So in future it is becomes very much essential to take proper steps towards minimizing the human induced climate change activities, and for this purpose detailed research and awareness among the population is becomes compulsory. While reviewing present situation one can be say that, if we were not gets aware about present climate change scenario, then in future it will going to give more trouble.

Keywords: Climate; climate change; primary productivity; ocean; effects

Introduction
Climate is defined as "the expected weather conditions of the certain locations for a given time period". It is varies from geographical locations to locations. In India mainly four seasons were observed with variation in the climatic conditions, respectively. If one can considers the geographical locations then average number of rainy days, average temperature, average water salinity *etc*. like parameters defines the climatic conditions of that particular geographic location. Whereas, the term Climate Change is defined as "the variation of statistical data over the years, decades or even centuries regarding, the average temperature, average rainy days, average seawater salinity, average pH content of seawater *etc*."

There were various researchers working on the climate change and their impacts on environment. The majority of them reports that, human activities is mainly induced the changes in the climatic conditions. The major human induced activities were; the burning of fossil fuels (coal, oil and gas), deforestation, agricultural activities and like these many more other activities which were responsible for climate change. Due to increase in transportation aids and industrial revolution, the rate of fossil fuels burning goes on increasing, which ultimately causes the release of greenhouse gases in the atmosphere, which included carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (NO_2) and water vapors; which impacted as they store the reflected sun infrared radiations (heat) within the Earth's atmosphere, instead it goes in the space. Due to storage of this heat in atmosphere surround the earth, negatively causes rise in the atmospheric temperature. And which ultimately results in greenhouse effect, resulting in climate change over the earth atmosphere.

If one considers about the ocean or any water body environment the primary productivity is defined as "the amount of phytoplankton biomass and their growth rate in that particular water body" (Cloern *et al*., 2014) [5]. In any aquatic water body food web dynamics, in biogeochemical cycles and fisheries productivity; primary productivity plays major role, as they were the sole energy provider to the aquatic fauna present in that water body (Chassot *et al*., 2010; Passow and Carlson, 2012) [3, 26]. If considering the any water body, there were mainly three types of planktons were recorded. The term plankton defines "the organisms which were wandering or drifting". Those plankton mainly composed of; the phytoplankton (which were the plant components also autotrophic in nature with consisting of photosynthetic compounds and so they plays major energy source to the whole aquatic environment), the zooplankton

(which were the animal components and mainly feeds on the phytoplankton, also plays major role in transfer of energy to the higher trophic level species) and the ichthyoplankton (which consists of fish larvae, who supports the fish productivity of that particular water body). As among these the phytoplankton were main source of primary productivity of any water body, so it is the base of the aquatic food web (Kyewalyanga, 2016) [20]. They acts as primary producers because they contains the photosynthetic pigments in their body like chlorophyll-a, they also consists of other accessory pigments like chlorophyll-b, chlorophyll-c and other carotenoids (Kirk, 1994; Barlow *et al*., 2008) [19]. These pigments utilizes the sun energy and carbon dioxide and produces the high energy organic carbon compounds, which fuels the growth of all other organisms. The major phytoplankton which were recorded in the any water body were diatoms, dianoflagellates, cyanobacteria, green algae etc. Apart from those in coastal areas some of the aquatic plant species like mangroves, seaweeds, sea grasses, corals etc. were also available, which plays major role in the water primary productivity (Oliveira *et al*., 2005; Duarte *et al*., 2005) [24, 7]. The another type of plankton i.e. zooplankton acts as primary and secondary consumer role, where they feeds on phytoplankton and transfer the food energy from producers to the top level consumers.

So, if considering both these organisms (phytoplankton and zooplankton) for climate change study then it gives the good results, because both were responds quickly to the changes in water quality attributes. The major reason behind this is that, both the species have smaller size (ranged between 1-500 µm) and having the shorter life span. Hence, both of them becomes immediate victims to the climatic change and so considers as good indicators for the climate change.

2. Major Indicators of Climate Change in Ocean

The physical, chemical and biological water quality parameters were the important sources to describe the changes in climatic conditions of the any water body. The land environment stated the increase in average global atmospheric temperature (Global Warming), changes in rainy seasons and cloud covers, due to increase in temperature melting of ice caps and glaciers etc. were the indicators of the land environment climate change. When considering the ocean environment, the change in the average values of physical, chemical and biological water quality parameters such as increase in ocean temperatures, ocean acidity, decrease in water salinity etc. were the major indicators of ocean climate change. The earlier reports stated that, the changes in ocean water temperature and increase in large amount of CO_2 deposition in ocean water; denotes the major impact of climate change in ocean environment. There were various reports studies about the above mentioned both changing oceanic water quality parameters, which was described as follows;

2.1. Increased Ocean Water Temperature: the major source of this increment is industrial revolution. Due to burning of large amount fossil fuels the amount of greenhouse gases gets increased in atmosphere, which causes the increment in sea surface temperature. As per the Intergovernmental Panel on Climate Change (IPCC, 2007) [17] report, during 1980-2015 average global surface temperature was rise by 0.9°C. While, the recent year of 2016 reported as hottest year, and the main reason of this is release of large amount of GHGs (Fig. 1; Henderson *et al*., 2018) [14]. The major impact of increased ocean temperature cause the increment in sea level, as per the IPCC report, nearly about 190 mm sea level gets changed up to 2000 (Henderson *et al*., 2018) [14]. Apart from increment in sea level, the areas where very negligible amount of freshwater is added, the salinity of that area decreases a lot due to more amount of evaporation. The oceans which were near to ice or glacial areas experiences the lower salinity due to melting of ice caps and glacial because of higher atmospheric temperature. So this ultimately negatively impacted on oceanic flora and fauna.

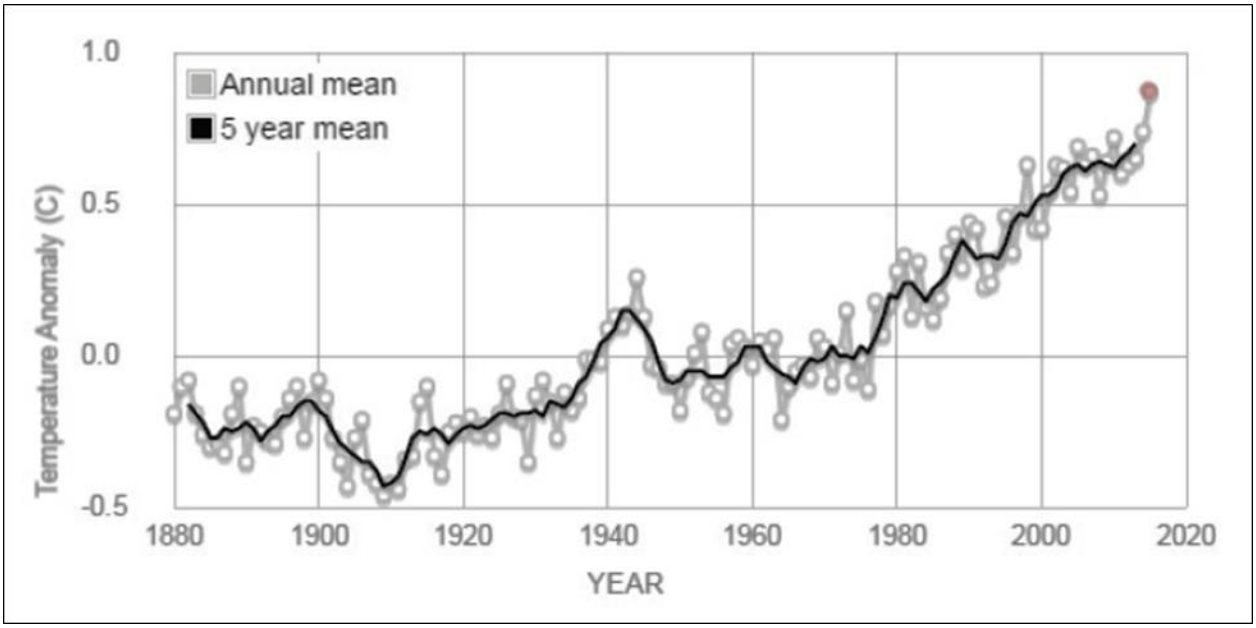

Fig 1: Global Land and Ocean Temperature Variation (Source: Henderson *et al*., 2018) [14].

2.2. Increased CO_2 Concentration: As per the IPCC (2007) [17] report, the highest concentration of CO_2 was reported in 2016 with value of around 404 ppm (Fig. 2). The main reason behind the increase in CO_2 level in the atmosphere is

deforestation, due to increased population and urbanization, the huge amount of cutting of forest was happens, which negatively impacted as the CO_2 absorption from atmosphere gets decreased by plants and this ultimately causes the higher amount of CO_2 gets dissolves in the ocean water. And if, the CO_2 level goes on increasing in such a way then in 2030 the concentration in atmosphere will reach up to 450 ppm and by 2100 it will be up to 750-1300 ppm (Henderson *et al*., 2018) [14]. The major impact of increased CO_2 concentration in ocean water causes the ocean acidification. The rising atmospheric CO_2 causes increment in ocean uptake, which impacted on carbon chemistry as dissolved CO_2 reacts with H_2O molecules to form carbonic acid ($CaCO_3$). This acid formation chemically known as ocean acidification and which causes the decrease in the concentration of carbonate ions concentration (CO_3^{2-}), increasing the solubility of calcium carbonate ($CaCO_3$) (Caldeira and Wickett, 2003; Doney *et al*., 2009) [2, 6], it also decreases the ocean water pH value (Fig. 3).

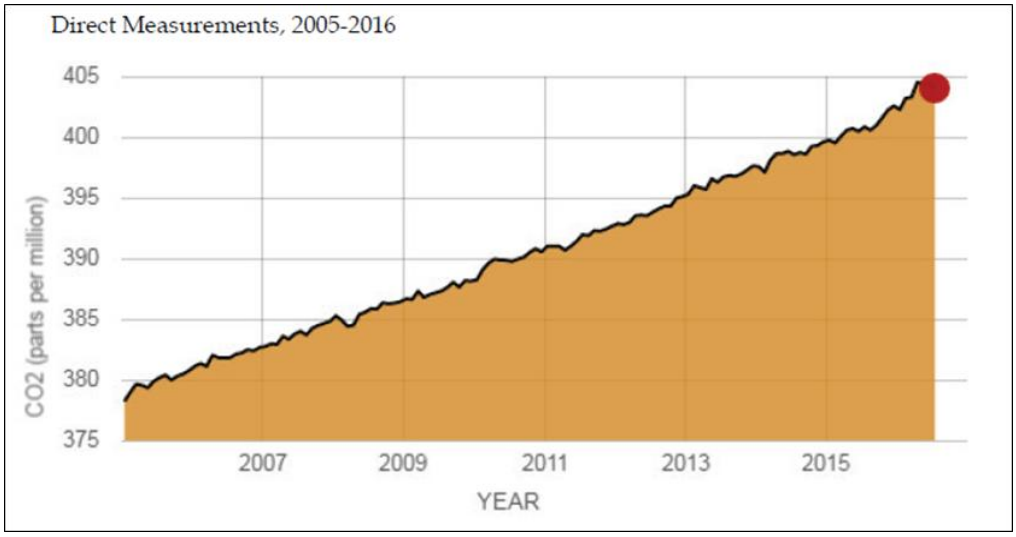

Fig 2: Atmospheric CO_2 Concentration (Parts Per Million; Source: Henderson *et al*., 2018) [14].

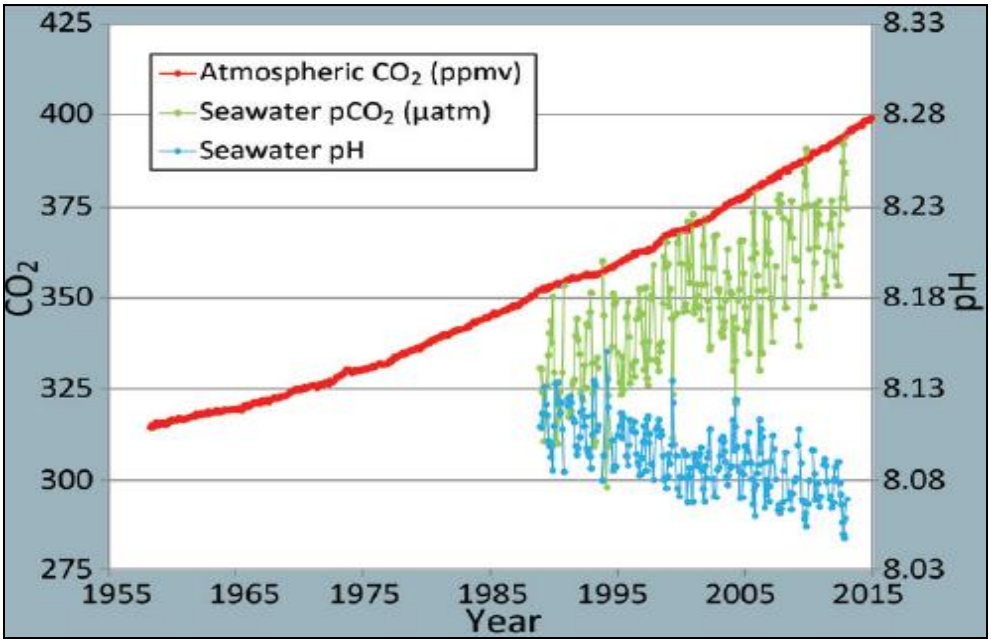

Fig 3: Ocean Water pH variation (Source: Henderson *et al*., 2018) [14].

3. Major Impacts of Climate Change On Primary Productivity

The various researchers reported that, various climate related changes in ocean ecosystems have been noticeably increased over last 50 years (Hays *et al*., 2005; Harley *et al*., 2006; Yang and Rudolf, 2010) [13, 12, 30]. At various study level the phytoplankton responses were studied at different spatiotemporal scales, like by using empirical formulae, by using field investigations as well as by using modelling approaches. As described above, the climate modifications, like ocean warming and rise in atmospheric CO_2 level, affects more to the marine life especially the primary producers through modifications in pH, carbonate availability, nutrient level variations etc. So, one can be say that tracking changes in the phytoplankton community structure is an accurate indicator of ecosystem worries (Irwin *et al*., 2006) [18]. The major impacts of oceanic climate changes on primary productivity of oceans water were reported as follows;

3.1. Ocean Water Warming

3.1.1. Direct effects on Primary Productivity: The Ocean Warming directly impacted on phytoplankton by affecting

their physiological rates, the activities such as respiration rates, metabolic rates, body size growth, enzymatic reactions etc. were gets impacted due to ocean water warming (Peters, 1983) [27]. The Eppley (1972) [9] reported that, for small range of temperature rise also phytoplankton experienced increase in enzymatic activities. This overall situation represents that as per McNeil and Matear (2006) [21], an increase of Sea Surface Temperature from 18 °C today to 21.5 °C in 2100, may leads to an increase of around 25% of phytoplankton population if no other water quality parameters were affected (Finkel *et al*., 2010) [10]. Apart from this increased temperature also causes the germination of resting spores from the sediments (Shikata *et al*., 2008) [29]. As temperature rises the salinity also gets varies, which mostly causes negative impact on plankton physiology, germination of spores, developments of blooms etc. (Mc Quoid, 2005) [22]. The changes in temperature and salinity also causes impacts on community structure as well as phytoplankton composition change in water body (Huertas *et al*., 2011) [16].

3.1.2. Indirect effects on Primary Productivity: Due to increase in sea surface temperature the water density at surface becomes less dense than that of subsurface water, this causes the temperature stratification. This stratified condition minimizes the vertical mixing of subsurface waters which is nutrient rich, with surface waters which was nutrient deficient. And this ultimately impacted as less availability of nutrients to the phytoplankton for their photosynthetic activities.

3.1.3. Bloom formation: The rising temperature of ocean water produces the advancement in seasonal ecological events like phytoplankton blooming events time gets changed, hatching of eggs time gets varies etc. Along Indian Coast there were about 80 blooming cases were recorded during 1998-2015 *viz*. 31 dinoflagellates, 27 cyanobacteria, 18 diatoms, 3 raphidophyte and 1 haptophyte (Fig. 4; Sahu *et al*., 2018) [28].

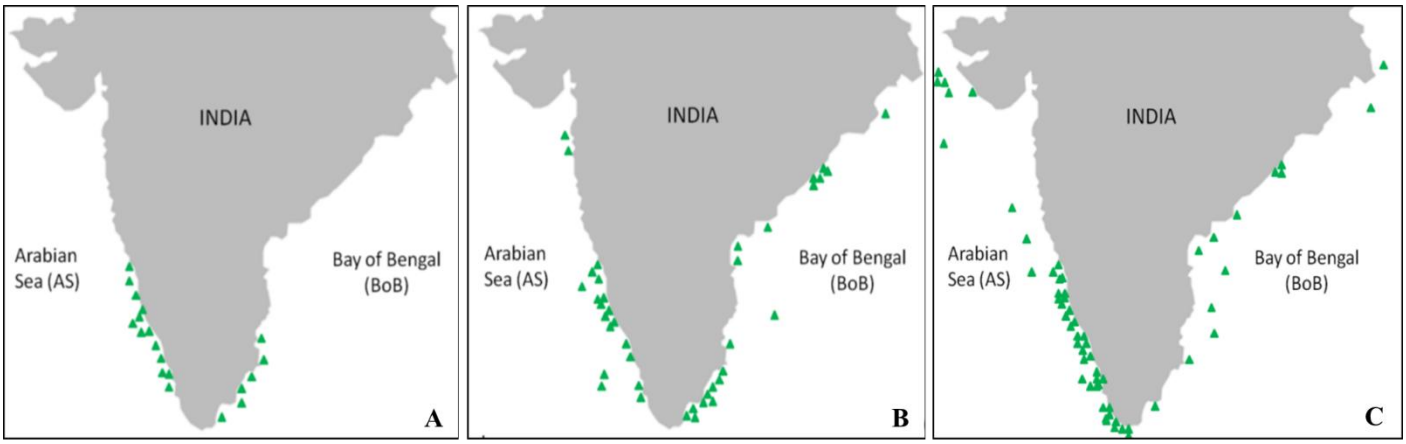

Fig 4: Phytoplankton blooms in Indian Seas (A) 1917-1957; (B) 1958-1997; (C) 1998-2015 (Source: Sahu *et al*., 2018) [28].

3.1.4. Harmful Algal Blooms (HABs): The human settlement near to the shore, causes increase in the nutrient load through the domestic pollution, apart from the human induced anthropogenic activities also causes eutrophication (Cloern, 2001) [4]. So when both of these conditions gets matched together, the algal blooms were gets started to form. When some of the phytoplankton which were having toxic compounds forms the bloom condition, then they considers as Harmful Algal Blooms (HABs). These HABs majorly impacted on oceanic ecosystem functioning, as they causes the detrimental effects on other biodiversity, by causing death of fishes which were feeds on them and ultimately on the human health and economy, if they consume the affected fish (Noyes *et al*., 2009) [23].

3.1.5. Changes in Phytoplankton Distribution: the phytoplankton were more sensitive to even small temperature change. The slight temperature changes also causes migration of these organisms to the suitable environment. The best example is coral bleaching, due to temperature rise. Due to temperature rise of water the zooxanthellae which were the energy provider to the corals, gets oozes out and settled to the another coral polyps where suitable water quality parameters were available. Likewise, many more documents were reported the large extension of phytoplankton species due to water warming (Parmesan and Yohe, 2003) [25].

3.2. Ocean Acidification

3.2.1. Calcification: Due to increased dissolution of atmospheric CO_2 in ocean water causes the ocean acidification process, which was discussed earlier. Because of carbonic acid formation, the solubility of calcium carbonate is gets increases (Caldeira and Wickett, 2003) [2] and so the metastable from of $CaCO_3$ (aragonite), becomes less available to the organisms for building of their skeleton. The organisms such as coccolithofores, foraminifera etc. were mainly affected due to calcification (Hoegh-Guldberg *et al*., 2007) [15] (Fig. 5).

3.2.2. Coral Bleaching: As like negative impact due to rising ocean temperature, the rise in dissolved CO_2 in ocean water also causes the coral bleaching. The carbonic acid which gets forms due to more amount of CO_2 dissolution, water pH gets acidic. This condition is not favorable to the coral associated zooxanthellae. So they ooze out and settled to the suitable environment (Fig. 5).

Fig 5: Ocean Acidification effects; A. Coccolithofores calcification, B. Coral Bleaching, C. Cell size reduction events.

3.1.3. Cell Size: As discussed above, the calcification process directly impacted as reduction in cell size of some phytoplankton species. Worldwide many more reports were provide evidence regarding reduction of phytoplankton cell size (Forster *et al*., 2012) (Fig. 5).

4. What Are The Impacts On Fisheries?

As per the above discussions, there was largest effect of climate change is happens on primary productivity of ocean ecosystems by triggering changes in their production rates, abundance and distribution patterns, so in the end this causes negative impact on the marine food webs (Edwards and Richardson, 2004) [8]. In oceanic environment, some of the adult fishes like mackerel, sardine etc. were forms major part in the fisheries are planktivorous for some part of their life span and apart from that fish larvae of mostly all fishes consume zooplankton. So this becomes more essential that synchrony between the peak in plankton abundance and recruitment of fish larvae is becomes must, as it thinks crucial for the survival of fish larvae. But, the changing climatic condition eventually causes the changes in plankton structure, which ultimately impacted as "Match-Mismatch Hypothesis" (Fig. 6; Edwards and Richardson, 2004) [8]. So, if sufficient quantity of phytoplankton biomass is not available then it will causes negative impact on survival of fish larvae for future fisheries prospective.

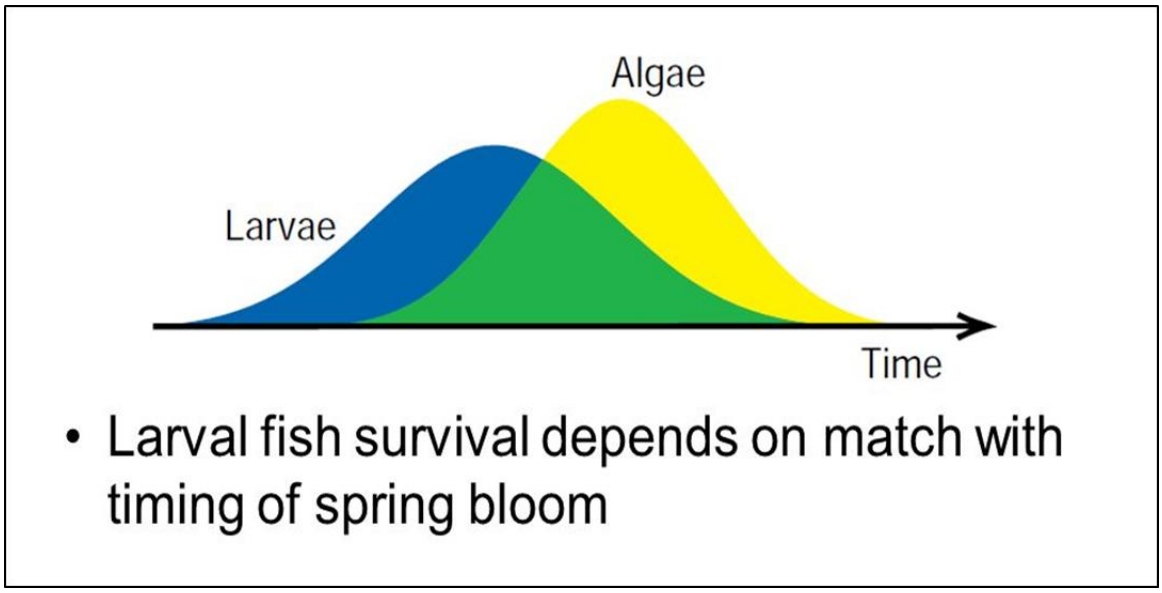

Fig 6: Match- Mismatch Hypothesis of phytoplankton and fish larvae.

5. Conclusion

So the review article suggest that the major cause of global climate change is human induced activities, so it becomes essential to control this awareness among us is becomes priority. The harmful effects about excess burning of fossil fuels, agricultural inputs, deforestation etc. have to discussed more and try to aware peoples about necessity of its usage control. As phytoplankton can be easily access through certain modelling or *in-situ* field studies regarding climate change impact, so more research have to require to control the perishability of ocean primary productivity. The integration of continuous monitoring with laboratory research causes better interpretation of current condition and this will be helpful for future prediction scenario. So overall to control the human induced climate change is not that much easy or one cannot stop fully, but by awareness among the peoples we can minimize the sources of climate change inducing factors.

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