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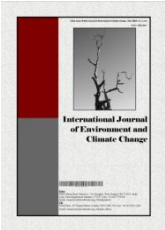

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Climate Disruption Caused by a Decline in Marine Biodiversity and Pollution

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Commentary

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ABSTRACT

The world has focused on carbon mitigation as the only solution for climate change. This discussion paper considers how marine biodiversity regulates the climate, and the factors that control marine biodiversity.

The main Greenhouse Gas (GHG) is water vapor, which accounts for 75% of all GHGs; the second most important is carbon dioxide, followed by methane and particulates such as black carbon (BC) soot. The concentration of water vapor in the atmosphere is regulated by air temperature; warmer conditions lead to higher evaporation, which in turn increases the concentration of water vapor, the Clausius-Clapeyron relation. This means that as the oceans and atmosphere warm, a self-reinforcing feedback loop accelerates the evaporation process to cause further warming.

It is not considered possible to directly regulate atmospheric water vapor. This explains why climate change mitigation strategies have focussed primarily on reducing carbon dioxide emissions as the means to reduce water vapor. This report concludes that the current climate change mitigation strategy will not work on its own because it depends on decreasing the concentration of atmospheric carbon dioxide and on the assumption that water vapor is only regulated by temperature.

71% of planet Earth is covered by an ocean that has a surface microlayer (SML) between 1 µm and 1000µm deep, composed of lipids and surfactants produced by marine phytoplankton. This SML layer is known to promote the formation of aerosols and clouds; it also reduces the escape of water molecules and slows the transfer of thermal energy to the atmosphere. The concentration of

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water vapor is increasing in our atmosphere, and 100% of this increase is evaporation from the ocean surface; water vapour from land systems is decreasing. This means that the oceans are almost entirely responsible for climate change.
The SML layer attracts toxic forever, lipophilic chemicals, microplastics and hydrophobic black carbon soot from the incomplete combustion of fossil fuels. Concentrations of toxic chemicals are 500 times higher in this SML layer than in the underlying water. Toxic forever chemicals combined with submicron and microplastic particles and black carbon particulates are known to be toxic to plankton. Marine primary productivity or phytoplankton photosynthesis may have declined by as much as 50% since the 1950s. Reduced phytoplankton plant growth equates to a degraded SML membrane, reduced carbon assimilation, and higher concentrations of dissolved carbon dioxide in ocean surface water, which accelerates the decline in ocean pH. The key phytoplankton species responsible for the production of the SML layer are the first to suffer from pH decline, a process called “ocean acidification”.
Ocean acidification will lead to a regime shift away from the key carbonate-based species and diatoms below pH 7.95 which will be reached by 2045. The SML layer will decrease, allowing evaporation and atmospheric water vapor concentrations to increase. A reduced SML layer will lead to fewer aerosols, cloud formation and precipitation, as well as increased humidity and temperature. When clouds form under these conditions, the higher humidity will cause torrential downpours and flooding. The result could be catastrophic climate change, even if we achieve net zero by 2050. In parallel, ocean acidification and the collapse of the marine ecosystem could also lead to the loss of most seals, birds, whales, fish, and food supply for 3 billion people.

Keywords: Climate; plankton; marine; biodiversity; pollution; evaporation; SML.

HIGHLIGHTS

- The SML could be as important as carbon but has not been factored into the climate change model, solutions are presented
- The SML regulates atmospheric water vapour pressure, temperature, cloud formation and precipitation
- Lipophilic toxic chemicals, microplastic and black carbon concentrate in the SML and may return to land in rainwater, after several weeks
- Lipophilic toxic chemicals, microplastic and black carbon are toxic to plankton and all marine life, they do not dilute or become dispersed in oceanic water.
- Marine plankton are the lungs for the planet and earths life support system, 50% have been lost since 1950’s decline continues at 1% year on year
- There will be a trophic cascade collapse of the entire marine ecosystem as the pH approaches pH7.95 by 2045, resulting in catastrophic climate disruption and global ecosystem crash on land and in the oceans

1. INTRODUCTION

All of the world’s oceans are covered by a surface microlayer (SML) composed of a complex mixture of proteins, carbohydrates and lipids [1]. The SML also contains particulate organic matter (POM), submicron plastic, microplastics, black carbon (BC) soot from the combustion of fossil fuels, chelated heavy metals along with microscopic marine plants and animals. The SML is characterized as having an operationally defined thickness that varies between 1 µm and 1000 µm, with physio-chemical and biological properties that are measurably distinct from underlying waters Fig. 1 ref [2].

In addition to all the particles, organic and inorganic molecules, the SML layer is also a complex living biofilm of bacteria and nanoplankton living in a mucopolysaccharide gel that binds the communities together in a three-dimensional matrix with the lipids and surfactants.

Although the thickness of the SML is variable, one of the techniques used to quantify the layer used a micro-pH meter. This technique demonstrated a sudden and marked change in pH as the probe passes through the surface layer [3,4]. The SML is described as a laminar layer free of turbulence and reduced gas exchange between the ocean and atmosphere [2]. High lipid layer concentrations are often easily observed as areas of flat water. Fig. 2 is from a quiet beach in Portugal. The lipid oil slick

and flat water stretched hundreds of meters downwind of the bathers who had just entered the water minutes before the photograph was taken. Lipid sunscreen from bathers may contain photoactive chemicals, for example, oxybenzone is known to be extremely toxic at 62 parts per trillion [5] to coral and plankton. Lipids, such as omega 3, produced by phytoplankton have the same effect and flatten large areas of the oceans, but even when they are not evident, they can still have an impact on gas exchange across the SML membrane.

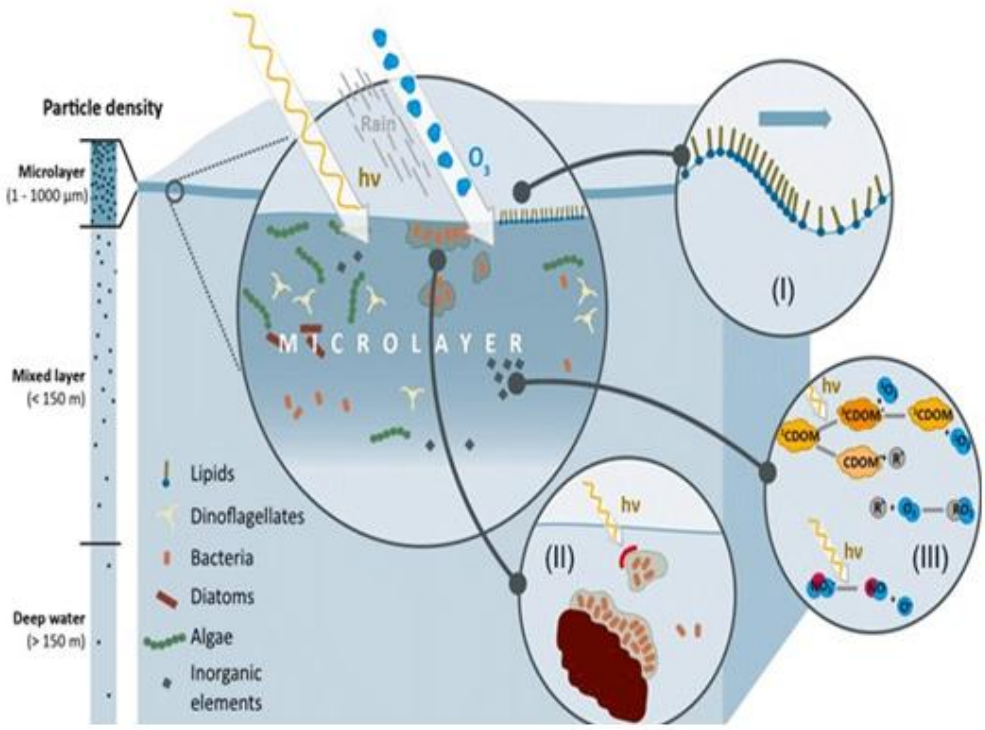


Fig. 1. The sea surface as a biochemical reactor Ref 2

Fig. 2. Lipid oil slick from beach bathers (circled in orange)
Source: GOES Foundation

Areas of flat water can be measured from space by satellites using bistatic radar measurements of ocean surface roughness. [6] This measurement system is based on an assumed reduction in wind-driven roughness caused by a pronounced SML layer that acts as a tracer for near-surface microplastics [7,8].

Although it is not possible to measure microplastics directly from space, microplastics have an indirect impact on the SML membrane in surface water throughout the oceans. Given the toxicity of microplastics, they will inhibit reproduction and/or kill marine zooplankton that would otherwise feed on phytoplankton. Reducing the numbers of zooplankton (animals) allows key phytoplankton (plants) species to flourish, including carbonate- based coccolithophores and silicon diatoms. This increase in phytoplankton numbers, increases lipid production, which in turn leads to a flattening of the water surface. The same key species mentioned above produce an enormous amount of polyunsaturated omega 3 fatty acid lipids. [9] The average monthly lipid production by phytoplankton is 108 million tonnes [10]. In the presence of microplastics there will be a decrease in the lipid and surfactant concentrations of the SML [8], which will increase water vapour gas transfer and impact on cloud formation as well as cause a regime shift in plankton biodiversity.

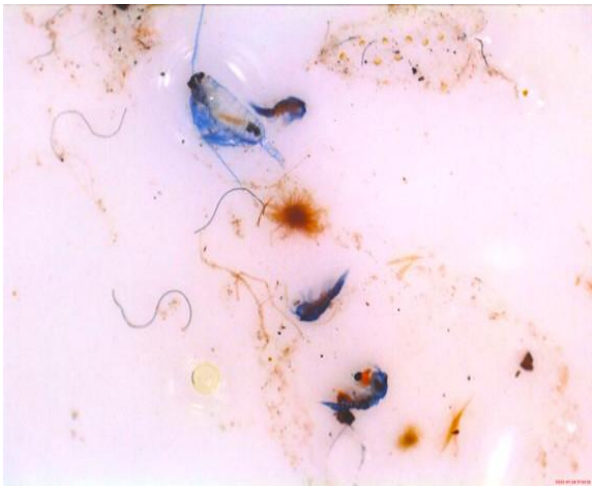


Fig. 3. Surface living zooplankton and microplastic fibres
Source: GOES Foundation

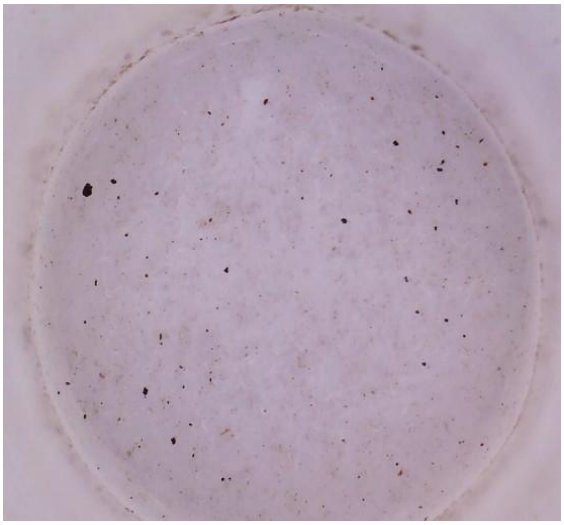


Fig. 4. 1000 particles of black carbon particles per litre of water; collected in the equatorial Atlantic Ocean. Ref 18

Phytoplankton numbers are not sustainable without zooplankton recycling nutrients back to surface waters, especially in the deep ocean off continental shelves. The conditions coupled with direct observation lend themselves to a collapse of ocean ecosystems due to the presence of microplastics. This could also be one of the reasons why the High Nutrient Low Chlorophyll (HNLC) zones now cover 25% of the Southern Ocean and are expanding [11].

Some surface-dwelling copepods develop a blue pigment as a protective mechanism against UV irradiation, indicating that they are using the SML as a habitat [12]. Fig. 3 is a plankton sample taken at 200 nm south of the Canary Islands. Note the blue zooplankton and the high concentration of plastic microfibres, image scale 5000 µm.

Due to the hydrophobicity of SML, it attracts and concentrates hydrophobic particles and lipophilic chemicals such as microplastics and black carbon particles, chemicals such as flame retardants, pesticides, antifouling agents, chelated heavy metals, and petroleum polycyclic aromatic hydrocarbons (PAHs). What these particles and chemicals have in common is that they are hydrophobic. Therefore, microplastic, black carbon and water-insoluble lipophilic chemicals are concentrated in this surface layer of the ocean. Although carbon is nontoxic, given its hydrophobicity, it will become as toxic as microplastics when it adsorbs and concentrates lipophilic toxic chemicals from the ocean surface [4]. Fig. 4 shows the contents of 100ml of Equatorial Atlantic Ocean surface water taken 1000nm from land. Note the high concentration of black carbon particles.

Particles and chemicals are 500 times more concentrated in the SML compared to concentrations occurring in the underlying water column [12]. The concentration of the chemicals will be even higher on the surface of hydrophobic particles (microplastic and black carbon) within the SML layer. These particles are toxic to all plankton and will have serious consequences when eaten by zooplankton [13-17].

The SML layer is responsible for aerosol development and nucleation of water vapour to form clouds. Lipophilic chemicals and particles in the SML layer will be part of the aerosol and cloud formation. The consequences are that lipophilic chemicals and hydrophobic floating particles discharged into the ocean will return as rainwater to the land, spreading the pollution to all regions subject to precipitation. It was considered that plastic would eventually sink to the abyss, this will certainly be the case for hard plastic such as PVC and ABS, but the lighter thermal plastics may return to land as microplastics in rainwater.

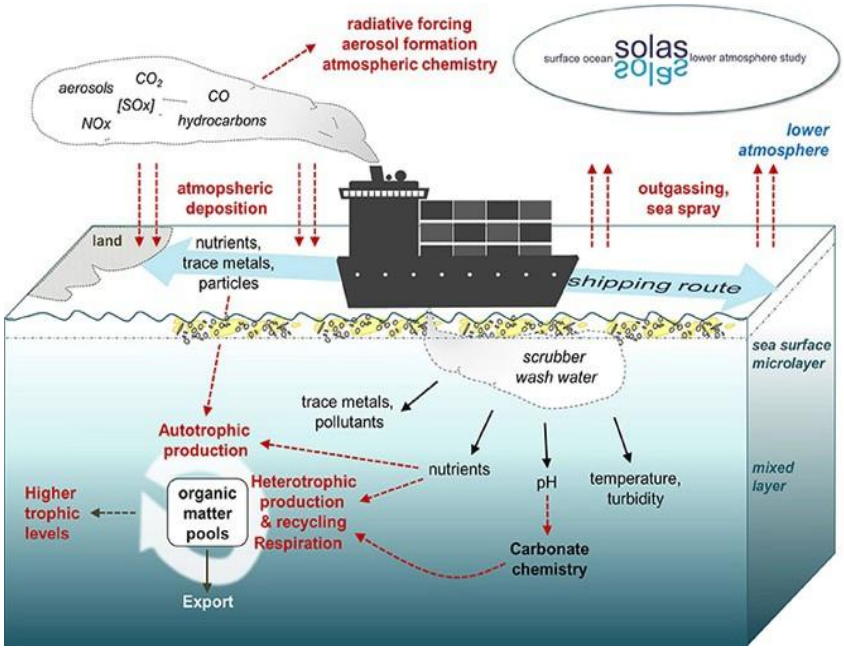


Fig. 5. The shipping industry contributed up to 20% of the world's pollution. Ref 20

Fig. 6. Taken by GOES team approximately 50km West of Finisterre Northern Spain

80% of the world does not have municipal or industrial wastewater treatment. The pollution will therefore return to impact on drinking water quality, agriculture, all animal and terrestrial ecology as well as the soil biome. The solution to pollution is not dilution in the oceans for lipophilic chemicals, plastic, or partially combusted components from the burning of fossil fuels.

2. GOES SURVEY OF EQUATORIAL ATLANTIC

There have been very few surface-water oceanographic surveys in the middle of oceans for 20um+ marine plankton and particles. Most oceanographic surveys, when they are conducted take water samples from 5m to 200m below the surface, yet the critical layer, and layer which contains most of the particles, and toxic chemicals is the surface of the ocean. The amount of data for this layer is seriously limited.

A quantitative survey of the Equatorial Atlantic Ocean at approximately 15 deg North for particles larger 20um included plankton, microplastics and Black Carbon (BC) in surface water was conducted by the GOES citizen science project.

Fig. 7. GOES plankton sampler

2.1 Method

Plankton nets are typically used for collecting plankton and micro-plastic samples, or water samples are collected and filtered under vacuum though filter paper. The GOES citizen science project team developed a technique that was quantitative, repeatable, and safe to use onboard sailing vessels. It was also essential that a sample could be taken by one person without a requirement to slow down the velocity of the vessel.

The filter was constructed out of readily available materials comprising of a 50mm diameter PVC clear plastic 560mm long tube connected to a socket union Figs. 7 and 8. The socket union was used to hold an acrylic plate cartridge with 5 x 5mm holes and hole alignment notch located on either side of the plate.

A 40mm to 50mm filter paper was sandwiched between the acrylic plates Fig. 9. Filter paper was Whatman type 4 with a nominal filtration level of 15um. The filter was connected to 3meters of stainless-steel wire which was used to launch and retrieve a water sample off the back or side of the vessel.

With a filter paper inserted, the whole assembly is cast out of the back of the sailing vessel, and flushed three times with seawater. On the fourth cast, the filter chamber is filled with water taken from the surface, and then suspended vertically by the stainless-steel wire. A cap is fitted over the tube to prevent air born plastic particles entering during the filtration stage. The water volume in the chamber is 500ml, the filter is suspended by the stainless-steel wire and allowed to swing with the motion of the sailing vessel.

By gravity the water will pass through the 5 x 5mm holes in the acrylic plate and through 5 x 5mm sections on the filter paper. The average time for the water to pass was 20 minutes, however the filter is left for a period of 4 to 6 hours to make sure that all the water has passed through the plate.

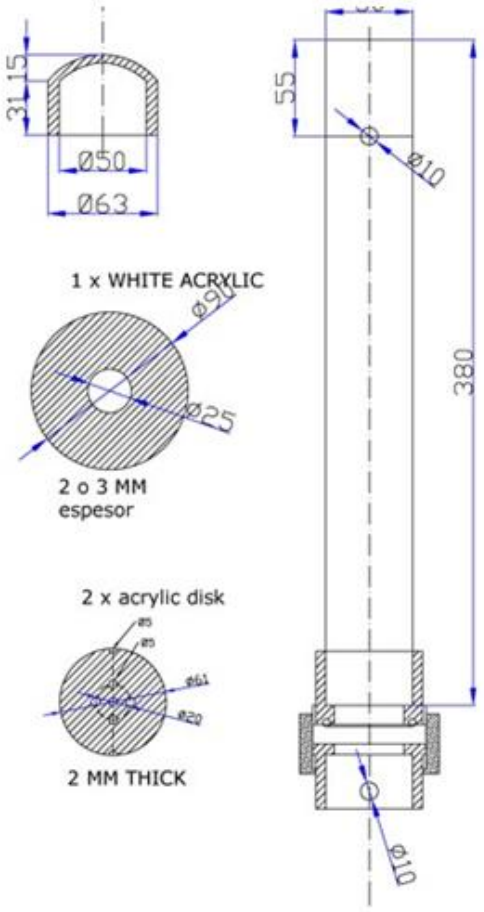


Fig. 8. Design of GOES plankton sampler

Fig. 9. GOES acrylic filter cartridge

Two samples were taken each day, on sample at 6 to 8 hours after sunrise, and a second sample 6 to 8 hours after sunset. The night-time sample was used to detect zooplankton that migrate to the water surface every night. The UTC (Coordinated Universal Time) and GPS position were recorded for the time and location of the sample collection, and if it was a day or night sample.

Once a sample had been filtered the acrylic plate was removed from the filter union and placed under a microscope. Due to space limitations onboard most sailing vessels a simple 5mp USB camera / microscope connected to a computer was used to view the samples and take a photograph.

The microscope is centred on one of the 5mm diameter holes in the acrylic plate. At maximum magnification, the 5mm holes (5000um) fills the field of view. Smallest resolution if 20um, so only particles above 20um can be viewed. Micro-plastic fibres are easily identified at this level of magnification. A photograph is taken of each of the 5mm holes, making 5 photographs per sample of 500ml of water. The method ensures that the whole sample and filter paper is covered Fig. 4.

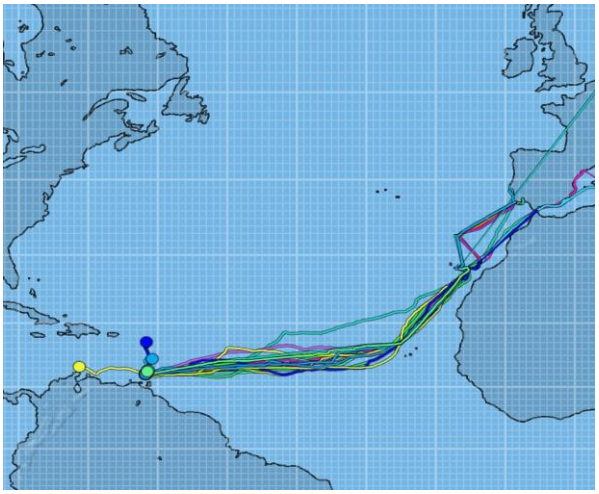


Fig. 10. Passage of 13 sailing vessels, water samples taken every 12 hours

Once the five photographs have been taken, the filter paper is discarded, or kept for further examination and a new filter paper is inserted between the acrylic plates ready for the next sample.

To test the protocol, samples were taken, and then the collected water sample was immediately discarded, the filter paper was examined under the microscope and compared against a properly filtered sample. The results confirm that contamination or interference is well below 1%.

For the first run, the sailing vessels started from the Canary Islands, via Cape Verde and then across the Atlantic Ocean to Port Louis in Grenada. 500 samples were collected, and 2500 images generated from the initial survey across the equatorial Atlantic Ocean at approx. 15 deg North. Fig. 4 is an example of the photographs generated from the survey.

2.2 Results

A more detailed analysis of the data is being conducted and will appear in a subsequent report. The following is a summary of our findings [18];

- 1 to 10 particles of microplastic fibre were found in water samples up 300 nautical miles (nm) from land. Microplastic particles could not be measured by the method, concentrations of particles are expected to be higher than the concentration of fibres.
- 100 to 1000 particles per litre of black carbon were found in all surface water across the Atlantic Ocean, we had only expected to find 10 to 20 per litre.
- Phytoplankton and zooplankton larger than 20 µm concentrations were less than 1 in 20 litres, concentrations down by more than 90% from expected values.

3. SOURCES OF MARINE POLLUTION AND THEIR IMPLICATIONS

80% of marine pollution starts on land from untreated municipal wastewater, industrial water, landfill sites, illegally dumped waste, agricultural run-off including herbicides and pesticides, deforestation, habitat destruction. Atmospheric industrial and domestic pollution will also end up in the oceans, from the burning of fossil fuels, generation of particulate carbon loaded with heavy metals and hydrocarbons. Particulate pollution also enters the oceans from the burning of trees and vegetation, while it may initially result in a bloom of phytoplankton, there are long-term consequences to the destabilisation of the ecosystems.

Direct marine pollution from the maritime industry, especially the shipping industry are responsible for 20% of the worlds pollution, but this is set to increase, perhaps catastrophically with the introduction of deep-sea mining. Currently the shipping industry burn 300 million tonnes per annum of bunker fuels oil.

The pollution contributes to greenhouse gases carbon dioxide and methane which account for 25% of all greenhouse gases. Water vapour accounts for 75% of all greenhouse gases. The lipophilic chemicals and hydrophobic particles of plastic and black carbon have a direct impact on atmospheric water vapour pressure, and marine biodiversity. The loss of marine biodiversity degrades the SML which causes a further increase in the rate of water vapour diffusion though the ocean surface water:air interface to cause further climate disruption.

3.1 Black Carbon

Polycyclic aromatic hydrocarbons (PAHs) are concentrated in the SML layer [19] from the shipping industry, and given that the transit route taken by the GOES Project vessel Fig. 10 was close to the International shipping lanes, it seems reasonable to conclude that the source of some of the black carbon particulate matter observed could be from combustion of bunker fuel oil.

Combustion of bunker fuel oil results in the production of 1.7 million tonnes per annum of sub 10 µm (PM10) particles of heavy metals and PAHs laden black carbon. According to the IPCC [20], PM2.5 black carbon can account for up to 8% of all GHGs [21], and PM10 particles were not included in their report.

Burning fossil fuels on land, including trees and vegetation, are examples of some of the other sources of particulate pollution. Carbon and other hydrophobic particulates including plastic will tend to concentrate in the top 1 mm of the ocean surface, where it will impact on the integrity of the SML layer. Lipophilic toxic chemicals can concentrate by factors of a thousand to over a million times on the surface of these particles. Marine lipids are adsorbed onto particles [22,23], meaning that the higher the concentration of particles, the lower the concentration of lipids in

the surface waters. Therefore, particulate pollution may directly influence the SML, which, in turn, could increase evaporation to the atmosphere from the ocean's surface.

Bacteria and organisms living in the SML biofilm layer also play a critical role in the structural stability of the surface biofilm SML. Given that lipophilic toxic chemicals concentrate in the layer, it is likely that they will have a toxicological impact on the biota with possibly profound implications for the structural integrity of the SML.

3.2 Microplastic

Since the 1950's the annual production of plastics has increased nearly 230-fold to 460 million tonnes in 2019 [24]. 11%, of plastic waste generated globally in 2016 entered aquatic ecosystems [25]. The global amount of Mismanaged Plastic Waste is estimated to be between 60 and 99 million metric tonnes in 2015. In a business-as-usual scenario, this figure could triple to 155–265 Mt per year by 2060 [26]. Most of the plastic is riverine, models based on the concept of mismanaged plastic waste (MPW) have been shown to be substantially greater than reported field measurements [27]

Not only is the plastic an issue for food security, food safety and human health [28], plastic leachates impair growth and oxygen production in Prochlorococcus, the ocean's most abundant photosynthetic bacteria [13] responsible for 20% to 30% of our oxygen, which means it is also impacting on the ability of marine plankton to sequester carbon dioxide.

Atmospheric transport is a major pathway of microplastics to remote regions, and one of the consequences is that plastic is now being found in Arctic snow at 14 particles per kg [29-31]. Plastic can also transport pathogenic bacteria [32], it has found to be capable of selectively incubating species such as Vibrio that are both human bacterium pathogens (Vibrio cholera) and marine pathogens of the same genus. With regards to marine ecosystems, the combined mass of just the three most-littered plastics (polyethylene, polypropylene, and polystyrene) of 32–651 µm size-class suspended in the top 200 m of the Atlantic Ocean is 11.6–21.1 Million Tonnes [33]. Most of this plastic will be in the top layers and will become toxic food for coral and zooplankton as well as phytoplankton and protist.

If the plankton survive the plastic then it will be carried up the food chain trophic layers to marine top predators [34], large fish such as tuna, sharks, whales, seals, birds and eventually back to humans. Marine plastic such as polyethylene is shredded by marine life in to millions of plastic particles [35]. this increases its ability to adsorb and accumulate chemicals such as PCBs [36] and other lipophilic chemicals [37,38].

Plastic is a global concern and a threat to human health, wellbeing, and our food supply as well as major threat to all of nature, and marine life. We do not have a full understanding and a mass-imbalance between the plastic litter supplied to and observed in the ocean currently suggests a missing sink [39]. One aspect that has not yet been considered is the atmospheric dispersal of plastic back to terrestrial systems, carried in water aerosols and deposited as rainwater. Precipitation disperses the plastic particles everywhere, and many will become trapped in the soil where it will impact on the soil biome [40].

Plastic is fragmented into microplastic, it becomes trapped in the ocean's surface layers where it adsorbs and concentrates lipophilic chemicals. The plastic impacts directly on the SML layer, it is also toxic to the plankton and the entire marine food chain, especially when it is combined with toxic lipophilic chemicals. The plastic and toxic chemical will then be dispersed by aerosols and returned back to land to contaminated water supplies, agriculture, all plants, and animals. There is no escape from the toxic effects of plastic unless we stop mismanaged waste plastic from being discharged to the environment.

3.3 Lipophilic Chemicals

It is worth noting that the Lancet 2017 [72] stated that 14000 new chemicals and pesticides have been synthesized since 1950. Of these materials, the 5000 that are produced in greatest volume have become widely dispersed in the environment and are responsible for nearly universal human exposure.

Pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide—three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from

all wars and other forms of violence. In the most severely affected countries, pollution-related disease is responsible for more than one death in four [42,41,72].

Lipophilic toxic chemicals will float on the ocean surface top 1000um layer, if mixed aggressively then they may form an emulsion and will be dispersed in the water column, but predominantly they will be on the surface where the concentrations are 500 times higher than in the lower water layers.

Hydrophobic particles of will tend to selectively adsorb lipophilic chemicals, and many of these particles such as most of the thermal plastics and carbon from the incomplete combustion of fossil fuels will also sit in the top 1000um layer of water. The particles will concentrate the chemicals like a sponge by many thousand or even millions of times. For lipophilic chemicals in combination with hydrophobic particles, dilution, and dispersal as a means of disposal in freshwater and the oceans does not work. The toxic chemicals will be made available to all marine life, and after a few days or weeks, may return back to land in rainfall. Chemicals such as PFAS now exceeds safe levels in drinking water, rainwater and soil biome everywhere [43].

4. CLOUDS AND AEROSOLS

The SML covers 100% of the oceans and thus 71% of the Earth's surface [44]. The SML influences not only sea–air gas transfer but also aerosol–cloud dynamics [45]. The higher the concentration of lipids and surfactants in the SML, especially long chain lipids greater than c-15, the more likely they are to form aerosols, and for the SML membrane to reduce the evaporation of water molecules.

Lipids and other polymers in the SML layer are involved in the generation of climatically active aerosols and cloud formation [46]. The transfer of greenhouse gases and aerosols, organic and sea salt aerosols SSA Fig 11, heat, and water vapor are all defined by gradients in tension at the sea-air boundary [47,48], the importance of which is only now being recognized [49].

Magnesium (Mg^{2+}) and calcium (Ca^{2+}) can enhance organic species in the SML, which has implications for increasing the layer's structural stability, surface packing of organic molecules and subsequent interfacial reactivity [50]. However, the seawater chemistry has changed over the last 70 million years, with Ca^{2+} decreasing from 1200 mg/l to 400 mg/l and Mg2+ increasing [54]. Historical data is often used in climate change modelling, given the importance of ocean-induced cloud formation and water vapor concentration, the models should factor in seawater chemistry and its influence on the SML because the historical data is no longer applicable for the modelling due to a change in water chemistry and SML structure.

Cloud formation and atmospheric water vapor concentration are controlled by the oceans and regulated by the SML, which is maintained by marine plankton and primary productivity. Any parameter that has a negative impact on marine plankton and the SML will have an impact on the climate, cloud formation and aerosol concentration of the atmosphere.

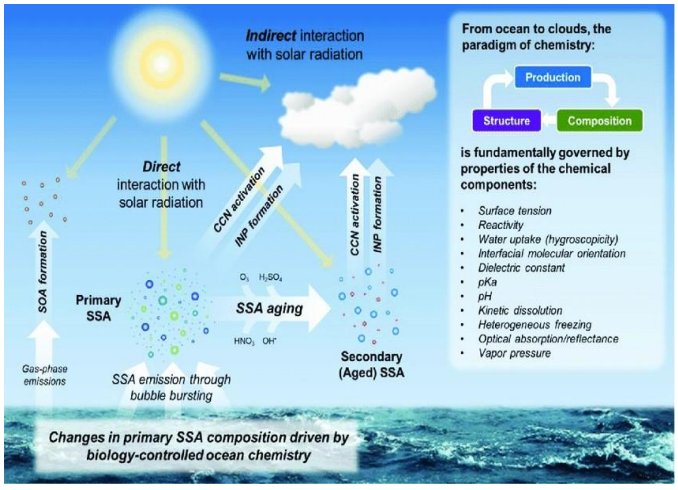


Fig. 11. Surface water evaporation and cloud formation [30]

5. EVAPORATION AND WATER VAPOUR PRESSURE

The oceans are the source of 86% of the global evaporation and the recipient of 78% of global precipitation [55]. Oceanic evaporation is the process by which water molecules change from a liquid phase to a vapour phase at the SML or air–sea interface [56]. Each water molecule that turns into water vapor takes with it a parcel of heat energy, and that energy remains latent until it is released during condensation in cloud formation. If the integrity of the SML is compromised, evaporation will increase the concentration of water vapor, meaning that the main warming GHG will trap more infrared radiation from the sun.

Very little data are available for the diffusion of water molecules through the SML layer, but more information is available for carbon dioxide. In the coastal waters of the North Sea, CO2 exchange was suppressed by 15–24% and by 32% in the Atlantic Ocean [44,57] by the SML layer. Models predict a reduction of 20% to 50% for the global annual net flux of CO2 and, based on Chlorophyll (a) as a proxy for surfactant coverage. In a wind-wave tank experiment, considerable suppression of the CO_2 flux rate ranging from 46% to 63% and up to a wind speed of 8.5 m sec–1 was measured [58].

The evaporation rate is a function of air and water temperature, relative humidity and wind velocity over the water surface [56]. It will also depend upon the surface water lipid layer. Lipid mono layers have been used to reduce evaporation from freshwater lakes by up to 40% [59]. We know that the rate of aerosol formation is controlled by the surface microlayer; this research suggests that the rate of evaporation may also be controlled by the integrity of the SML.

Water evaporation rates have been recorded since 1958, the data in Fig 12 show a decline to 1977–78 and thereafter an upward trend to 2005, which was the end of the study [56]. The period since 1978 has also been marked by a change in climate worldwide [60,61]. The Arctic has also warmed four times faster since 1979, as published in a recent paper in Nature [62]. The physical mechanisms behind the underestimation in climate models remain unknown, but one explanation was the possible reductions in Asian aerosols. Fig. 12 reflects the humidity increase and Fig. 13 and shows the reduction in cloud cover at the same time from 1980 to 2020. The reduction in cloud cover could be attributed to the reduction in aerosol concentration caused by a diminished SML layer.

6. ECOSYSTEM REGIME SHIFT AND THE COLLAPSE OF THE SML

If it was climate change affecting the concentration of water vapor in the atmosphere, one would expect the graph to closely follow the same pattern as carbon dioxide emission and GHG concentration in the atmosphere. The graph Fig. 12 shows a very clear transition on a global scale of decreasing and then increasing water vapor emissions. This cannot be an

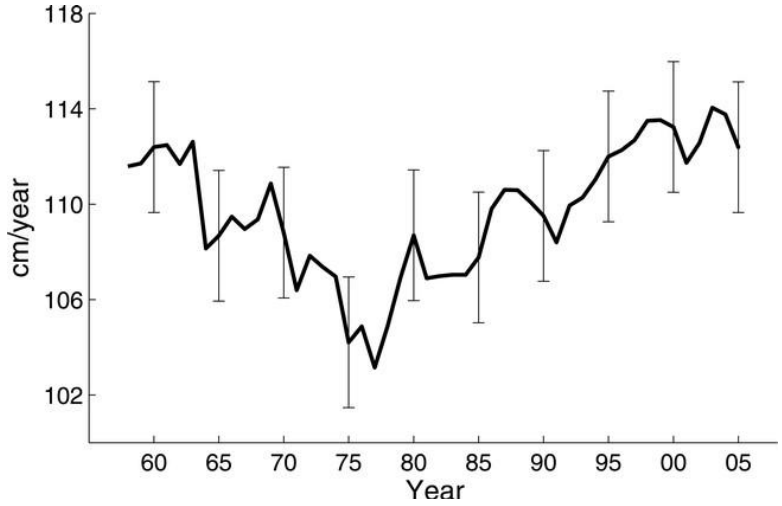


Fig. 12. Global water evaporation from ref 35

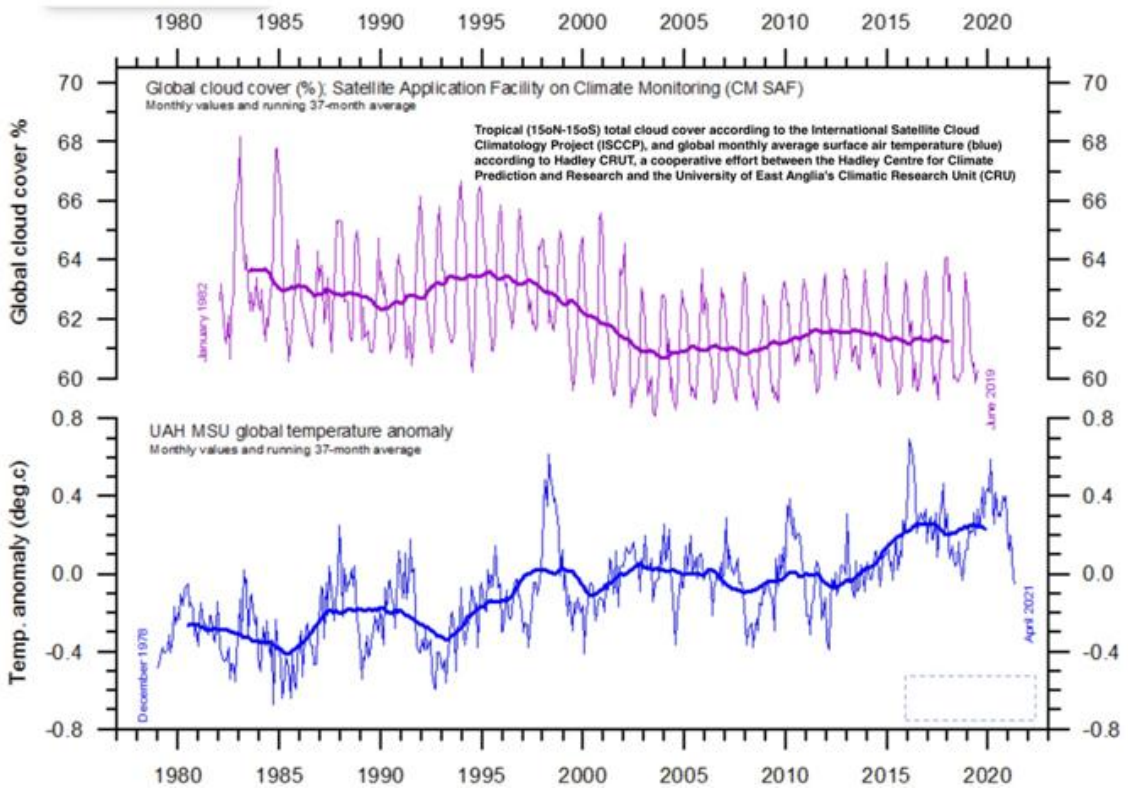


Fig. 13. Cloud cover and humidity between 15 deg north and 15 deg south

atmospheric temperature change due to the enormous inertia of ocean water to a temperature change. This suggests that the SML layer started to fail and changed the rate of water evaporation. This could occur if there was a change in marine plankton, and the most obvious explanation is chemical and particle pollution. It is also conceivable that a chemical or group of chemicals is destroying the SML layer directly; we see parallels with CFCs and the ozone layer.

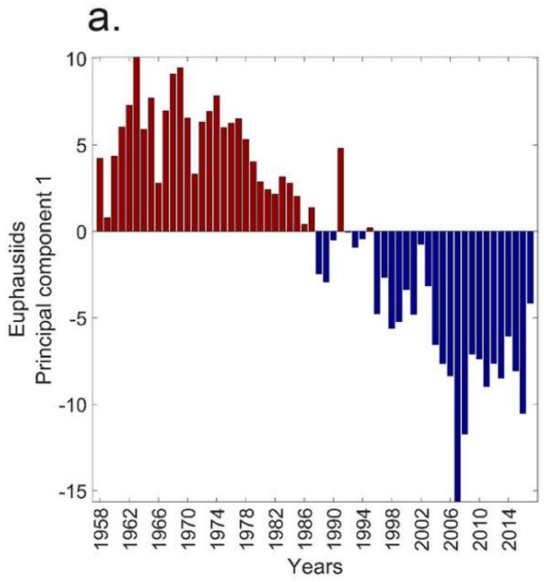


Fig. 14. First principal component time-series (PCTS) of euphausiids for the North Atlantic, ref 42

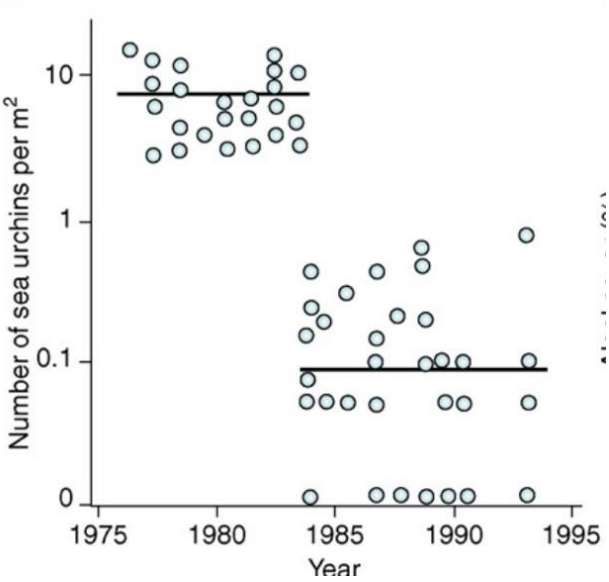


Fig. 15. The Caribbean coral regime shift illustrated by changes on Jamaican reefs, ref 45

Nutrients, chemicals, and plastic concentrations have increased at an accelerating rate since the 1950s. Initially, pollution concentrations from the Chemical Revolution would have been low with minimal impact on the plankton, but nutrients would have a more immediate effect and would have increased plankton growth and developed the SML to reduce evaporation. The increased growth and development of the SML would have progressed to the point when pollution from plastic, black carbon, and bioaccumulating toxic for ever lipophilic chemicals outweighed the benefits of eutrophication, at which point the system shifted to a declining SML layer and increase in water evaporation. A toxic chemical and substance tipping point on marine biodiversity that initiated climate disruption starting in 1978.

Euphausiids (krill) are found in the world's oceans, especially at high latitudes. They are an extremely important part of the marine ecosystem and have a mass equivalent to all humanity but have declined by 50%, as detailed in a 60-year study [63] (Fig. 14). The reason was attributed to climate change and decadal rhythms. In addition, reports of marine life crashes and regime shifts around the same time in the Pacific [64,65]. In Jamaica and Caribbean, most corals declined by more than 50 percent in the late 1970s to less than 5 percent [66] (Fig. 15). More data are required, but there appears to be a total change all over the world at the same time during the late 1970s to marine life, the climate and water vapor pressure.

The events have been related to the Pacific Decadal Oscillation PDO. The cause of the changes in the PDO has not yet been identified, and it may even be due to a combination of factors, including long-lasting fingerprints of El Niño and La Niña events in the tropical Pacific Ocean, changes in atmospheric pressure in the northern Pacific, the impact of industrial pollution, and natural variability. This important phenomenon continues to be a subject of ongoing research [67].

Measurements of evaporation over land show a decreasing trend since the 1980s, even though air temperature has increased [68]. It is therefore only the oceans that contribute to the increase in atmospheric humidity [56].

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimates that approximately 77% of the land and 87% of the ocean have been altered by humans, which has led to a loss of 83% of wild mammal biomass and 50% of the world's plant biomass. IPBES also suggests that more than a million plant and animal species are currently threatened with extinction, potentially putting us on a path to what has been dubbed Earth's sixth mass extinction [69]. A report published in Nature gives us a less than a 10% chance as the most optimistic estimate to survive without facing a catastrophic environmental collapse [70,71].

Given that we have lost at least 50% of terrestrial plants and the water transpiration from the

plants, this would explain why the water vapor concentration is going down from terrestrial sources. The loss of marine plants and animals explains the increase in evaporation and vapor concentration in the world's atmosphere.

With water vapor representing 75% of all GHGs, the oceans have been responsible for 86% of the total and 100% of the increase in water vapor pressure since 1978. The oceans, and the anthropogenic impact on the oceans would appear to be a primary factor driving climate change.

7. PLANKTON PRODUCTIVITY AND OCEAN ACIDIFICATION

Diatoms and coccolithophores produce most of the marine lipids and surfactants that make up the SML and are also the most sensitive to ocean acidification and climate change. Anthropogenic carbon dioxide production has led to ocean acidification. Carbon dioxide dissolves in the surface water of the ocean, and carbonic acid is formed, which causes the ocean's pH to drop.

In the 1940s, oceanic pH was 8.17; today, it is pH8.03, and by 2045, according to the International Panel on Climate Change (IPCC), representative control pathway (RCP) 8.5 (business as usual), oceanic pH will be 7.95 by 2045 [73,74] (Fig 16).

Life forms such as coccolithophores, coral reefs and all ocean organisms composed of magnesium calcite and aragonite start to dissolve at pH 8.04, and the process is essentially completed at pH 7.95. This process has already begun, and some organisms may survive this stressor or evolve to cope with lower pH values and warmer seas, but their reproduction will be seriously compromised, and they will be stressed and predisposed to infection and elevated temperatures. We also know that silica-based diatoms are very sensitive to lower pH [75].

Plankton productivity has also declined since the 1950s [76-80], and many species are threatened with extinction [81]. The GOES Project team compiled an ocean acidification and productivity graph (Fig. 17) [71].

The GOES Project graph parallels the work of respected non- governmental bodies (NGOs), such as the International Pollutant Elimination Network (IPEN), whose pyramid graph [82] in Fig. 18, and the IIASA-led study bio-curve of terrestrial ecology Fig. 19 [83] is provided here by way of illustration. All indicators point to a catastrophic decline in both terrestrial and marine life over the next 25 years and reflect the looming 6th mass extinction, as discussed in the IPCC report.[69]

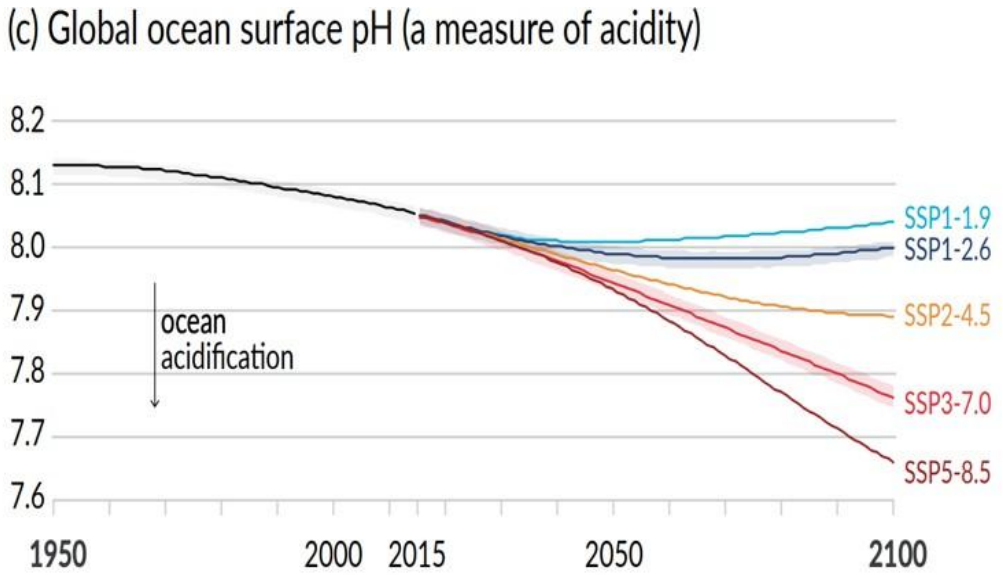


Fig. 16. Oceanic pH, from IPCC [52]

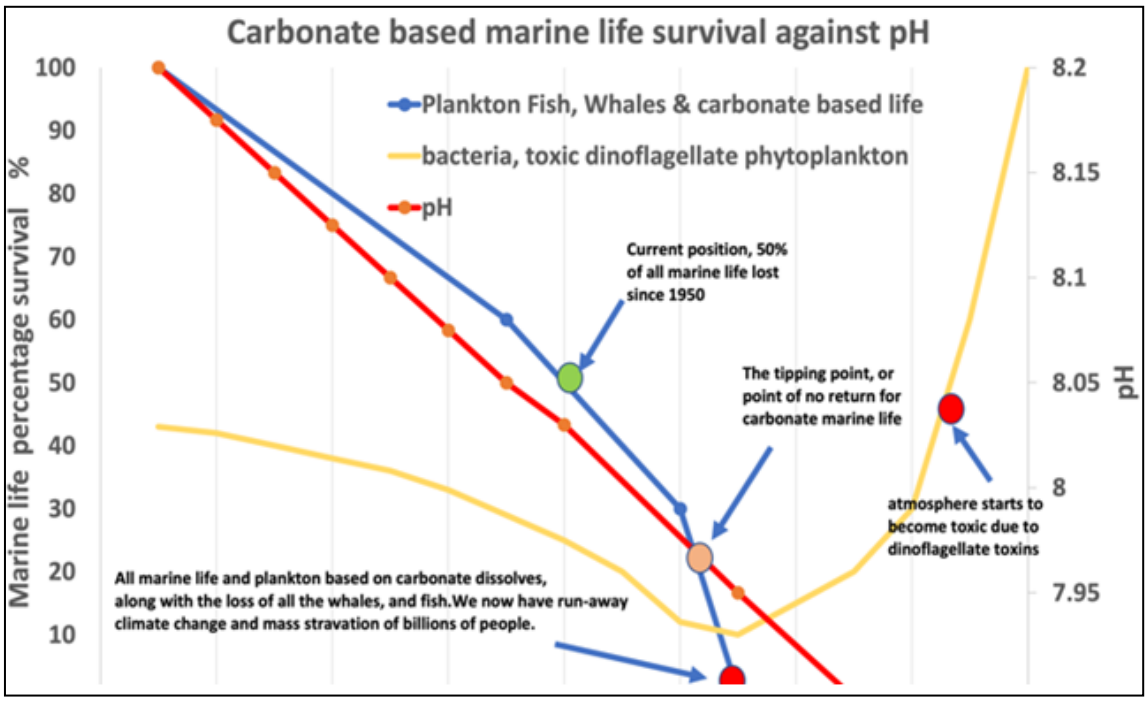
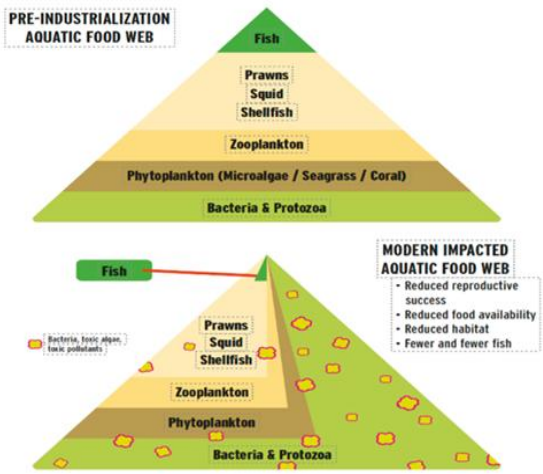


Fig. 17. Oceanic pH in relation to marine life
Source: GOES Foundation –Ref 52

8. CARBON DIOXIDE AND MARINE BIODIVERSITY

There is a high degree of certainty that anthropogenic carbon dioxide is causing a decrease in ocean pH, and the consequences include the dissolution of marine life forms that play a key role in sequestering carbon dioxide, which is locked up in the abyss (deep ocean 3,000m to 6,000m). Most of the Abyss, an area equivalent to the world's dry land area, is covered by 1000 m of organic matter and sediment [84], constituting the world's main carbon bank, where all carbon is eventually deposited.



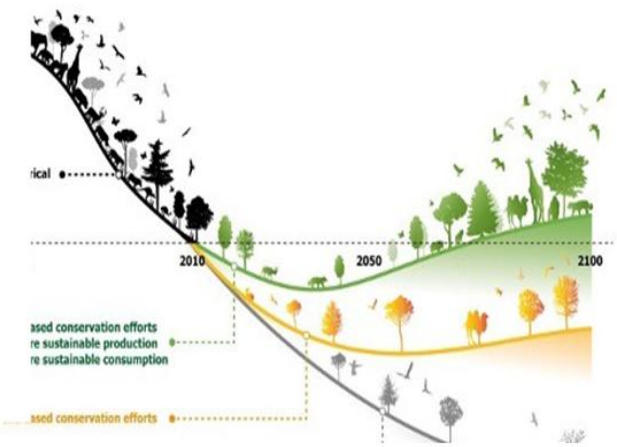


Fig. 18. (Left): Pyramid graphic of marine life (what is the IPEN ref 62)
Fig. 19. (Right): The terrestrial bending the curve ref 63

The decline in marine phytoplankton will accelerate the process of ocean acidification and, with a very high degree of certainty, will cause a regime shift (to bacteria, protozoa, dinoflagellate algae and jellyfish) in the oceans that could lead to the loss of all seals, birds, whales, fish, and food supply for 3 billion people. This represents an existential threat to humanity, and every effort to reduce carbon dioxide emissions must be accompanied by all efforts to bring toxic chemicals, plastic and black carbon particle emissions to zero [85].

The loss of carbonate- and pH-sensitive phytoplankton and zooplankton will also decrease the SML microlayer, leading to increased water evaporation and decreased aerosol formation. The consequences will be an acceleration of water vapor as a GHG and a decrease in cloud formation. The atmosphere will become warmer and more humid, but cloud formation and precipitation will be reduced. Particulate matter from seawater spray, from land, pollution and organic matter from trees may still be able to nucleate clouds. However, when clouds form, due to the higher water vapor concentration, precipitation will be higher, leading to torrential rain and floods.

As energy transfer to the atmosphere increases, wind speeds are expected to increase, which will increase evaporation, which will in turn increase wind speed. This is another self-reinforcing loop that will lead to more frequent and stronger hurricanes. Stronger winds and torrential downpours can be expected to occur next to seas that already have low pH and primary productivity, for example, countries surrounding the Mediterranean Sea, especially Italy and Greece will be subject to adverse weather conditions.

Given that the SML covers the surface of the ocean and 71% of planet Earth [86,87] has not been accounted for in climate change modelling, would seem to be an oversight that needs attention. The National Oceanic and Atmospheric Administration (NOAA) states that 50% to 80% of our oxygen is produced by marine phytoplankton [88], which also means that 50% to 80% of our carbon dioxide is sequestered by plankton. The Lancet [72] states that pollution, climate change, and biodiversity loss are closely linked and that 80% of the world's wastewater is discharged untreated.

Oceans are responsible for more than 80% of climate change, indirectly due to carbon dioxide emissions and black carbon soot from the burning of fossil fuels. Equally important are toxic lipophilic chemicals and plastic pollution, but the oceans have been neglected and used as a dumping ground for all human waste.

9. CONCLUSION

Humanity faces multiple existential threats, and carbon dioxide emissions must be reduced as a matter of extreme urgency. We must also eliminate the discharge of black carbon, toxic-forever lipophilic chemicals, and plastic into the environment. The marine ecosystem has enormous resilience, but only if we stop the pollution and ecosystem destruction now and achieve a toxic free world by 2030.

Failure to act now to reduce carbon dioxide emissions and eliminate pollution will result in the loss of the SML layer, which will cause higher atmospheric humidity and reduced cloud formation. The consequences will be higher temperatures, torrential rainstorms, and more frequent and stronger winds, even if we achieve net zero for carbon by 2050.

Failure to act now will result in ocean acidification and pH 7.95 by 2045, which will cause the loss of coral reef coastal defences and global starvation attributed to the loss of most fish and marine life. A regime shift with the loss of carbonate phytoplankton and declining diatom productivity will collapse the SML layer, leading to potentially uncontrollable runaway climate disruption. Carbon mitigation is not going to stop Ocean acidification, and it will not stop catastrophic climate change caused by the loss of marine biodiversity and the SML

Planktonic marine life is the lungs and life support system for the planet; they can double in mass in just 3 days as soon as we take the toxic brakes off and transition to a nontoxic, carbon net zero world by 2030. The take-away from this report is that if we regenerate marine life, there is the potential to stop climate disruption and make the world a better place.

10. RECOMMENDATIONS

We must continue with carbon mitigation, but as a matter of urgency, we must eliminate the dumping of all toxic forever lipophilic chemicals, as well as plastic and black carbon soot, into the

environment. All wastewaters must be treated, we must not pollute our environment, we must DO NO HARM to nature on land and to marine life in the Oceans. We must start doing some GOOD and transition from destructive farming and unsustainable fishing practices to rewilding and regenerate ecosystems on land and in the oceans. We should also give serious consideration to changing sea water chemistry by increasing calcium and alkalinity concentrations, which we consider to be a no-risk strategy..

ADDITIONAL INFORMATION

GOES is a citizen Science project, our thanks are extended to all the participating sailing vessels that have donated their time, energy and risked their lives to sample the ocean surface to collect the data presented in this report. Some of the participating vessels may be viewed on the Automated Identification System (AIS) at the following link. https://www.goesfoundation.com/news/posts/2020/december/goes-foundation-fleet-of-yachts/
The GOES sailing vessel is s/v Copepod https://my.yb.tl/Copepod

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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