Published in final edited form as:
Biotechnol Adv. 2011 ; 29(4): 388–390. doi:10.1016/j.biotechadv.2011.02.003.

Omega-3: A Link between Global Climate Change and Human Health

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Abstract

In recent years, global climate change has been shown to detrimentally affect many biological and environmental factors, including those of marine ecosystems. In particular, global climate change has been linked to an increase in atmospheric carbon dioxide, UV irradiation, and ocean temperatures, resulting in decreased marine phytoplankton growth and reduced synthesis of omega-3 polyunsaturated fatty acids (PUFAs). Marine phytoplankton are the primary producers of omega-3 PUFAs, which are essential nutrients for normal human growth and development and have many beneficial effects on human health. Thus, these detrimental effects of climate change on the oceans may reduce the availability of omega-3 PUFAs in our diets, exacerbating the modern deficiency of omega-3 PUFAs and imbalance of the tissue omega-6/omega-3 PUFA ratio, which have been associated with an increased risk for cardiovascular disease, cancer, diabetes, and neurodegenerative disease. This article provides new insight into the relationship between global climate change and human health by identifying omega-3 PUFA availability as a potentially important link, and proposes a biotechnological strategy for addressing the potential shortage of omega-3 PUFAs in human diets resulting from global climate change.

Keywords

global climate change; phytoplankton; photosynthesis; omega-3 polyunsaturated fatty acids; omega-6/omega-3 ratio; ocean sustainability; human nutrition; public health; human diseases; biotechnology

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Global climate change is currently a hot topic of discussion due to its allegedly detrimental impacts on the environment, society, and human health. The consequences of global climate change are already visible in worldwide shifts in temperature and an increase in atmospheric greenhouse gases, such as methane and carbon dioxide. These increased atmospheric concentrations of greenhouse gases have been associated with stratospheric cooling and thus exacerbate the depletion of the stratospheric ozone layer, promoting further ultraviolet (UV) irradiation (Keller 2007, Shindell 1998). At the same time, we have witnessed a rise in the prevalence of life-threatening human diseases such as heart disease, cancer, diabetes, and Alzheimer's disease, contributing to mounting healthcare burdens (World Health Organization 2008). Could there be a relationship between these two crises? Scientists are

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exploring a number of possible connections, including changes in ultraviolet radiation, air pollution, and agricultural productivity (Leaf 1989; McMichael et al. 2003; Epstein 2005). Here, I identify a potentially important link between global warming and human health that merits further investigation: the availability of omega-3 polyunsaturated fatty acids (PUFAs) (Figure 1).

Omega-3 PUFAs are a family of unsaturated fatty acids that appear as a chain of carbon and hydrogen atoms containing up to six carbon-carbon double bonds; the first double bond occurs on the 3^{rd} carbon atom from the methyl end of the fatty acid (thus, the name omega-3). Omega-3 PUFAs are essential nutrients for normal human growth and development; they cannot be *de novo* synthesized by the human body, so we must rely on dietary means to acquire them. These fatty acids can modulate physiological and pathological conditions through multiple mechanisms, such as the inflammatory response (Kang and Weylandt 2008), and have received great attention in recent years for their critical role in disease prevention and management (Gebauer *et al.* 2006). Recent research shows that adequate levels of long-chain omega-3 PUFAs—especially those found in fish or fish oils, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)—optimize health and prevent disease (Kang 2005). Today, many foods common to the Western diet are deficient in omega-3 but abundant in omega-6 PUFAs, resulting in a very high omega-6/ omega-3 ratio. Such an unbalanced ratio is thought to be associated with the modern prevalence of cardiovascular disease, cancer, diabetes, and neurodegenerative diseases, all of which affect millions worldwide (Simopoulos and Cleland 2003). Emerging evidence indicates that dietary supplementation with omega-3 PUFAs can reduce the risk of these diseases (Wang 2006). Consequently, government and scientific organizations now recommend an increased dietary intake of omega-3 PUFAs (Gebauer *et al.* 2006). The availability of omega-3 PUFAs in our diet is evidently crucial for human health.

The primary source of omega-3 PUFAs in the human diet are marine products. Specifically, marine phytoplankton and other single-cell algae are the main producers of omega-3 PUFAs, particularly EPA and DHA, and represent the basis of the food web for all aquatic creatures (Randall *et al.* 1990). Humans obtain omega-3 PUFAs through multiple levels of this food web: microalgae, which are directly used for food products or as animal feed; fish, which consume phytoplankton directly or eat other animals that feed on phytoplankton; and livestock, which are fed meal produced from various organisms in the food web (Borokowitz 1997). In essence, phytoplankton are the origin of the majority of our omega-3 PUFAs.

While land plants such as flaxseed are a good source of another omega-3 PUFA, alpha-linolenic acid (ALA), a very low metabolic conversion (<5%) of ALA to EPA and DHA makes land sources insufficient for meeting our dietary needs, as these three types of omega-3 PUFAs have distinct biological functions with EPA and DHA being more beneficial (Anderson and Ma 2009). Marine phytoplankton, due to their fatty acid composition of relatively large amounts of EPA and DHA, are thus particularly valuable in maintaining the availability of the important omega-3 PUFAs in our diet. However, phytoplankton are very vulnerable to climatic and environmental changes.

Global climate change could significantly affect the overall availability of long-chain omega-3 PUFAs in two ways: 1) by decreasing overall phytoplankton biomass and rate of growth, and 2) by reducing the algal content of PUFAs, due to a decrease in PUFA synthesis or the destruction of already synthesized PUFAs.

The overall state of the marine phytoplankton population is susceptible to several consequences of global climate change. The reduction of the stratospheric ozone layer, heightened by the growing atmospheric concentrations of greenhouse gases, has resulted in an increase of ultraviolet-B irradiation (UVB, 280–320 nm) (Shindell 1998, Smith 1992), to which marine phytoplankton are highly sensitive as their smaller surface area renders them less effective at screening and protection than other marine organisms (Karentz 1994). UVB irradiation detrimentally affects phytoplankton by inhibiting photosynthesis and damaging DNA, thus reducing phytoplankton biomass production. Different studies (using various conditions of irradiance, exposure periods, and chosen species of phytoplankton) have reported varying results on the potential reduction of PUFA content of phytoplankton by UV irradiation, but it is clear that UV irradiation considerably decreases overall phytoplankton growth (Smith 1992, Skerratt et al 1998, Leu et al 2007). The predicted rise in ocean surface temperature as a result of global climate change may also cause ocean stratification, which could separate the sunlight-dependent phytoplankton from their essential nutrients, including nitrogen, iron, and phosphate, that lie in lower water depths (Behrenfeld et al. 2006). The phytoplankton population would diminish from lack of nutrients, resulting in a more limited diet for phytoplankton consumers in higher waters. Here, then, as the UVB irradiation and rising ocean temperatures induced by global climate change lead to less-nourished marine organisms and a lower yield of phytoplankton, it is clear that the amount of omega-3 PUFAs available to us would drop due to the significant decrease of omega-3 PUFAs in marine food webs.

The synthesis of omega-3 PUFAs in marine phytoplankton could also be notably inhibited by effects of climate change, particularly due to UVB irradiation and increases in atmospheric carbon dioxide. UVB irradiation limits ATP production in phytoplankton cells, and the processes needed to synthesize long-chain omega-3 PUFAs (e.g. elongation and desaturation) are heavily ATP-dependent. Studies have reported that exposure of phytoplankton to UVB irradiation resulted in up to a 50% decrease in PUFA, particularly DHA and EPA, while saturated and monounsaturated fatty acid concentrations were increased (Goes *et al.* 1994, Wang and Chai 1994, Hessen 1997). As DHA and EPA are limiting factors of growth, the availability of omega-3 PUFAs in phytoplankton directly regulates the growth and nutrient content of its many consumers. Therefore, decreased synthesis of DHA and EPA due to limited ATP production would not only negatively impact the omega-3 PUFA content of phytoplankton, but that of its consumers as well.

Increased levels of carbon dioxide due to the emission of greenhouse gases may also affect omega-3 PUFA synthesis. Studies have observed that supplementary carbon dioxide to microalgal cells increased omega-6 and omega-9 fatty acid concentrations (Tsuzuki *et al.* 1990), and decreased omega-3 PUFA content (Carvalho and Malcata 2005). When carbon dioxide levels were reduced, the levels of omega-3 PUFAs increased (Carvalho and Malcata 2005). These results suggest that high levels of carbon dioxide can suppress omega-3 PUFA production in microalgae, a consequence that will be echoed in the nutrient profile of organisms that depend on microalgae for their omega-3 PUFA content. Thus, a significant decrease in omega-3 PUFA synthesis by phytoplankton, due to global climate change, will be heavily reflected in the aquatic ecosystem from which we draw our dietary omega-3 PUFA resources.

The decreased production of PUFAs by phytoplankton in environmental conditions affected by climate change may also reduce the overall amount of marine photosynthesis. The photosynthesis of phytoplankton and other marine organisms account for at least one-half of atmospheric carbon dioxide uptake (Häder et al. 2005), and are therefore critical for the maintenance of marine and land ecosystems. However, photosynthesis in phytoplankton is already inhibited by ozone depletion-induced UVB irradiation (Neale *et al.* 1998). As omega-3 PUFAs are a limiting factor of phytoplankton growth, their reduced presence in phytoplankton as a result of UVB irradiation and increased carbon dioxide would lead to a decrease in the amount of phytoplankton biomass available for photosynthesis, again lowering marine photosynthesis activity. Evidently, there is potential here for a negative feedback cycle of marine photosynthesis that would not only significantly diminish air quality and be deleterious to aquatic and terrestrial organisms, but also further inhibit omega-3 PUFA synthesis.

Omega-3 PUFAs are undeniably significant factors in human health, yet their availability is being threatened by the consequences of global climate change. The foremost issue at hand, of course, is that we make every attempt to counter global climate change and its harmful effects. In the meantime, as we fend off the immediate health repercussions, we must also look to other methods of obtaining our omega-3 PUFA quotient.

To boost the essential fatty acid content of goods such as meat, milk, and eggs, more livestock is being fed with omega-3 PUFA-enriched feed (Gebauer *et al.* 2006). Biotechnology may also provide viable solutions for our nutritional demands. Through genetic engineering, animals and plants could be able to efficiently convert omega-6, which is highly abundant, to omega-3 PUFAs so that they and their byproducts would contain higher omega-3 PUFA concentrations without the need for supplementation (Kang *et al* 2004, Qi *et al.* 2004; Lai *et al.* 2006). These omega-3-rich food products will provide a more accessible land source and reduce our reliance on marine fishing and the aquaculture industry. The output of greenhouse gases would also be diminished, as increased omega-3 PUFA levels have been shown to improve the digestive system of cows and reduce their methane production (Martin *et al.* 2008). Through such innovations, not only would the omega-3 PUFA content in foods from salad to hamburgers be enhanced, but a more sustainable environment could also be maintained.

By establishing an awareness of the possible link between global climate change, omega-3 PUFAs, and human health, further investigation is now warranted in order to more precisely understand this relationship, as well as to develop biotechnologies for addressing the potential shortage of omega-3 PUFAs in human diets resulting from global climate change.

Acknowledgments

This work was partly supported by NIH grant CA113605. I thank Marina Kang for discussing and assisting in the preparation of this manuscript.

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Fig 1.
Flow chart illustrating how omega-3 PUFA relates global climate change and human health. (↑—increase; ↓—decrease)