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Climate Warming Reduces Essential Fatty Acid Production in Algae

ARTS, M.T., HIXSON, S.M., & MERCIECA, S.

Department of Chemistry and Biology, Ryerson University, Toronto, Ontario, Canada

Climate change predictions range from an overall warming of our planet to more subtle, regional, changes in the global distribution of surface air temperatures and rainfall patterns (IPCC 2014). Climate change is also associated with increased ocean salinity and acidity, increasing sea levels, intensification of coastal upwelling, and decreased lake levels. There is an urgent need to understand how life will be affected, at the biochemical level, in our warming world. For example, temperature is expected to have strong directional effects on the quantity and especially on the quality of fatty acids in algae and other microorganisms. The mechanism that explains this is called homeoviscous adaptation (the ability of cells to reduce the degree of unsaturation of membrane fatty acids in order to maintain a desired level of fluidity as temperature increases) (Sinensky 1974).

Algae fix carbon through photosynthesis into a vast array of compounds which are utilized by consumers. One such important class of compounds are essential fatty acids (EFA), compounds that animals cannot produce at all, or produce inefficiently, so they must be supplemented through their diets. Examples include polyunsaturated fatty acids (PUFA) such as, alpha-linolenic acid (ALA; 18:3n-3), linoleic acid (LNA; 18:2n-6), and long-chain polyunsaturated fatty acids (LC-PUFA) such as, eicosapentaenoic acid (EPA; 20:5n-3), docosahexaenoic acid (DHA; 22:6n-3) and arachidonic acid (ARA; 20:4n-6). Freshwater and marine animals ultimately depend, to varying extents, on algae for access to these five EFA. An important, and not fully appreciated, threat posed by climate warming is that increasing water temperatures (through the process of homeoviscous adaptation) will reduce the global production of PUFAs in algae at the base of aquatic food chains. Such profound changes in the biochemical composition of algal cell membranes (Fuschino et al. 2011) are expected to lead to cascading effects throughout the world's aquatic ecosystems. Furthermore, the repercussions of these biochemical and physiological cascades are also anticipated to propagate to land animals because of the flux of aquatic biomass (e.g., insect and amphibian emergence, fish taken by terrestrial predators) that routinely passes from aquatic to terrestrial ecosystems. This is critical because LC-PUFA not only enhance the growth rates and reproductive capacities of aquatic animals (Von Elert 2004; Ballantyne et al. 2003); they also have been shown to be of vital importance to the cardiovascular and neural/cognitive health of terrestrial vertebrates (Lands 2009).

Here we use a meta-analytic, regression-based, approach to examine the main effect of temperature on EFA profiles of green algae, diatoms, flagellates and cyanobacteria. Green algae, as a group, demonstrated a negative relationship between ALA and temperature. At the species level, the green algae *Tetraselmis suecica* and *Chlamydomonas reinhardtii* contained significantly less ALA as temperature increased. Diatoms, as a group, had significantly lower levels of both EPA and DHA as temperature increased. At the species level, *Thalassiosira pseudonana* and *Nitzschia paleacea* had significantly less EPA with increasing temperature, and *Chaetoceros calcitrans* had significantly less DHA with increasing temperature. Both diatoms and green algae generally showed a negative relationship with total PUFA and temperature, specifically the genera *Botryococcus, Chlamydomonas, Chaetoceros,* and *Nizschia*. Conversely, while ALA, EPA, and DHA tended to decrease with increasing temperatures, LNA, ARA and saturated fatty acids tended to increase with increasing temperature. For example, the diatoms *Chaetoceros calcitrans* and *Chaetoceros simplex* had higher levels of LNA as temperature increased. These findings transform our understanding of how climate-driven increases in water temperature may be affecting the production of EFAs in algae which form the base of aquatic food chains and which, in myriad interconnected ways, affect the health and vitality of all organisms.

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