Climate change and the balance of respiration and photosynthesis in shallow lakes

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The granting of the Hugh Carey Gilson award in 2007 allowed us to employ Charlotte Whitham, a recent graduate in Environmental Biology at the University of Liverpool, to coordinate a set of experiments within a larger experiment near Liverpool on climate change. The University has 48 experimental $3m^3$ tanks in which reasonably complete shallow lake ecosystems have been established and during 2005 to 2007 we carried out experiments on the combined influences of warming by 4ºC above ambient, presence of absence of fish (three-spined sticklebacks) and nutrient loading, on a hypertrophic system dominated by submerged aquatic plants. The particular thrust of the work under the award was to determine whether warming would significantly alter the balance of gross photosynthesis and community respiration within the systems. Much of the world's landmass is covered by wetlands and shallow lakes, particularly in the extensive tundra and boreal zones and throughout south-east Asia. Recent work on lakes has suggested that they are sources not sinks for carbon dioxide in that their ecosystems depend on organic matter imported from the terrestrial vegetation of the catchment or surrounding wetlands. There is an immense amount of carbon stored in such systems and were warming to increase respiration rates compared with gross photosynthesis there would be an enhanced release of carbon dioxide and perhaps methane, with the dangers of a positive feedback on warming processes that would rapidly worsen the climate change problem.

With the Gilson Award, we carried out three 24-hour long experiments in which the oxygen concentrations were measured every two-hours in each of sixteen tanks by the laborious but reliable Winkler titration. The tanks were those in which there was no heating and no added nutrients, those heated but unfertilised, those fertilised with a high N to P mixture but not heated and those both heated and fertilised. Each of these four treatments was quadrupally replicated. From these data we calculated, using principles akin to those of the classic light and dark bottle technique for determining production, but using the night time to measure respiration and making allowance for gas exchange with the atmosphere, the community respiration and the gross photosynthesis of the plants and algae in the tanks. The results were very clear-cut. The ratio of community respiration to gross photosynthesis was lower than unity in the high summer of our experiments, suggesting that the tanks were autotrophic during this period but warming increased the ratio by about 15% from around 0.65 in ambient tanks to 0.75 in warmed ones. Added nutrients had no additional effect on the ratio but increased the rates of photosynthesis and respiration. Since a rise of 4º C is reasonably likely later this century, the results have serious implications. By using separate bottle experiments on plankton, plants and periphyton, we also established that this overall effect arose from direct influences on the physiology of the plants and algae but also through indirect effects. Plankton production was reduced by a stimulation of surface duckweed cover in the warmed treatments and

this led to reduced photosynthesis and increased respiration, whilst the effect on *Lemna trisulca*, a major component of the plant community, was likely a direct physiological one.

The experiments had major implications for future fisheries. The tanks were hypertrophic and not unlike a myriad of small shallow waters in the lowlands of the UK. Warming reduced both the maximum and minimum values recorded for oxygen and the latter in warmed tanks usually went below 1 mg O_2 L^{-1} by dawn and often reached zero. The prospects for future fish survival in such waters are thus not good.

The experiments also revealed useful information on the reliability of oxygen probes, a chemical problem in the Winkler titration at supersaturating concentrations of oxygen and our abilities to survive all-night experiments with equanimity. All in all, the award proved extremely valuable to us. The results will be published in a high quality journal alongside those obtained on other aspects of warming during the long-term experiment.