

delays in mitigation efforts. However, the dedication of resources to adaptation at the expense of mitigation does not follow from a correct interpretation of committed climate warming.

This is a fundamentally hopeful conclusion; if we can successfully coordinate international emissions reductions in the coming decades, we can successfully restrict global temperature increases to a level that will prevent dangerous impacts on both human and environmental systems. □

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Nitrous oxide from aquaculture

To the Editor — The farming of fish and shellfish under controlled conditions — collectively known as aquaculture — is a significant component of global food production. In 2006 aquaculture supplied an unprecedented 47% of the total food fish harvest¹. The aquaculture industry has grown at a rate of 8.7% per year since 1970, due to a rapidly expanding global demand for fish, particularly from China. Given that wild fish stocks are close to their maximum exploitable levels, there are strong economic and demographic incentives for this trend to continue. Here we argue that aquaculture may become an important source of nitrous oxide (N₂O) — a potent greenhouse gas and the dominant source of ozone-depleting substances in the stratosphere^{2,3}.

Aquaculture is associated with a number of environmental problems at the local to regional scale. Nutrient-rich waste from aquaculture ponds can leach into surrounding waters, resulting in eutrophication and algal blooms. Non-native species can escape, disturbing local ecosystems. Moreover, natural mangroves, which protect coastal areas from erosion and storms, are often sacrificed for aquaculture farms. Although the environmental impact of a single fish farm has been examined⁴, the effect of global aquaculture on climate is uncertain.

Around 55 million tonnes of fish are harvested from fish farms each year¹. Fish are remarkably efficient at converting fishmeal into body mass, and the ratio of input in the form of fishmeal to output in the form of fish mass (known as the feed-conversion ratio) typically ranges from one to two. Given that fish contain on average 2.7% nitrogen⁵, we estimate that approximately 1.5 × 10⁶ tonnes of nitrogen are consumed by farmed fish each year. Assuming a typical feed-conversion ratio of 1.4, we estimate that 2.1 × 10⁶ tonnes of

nitrogen would be required; waste nitrogen from aquaculture farms would therefore amount to 0.6 × 10⁶ tonnes. Following consumption by humans, the nitrogen contained in the fish will pass into sewage processing plants.

Collectively, the nitrogenous waste generated by fish farming, and the associated human waste, has the potential to produce nitrous oxide through the processes of denitrification and nitrification. Indeed, in rivers and coastal regions located downstream from wastewater treatment plants and fish farms, high concentrations of nitrous oxide have been observed^{6,7}. However, the amount of nitrous oxide produced by aquaculture is hard to quantify, as it is highly dependent on the technology used to treat the waste. One treatment option, which is used in many fish farms and sewage-treatment systems, is to capture and filter the nitrogenous sludge and wastewater, and then store it in anaerobic stockpiles or sediments. In this situation, the amount of nitrous oxide produced per unit mass of ammonium or nitrate — the nitrous oxide yield — can be high, with values ranging from 2–80% (refs 8, 9 and references therein). The overall yield is highly dependent on parameters such as dissolved organics, oxygen and pH. Studies of actual wastewater treatment plants have reported much lower nitrous oxide emissions than laboratory experiments.

Tentatively assuming a nitrous oxide yield of 5%, we estimate that fish-farm waste generates 0.09 Tg of nitrous oxide per year. If we include human wastewater in the equation, and assume a nitrous oxide yield of 2% (ref. 10) for this component, emissions rise to 0.19 Tg nitrous oxide per year (0.12 Tg N₂O-N yr⁻¹). According to these estimates, nitrous oxide emissions from aquaculture represent 3.2% of oceanic nitrous oxide emissions, and 4.3% of agricultural emissions. However,

if the aquaculture industry continues to grow at the present rate¹, we estimate that annual nitrous oxide emissions could reach 1.01 Tg after 20 years — equivalent to 17% of the oceanic source. As the availability of wild fish for fish feed becomes limiting for aquaculture, alternative crop-based fish feed is likely to be used¹, and the application of fertilizer to these crops will further increase emissions.

Our estimates of nitrous oxide emissions from aquaculture are probably conservative, given the omission of other pathways of nitrous oxide production, such as fish-feed production and subsequent uses of nitrogenous waste. Furthermore, fish-farm nitrous oxide yields may be greater than the 5% we assume⁹. Measurements are therefore needed to quantify nitrous oxide yields from aquaculture, especially from carp and shrimp farms, which account for a large part of the rapidly expanding industry in the Asia-Pacific region. □

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