LINK TO ORIGINAL ARTICLE
LINK TO INITIAL CORRESPONDENCE
LINK TO AUTHOR'S REPLY 2

Increasing the microbial carbon sink in the sea by reducing chemical fertilization on the land

Nianzhi Jiao, Kai Tang, Haiyuan Cai and Yujiao Mao

In their response to our recent article on the microbial carbon pump (MCP) for carbon sequestration in the ocean (Microbial production of recalcitrant dissolved organic matter: long-term carbon storage in the global ocean. *Nature Rev. Microbiol.* **8**, 593–599 (2010))[1], Liang and Balser (Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy. *Nature Rev. Microbiol.* 29 Nov 2010 (doi:10.1038/nrmicro2386-c1)[2] propose that microbial production of recalcitrant organic matter occurs in terrestrial soils in addition to occurring in the ocean. Indeed, microbial processing of carbon in sea water is influenced by land inputs — not only organic matter but also nutrients — that provide a link between land and sea, which can address, at least partially, the paradox that estuaries are often sources of atmospheric CO_2 (REFS 3,4) as well as being the most productive marine waters.

Enhanced terrestrial nutrient inputs are usually thought to increase the biological pump in the sea as a sink of anthropogenic CO_2 (REF. 5). However, in estuarine waters the biological pump that is based on the sinking of carbon is inefficient owing to the shallow water depth, the strong mixing process and the severe resuspension of particles. By contrast, the MCP that is based on dissolved organic carbon (DOC) is not influenced by such physical conditions, being influenced by chemical conditions instead. When nutrients are replete, DOC can be mobilized for degradation and respiration[4,6]. Both ammonium and nitrate can be used by heterotrophic bacteria with nitrate reductase genes that can be induced by ambient nitrogen availability[7]. In eutrophic waters, *nasA*, the gene that encodes the catalytic subunit of nitrate reductase, is more abundant than in oligotrophic waters[7]. In one scenario, enhanced terrestrial input of nutrients would reduce the carbon/nitrogen and carbon/phosphorus ratios and so mobilize DOC for microbial respiration, contributing to the argument that coastal waters can be a source of CO_2, as observed in the case of the Pearl River estuary[4] (FIG. 1a). In a contrasting scenario, if DOC is immobilized by the MCP, it can contribute to carbon sequestration[1]. Microbial carbon accumulation occurs in the ocean, where nutrients are limiting[8–10]. Polymers such as polyhydroxyalkanoates that act as carbon storage are generated where high carbon/nitrogen ratios prevail[11], even under eutrophic conditions (FIG. 2). Rivers and estuaries transport 400 Mt of organic carbon annually[12,13], of which 60% is DOC[13], and surface DOC can be efficiently exported to the deep sea, constituting an important control of atmospheric CO_2 levels[14] (FIG. 1b).

Each year large amounts of terrestrial nutrients (54 Mt of nitrogen and 8.5 Mt of phosphorus) are discharged to the coastal ocean[5]. Fertilizer is a major source of these nutrients, particularly in developing countries. The level of inorganic nitrogen that enters the Yangtze River and is carried

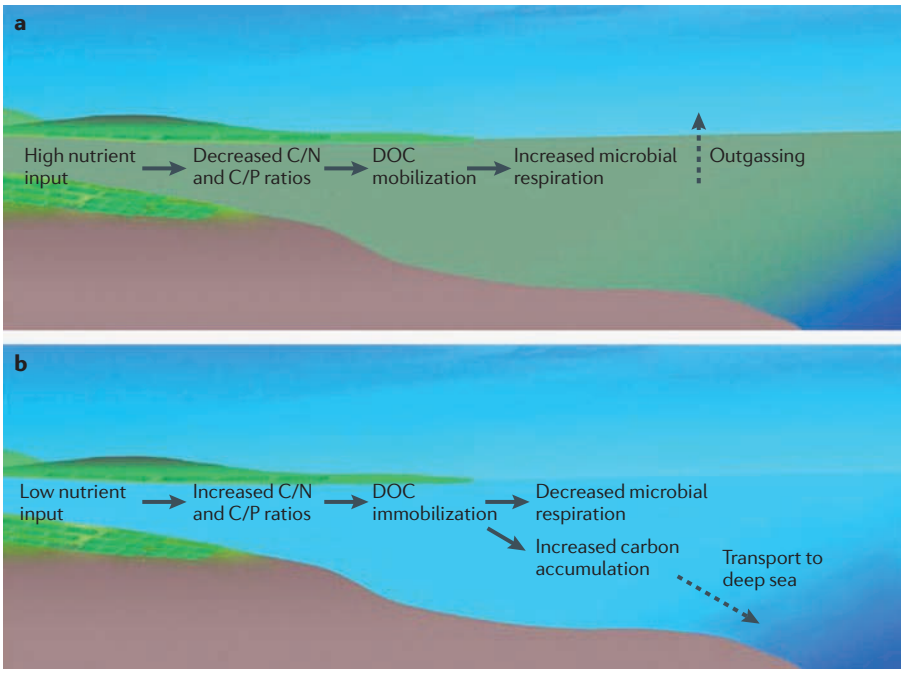

Figure 1 | **Microbial carbon processing scenarios under different environmental conditions.** **a** | Microbial respiration of dissolved organic carbon (DOC) is mobilized by enhanced terrestrial nutrient input. **b** | Microbial carbon sequestration is enhanced by reducing terrestrial nutrient input.

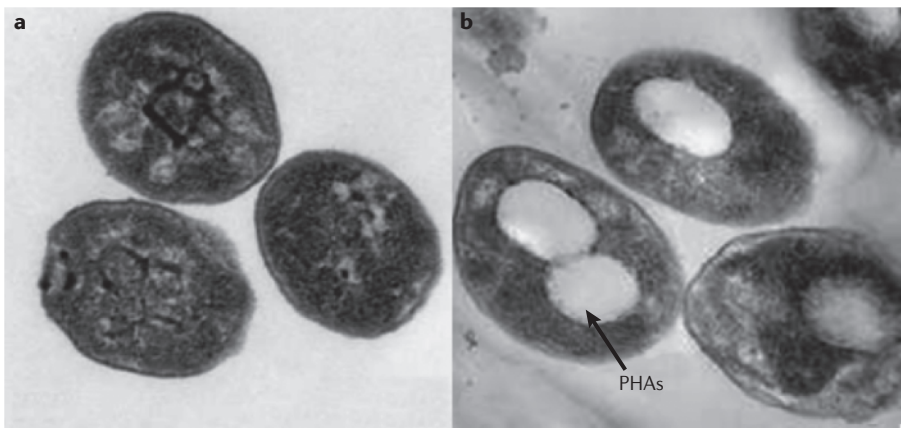

Figure 2 | **Increased carbon/nitrogen ratios induce the formation of polyhydroxyalkanoates (PHAs) as carbon-storage compounds.** Ultrathin-section transmission electron micrographs of *Dinoroseobacter* sp. JL1447 cultured with rich organic media. **a** | Glucose was added to the medium at a carbon/nitrogen ratio of ~3. **b** | Glucose was added to the medium at a carbon/nitrogen ratio of ~6.

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to the East China Sea has increased by more than threefold in the past 30 years[15]. Anthropogenic nutrient inputs could continue to dominate river nutrient discharge in the coming decades[5]. This should be given a large amount of attention, given the negative effects of excess nutrients on microbial carbon sinks in addition to the notorious eutrophication and harmful algal blooms.

Between autochthonous production and terrestrial inputs, coastal waters contribute 20% of global marine primary production, making them the waters that are the richest in carbon in all the world's oceans[16]. Reducing chemical fertilization on land and, consequently, anthropogenic nutrient discharge into the sea could enhance the MCP, contributing to the formation of atmospheric CO_2 'sinks' in estuarine and near-shore waters (FIG. 1b), a possibility that deserves further study not only for science but also for policy.

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Competing interests statement
The authors declare no competing financial interests.

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