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DIATOMS – keeping estuaries clean

Diatoms help maintain water quality by moving nitrogen into estuary sediments.

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Eutrophication of waterways occurs when the rate of nutrient addition exceeds the rate of removal. Nutrient enrichment can cause prolific plant growth, clogged waterways, nuisance algal blooms, anoxic events, fish kills and a general deterioration in water quality. Nitrogen and phosphorus are the 'culprit' nutrients, but nitrogen is most important in controlling plant growth in temperate estuaries.

Geoscience Australia has conducted several surveys in estuaries in temperate southwest and southeast Australia to identify processes that control eutrophication and maintain 'good' water quality. Because these estuaries are characteristically poorly flushed, they effectively trap sediments and nutrients from their catchments and are particularly prone to eutrophication.

The sediment–water interface

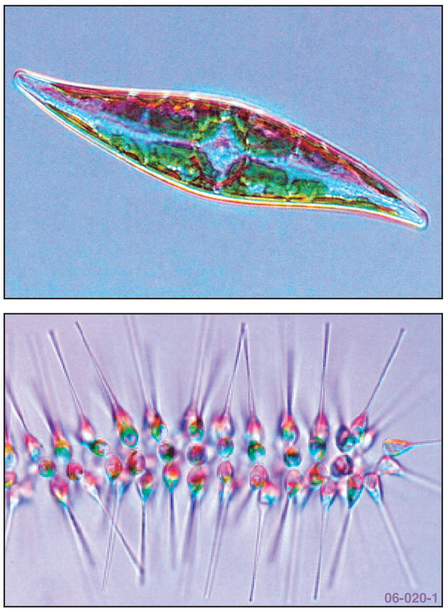
The sediment–water interface in an estuary is a place of intense microbial activity and chemical reactivity. Sediment grains and plant debris—both living and dead—support microbial populations which feed on the organic matter. Animals feed on the microbes and other plant debris, ventilating the sediments as they forage. Oxygen from the overlying waters is moved into sediments around particle grains and used by microbes as they degrade organic matter and release nutrients into water between the grains. Some of these nutrients may migrate into the overlying waters and exacerbate the eutrophication process, but other reactions remove the problematic nitrogen and phosphorus and help to limit or prevent eutrophication.

Geoscience Australia has focused on the sediment–water interface to identify these various reactions and the processes that either release nutrients or remove them from the system.

Phosphorus is very particle-reactive and, once liberated from organic matter, remains trapped in most Australian estuarine sediments. However, after nitrogen is released from organic matter it undergoes a series of microbially mediated reactions (coupled nitrification and denitrification), which may convert some or all of it into nitrogen gas that is lost to the atmosphere. Denitrification occurs under anoxic conditions (no oxygen), but its precursor (nitrification) occurs under oxic conditions, juxtaposed at the sediment–water interface over millimetre scales.

The efficiency of these nitrification–denitrification reactions is an important control on the eutrophication process. When the denitrification efficiency is high, most nitrogen is lost to the atmosphere and eutrophication may be prevented, but when the denitrification efficiency is low, most nitrogen stays within the estuary and exacerbates eutrophication.

▲ **Figure 1.** A benthic chamber (Photo D Heggie).



▲ **Figure 2.** Diatoms are abundant in temperate marine and coastal waters (Images by L Drake & M Doblin).

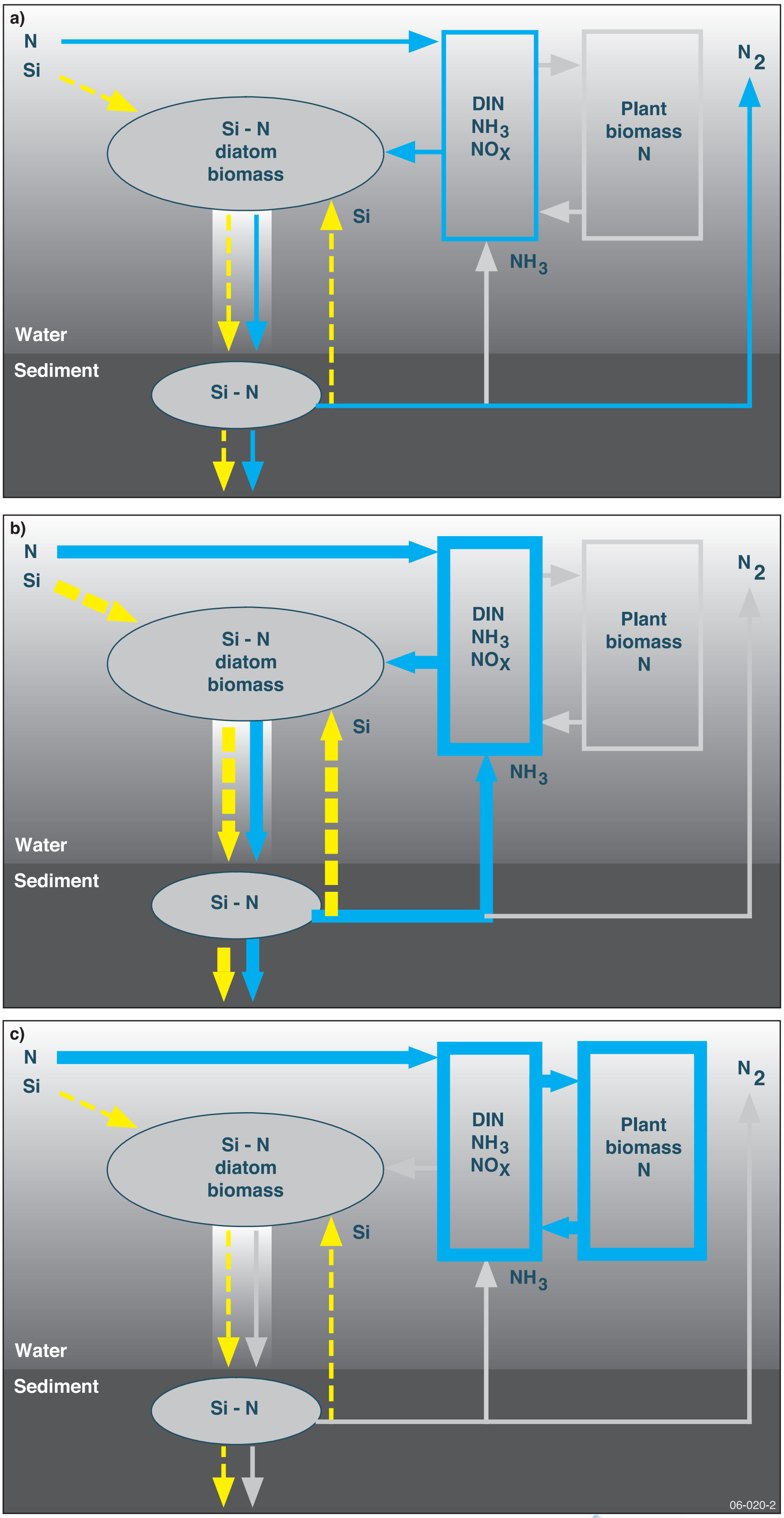


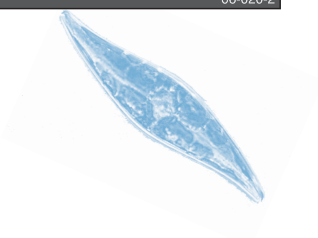
Figure 3. Silicate and nitrogen cycles. (a) Denitrification efficiency is high and N_2 is lost to the atmosphere. (b) Denitrification efficiency is low and N is recycled internally to the overlying water as ammonia. (c) Non-diatomaceous biomass is predominant and N is recycled internally in the water column with no denitrification.

Diatoms move nitrogen into sediments

Geoscience Australia has examined these reactions using benthic chambers in several temperate Australian waterways (figure 1). A synthesis of the results from more than 450 chamber deployments found that 86% of the observations could be explained by the degradation of diatomaceous organic matter in the sediments, while the remainder showed mixtures of diatomaceous matter and other unspecified organic plant materials.

Diatoms are generally about 0.1 millimetres in diameter and are predominant in temperate waters (figure 2). They are relatively heavy, so they sink rapidly to the sediments. Their abundance in temperate Australian waterways is important, because they transport nitrogen into the sediments where coupled nitrification and denitrification leads to nitrogen being lost to the atmosphere.

Three scenarios, each with different pathways of nitrogen-cycling, illustrate how both the absolute and relative abundances of diatomaceous plant biomass produced in an estuary affect denitrification and, ultimately, eutrophication and water quality.



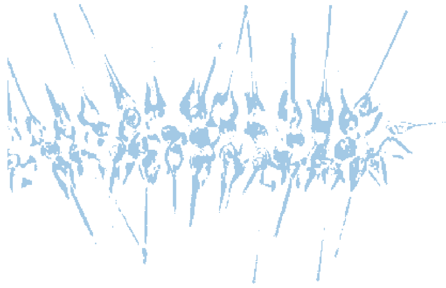


Figure 4. Abundant macrophytes and macroalgae in an estuary (Photo D Heggie).

Healthy estuaries and 'good' water quality

Reactive nitrogen dissolved in estuarine waters occurs principally in two species—ammonia (NH_3) and oxidised nitrogen (NO_x), which are jointly known as DIN (dissolved inorganic nitrogen, shown in blue in figure 3). Silicon exists as a single-species silicate (yellow). Silicon, nitrogen and phosphorus (not shown) combine (figure 3a) during the photosynthetic process to form diatoms, which sink to the sediments, degrade and liberate silicate back into the overlying waters to participate in further rounds of plant growth.

Nitrogen is released to the water in the sediment as ammonia and oxidised (nitrification) to produce nitrate and nitrite, which are subsequently reduced during denitrification to produce nitrogen gas (in figure 3a, the bold blue line illustrates this pathway). Low loads of nitrogen and abundant silicate favour diatom biomass, which sinks to the sediment and, when combined with an active benthos ventilating the sediments with oxygen, promotes efficient nitrification and denitrification and eventual nitrogen removal. Diatom production and sinking are mechanisms to remove nitrogen from estuaries via efficient denitrification, helping to alleviate eutrophication and maintain 'good' water quality.

Eutrophic estuaries and 'poor' water quality

Two scenarios result in eutrophic conditions and 'poor' water quality. The bold nitrogen pathways highlighted in blue (figure 3b) involve diatom production, but in this scenario the rate of diatom biomass production is high, driven by comparatively higher inputs of nitrogen than in the first scenario. The cycling of silicate (yellow) is the same, but the cycling of nitrogen is significantly different.

Diatoms transport nitrogen to the sediments, but high loads of nitrogen cause the nitrification and denitrification reactions to be inefficient. Nitrogen is then released into overlying waters principally as ammonia, which fuels further plant growth. Nitrogen is recycled internally in this pathway rather than being removed from the estuary, exacerbating eutrophication and probably eventually resulting in significant ecological changes, such as an abundance of macroalgae, macrophytes (figure 4) and/or nuisance phytoplankton and bacteria.

The third scenario (figure 3c) involves preferential assimilation of nitrogen into nonsiliceous phytoplankton, macroalgae and macrophytes. Silicate is limiting in this scenario because of comparative nitrogen enrichment, and diatom production is not favoured during photosynthesis. Nonsiliceous phytoplankton do not contain a silicate frustule (siliceous cell wall) and do not rapidly or always sink, so they do not transport nitrogen effectively to sites of nitrification and denitrification in the interfacial sediments. Instead, nutrients are released directly from the plants into the water column overnight, as part of the respiration cycle.

These plants therefore act simply as 'sponges', soaking up nutrients from various sources during daylight and releasing them into the water column at night. In this way, little nitrogen from the catchment gets to the sediments where it can be denitrified. This pathway (shown in bold) is also one through which nitrogen is recycled internally; it results in the retention of nitrogen in estuaries, exacerbating eutrophication and possibly leading to further shifts in local ecology.

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