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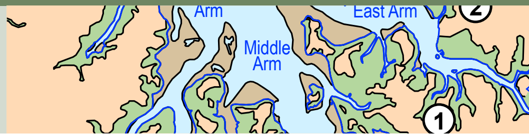
The role of sediments in nutrient cycling in the tidal creeks of Darwin Harbour

Research project aims to assess ecosystem health



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Darwin Harbour is a largely unmodified estuary in the wet tropics of northern Australia and the water quality varies greatly with tides, season and location. Darwin Harbour is surrounded by extensive intertidal mudflats and mangroves fringe at least two-thirds of the foreshore (figure 1).

Numerous water quality studies have been conducted in Darwin Harbour by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport (NRETAS) over the past 20 years. These have determined the contribution of diffuse sources, such as urban and rural runoff, as well as point sources such as treated sewage effluent, to total catchment loads (see related websites).

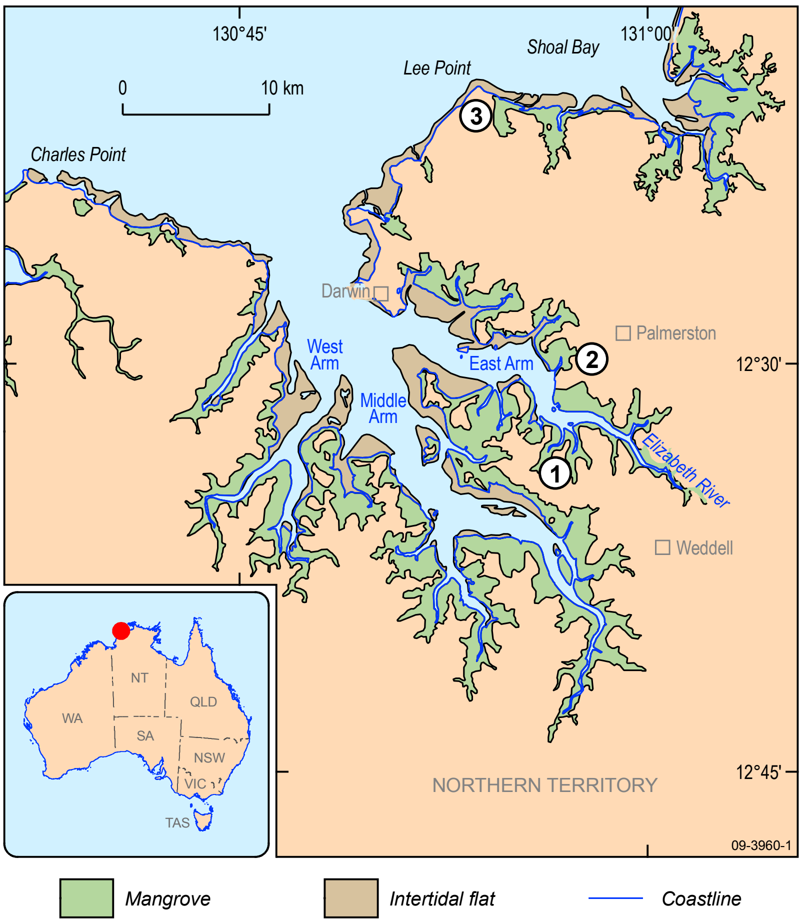

Figure 1. Map of Darwin Harbour showing the extent of intertidal mudflat areas and mangroves, and (1) the reference creek; (2) Myrmidon Creek; and (3) Buffalo Creek.

Impacts on water quality in the harbour from urbanisation have already been reported (Water Monitoring Branch 2005) and it has been found that treated sewage effluent is the main contributor to total nutrient loads (Skinner et al 2009).

On a whole-of-harbour scale, diffuse runoff and point-source sewage discharges are relatively minor compared to the overall nutrient status of the harbour. However, research suggests that the effects may be significant at local scale, that is, within tidal creeks where point source nutrients are discharged (Fortune and Maly 2009). A need for further research has been identified to assist in understanding how nutrients from sewage effluent are assimilated in the receiving tidal creeks (Skinner et al 2009).

To ensure that water quality objectives are maintained, and that community values associated with the Harbour are protected, NRETAS is developing a Water Quality Protection Plan for Darwin Harbour. A recent detailed report on the development of the Plan (Fortune and Maly 2009) included a summary of previous water quality studies, the development of water quality objectives, pollution load assessment and targets and priority research being undertaken to support the Plan. The report also identified a number of key elements, including nutrient cycling and algal interactions, as well as priority zones for future research efforts.

Consequently, a number of research projects have been initiated to provide insights into key water quality processes in Darwin Harbour and inform water quality model parameters (Fortune and Maly 2009). One of these projects aims to assess the effect of sewage inputs on the ecosystem health in Darwin Harbour. The project involves collaboration between NRETAS, Geoscience Australia, Griffith University (Queensland), CSIRO and Charles Darwin University (Darwin). It was funded through the Tropical Rivers and Coastal Knowledge (TRaCK) research hub which was established under the Commonwealth Environment Research Facilities Program.

Study of nutrient transformation and retention processes

Field studies examining nutrient cycling were conducted in three tidal creeks which each receive different amounts of sewage discharge. The field sites are within the identified priority zones for the harbour. Surveys during the wet and dry season were undertaken to differentiate land runoff effects from sewage inputs. The project focused on the extensive intertidal mudflat sediments which have received little attention in previous nutrient studies, despite occupying a substantial area within the harbour (figure 1). In addition, intertidal mudflats play an important role in regulating primary productivity (that is, algal growth) by storing and recycling nutrients and therefore act as a potential buffer against increased nutrient loads. However, it is not clear whether nutrient transformation processes within the extensive intertidal mudflat areas will retain the additional nutrient discharge. This project is designed to advance the scientific knowledge beyond the traditional water quality monitoring programs and to develop a greater understanding of the longer term impacts and implications for ecological health from increased nutrient loads.

Scientists from Geoscience Australia studied nutrient transformation and retention processes in the sediments. The key factors quantified were:

- release of nutrients from sediments (‘benthic nutrient fluxes’)
- sediment nutrient pools
- the capacity of sediments to convert bioavailable nitrogen into dinitrogen gas (‘denitrification’)
- the capacity of sediments to retain phosphorus
- breakdown (‘respiration’) and growth (‘photosynthesis’) of microalgae.

Partners from Griffith University (Queensland) and CSIRO focussed on the biological aspects of the project and gathered information on:

- the extent of the sewage signal on microphytobenthos, benthic infauna and phytoplankton
- the interactions between turbidity and nutrients with respect to phytoplankton and microphytobenthic production
- the effectiveness of benthic bioindicators in tracing sewage in the food web.

Darwin Harbour water quality

River flow into Darwin Harbour reflects the highly seasonal rainfall pattern, with maximum flows between January and March each year. The rivers have naturally low concentrations of nutrients and sediment because of the low relief and infertile soils of the highly weathered catchment. Darwin Harbour is macrotidal, with a maximum tidal range of 7.8 metres. The large tidal movement produces strong currents up to two metres per second which cause resuspension of fine sediments and lead to a naturally turbid system and a general perception of poor ecosystem health (McKinnon et al 2006). However, nutrient concentrations are low in the main body of the harbour (0.05-2.0 milligrams per litre of nitrogen and 0.01-0.04 milligrams per litre of phosphorus) with slight seasonal variations due to river runoff during the wet (Water Monitoring Branch 2005).

The majority of nutrients that enter the harbour are imported from the ocean and are typically in the particulate or organic form (Burford et al 2008). These nutrients are not considered to be bioavailable, that is, able to be used by biological organisms. Nutrients also enter the harbour from the surrounding catchment and are derived from both diffuse sources, such as urban and rural runoff, as well as point sources such as treated sewage effluent. The impacts of urbanisation on water quality in the harbour have already been reported with nitrogen and phosphorus loads from the catchment 1.7 and 5.9 times higher than pre-urbanisation loads (McKinnon et al 2006). Treated sewage effluent contributes 71 per cent of total phosphorus and 31 per cent of total nitrogen of the annual catchment load (Skinner et al 2009) and these nutrients are typically bioavailable. The sewage effluent is typically discharged into tidal creeks on the fringes of the harbour. There is evidence of localised impacts on the water and sediment in tidal creeks receiving sewage effluent, including anoxic water conditions, elevated chlorophyll concentrations and higher sediment nutrient concentrations (Padovan, 2003). However, most of the harbour remains in a healthy state with some areas such as West Arm considered relatively pristine (Water Monitoring Branch 2005).

There is potential for more severe impacts on coastal water quality and overall ecological health in the future due to increasing population and land development. The harbour is adjacent to the cities of Darwin and Palmerston (figure 1). Darwin is the fastest growing capital city in Australia with the population expected to double by 2050. Skinner et al (2009) have predicted the impact of future population growth and development on nutrient loads entering Darwin Harbour. While previous studies have identified the contribution of sewage effluent to catchment nutrient loads, they do not address the fate of nutrients and their ecological consequences once they enter the harbour.

Geomorphology, hydrodynamics and sewage loads

The tidal creeks studied as part of the TRaCK project were the unnamed reference creek and Myrmidon Creek in East Arm of Darwin Harbour and Buffalo Creek in Shoal Bay (figure 1). The reference creek, on the western side of East Arm, is considered to be near-pristine with no known impact from urbanisation or land development. Myrmidon Creek, on the eastern side of East Arm, is adjacent to Palmerston. Both creeks display relatively simple geometry, with predominantly straight channels, widening downstream, and extensive intertidal mudflats along the length of the creeks. As a result, both creeks are well flushed during each tidal cycle.

Throughout the dry season, Myrmidon Creek and the reference creek typically have high salinity (greater than 37), are well oxygenated and have low nutrient concentrations. During the wet season, freshwater inputs to East Arm from the Elizabeth River are pushed into the creeks during high tide, lowering the salinity and slightly increasing nitrogen concentrations.

Buffalo Creek consists of a long, narrow channel with a few large meander bends at the downstream end. A large intertidal sand bar across the mouth inhibits tidal movement to a significant degree. Upstream the channel becomes even narrower and meanders through dense, overhanging mangroves. The majority of the creek has straight-sided banks but there are sections of intertidal mudflats on the meander bends and parts of the main channel.

Treated sewage effluent is discharged from sewage treatment plants into the mangroves fringing Myrmidon and Buffalo Creeks. These are licensed under the *Water Act* and administered by NRETAS (Water Monitoring Branch 2005). The Palmerston sewage treatment plant discharges into Myrmidon Creek. The discharge point is approximately 850 metres from the mouth of the creek. At this point the creek is approximately 100 metres wide and six metres deep at high tide. There is a distinct green sewage plume which enters the creek at the discharge point (figure 2a). The plume, typically restricted to the surface layer, is low in dissolved oxygen and enriched in nutrients, suspended matter and chlorophyll-a. The plume gradually disperses during the ebb tide and is rapidly diluted and mixed, becoming undetectable within a few hours (figure 3a).

The Leanyer Sanderson sewage treatment plant, the largest in Darwin, discharges into Buffalo Creek. The sewage outfall is at the upstream end of the creek, approximately 5000 metres from the mouth, where the creek is very narrow. Buffalo Creek experiences episodic hypereutrophic events with very high algal concentrations in the water column and sediment (figure 2b). Anoxic conditions occur in Buffalo Creek and the very low dissolved oxygen concentrations suggest significant respiration is occurring as a result of organic carbon and nutrient inputs, and this is likely to have major effects on the ecosystem functioning of this creek. The impacts of the sewage discharge are detectable along the entire length of the creek, with high nutrient concentrations and low dissolved oxygen concentrations measured even at the downstream end of the creek (figure 3b). Dissolved oxygen and nutrient concentrations vary with tidal levels and there is a general improvement in water quality conditions during high tide. The impacts of the continual inflow of nutrient-rich sewage discharge at the constricted upstream end of the creek is exacerbated by minimal mixing and poor flushing, particularly during neap tidal conditions (when tides attain the least height).

While there is a clear distinction in the level of impact from sewage outfalls on water quality between the three tidal creeks, there is also a significant difference in nutrient cycling within the intertidal mudflats that is relevant to this project. A water quality model for Darwin Harbour has been developed (Fortune & Maly 2009). The concentration of nitrogen and phosphorus in the harbour, as a result of catchment runoff and sewage treatment plant discharge has been simulated to estimate the total maximum pollutant loads to achieve water quality objectives. Refinement of the model will continue as monitoring data is collected and specific research addresses critical parameter inputs. The results presented here address some of the key parameters associated with nutrient cycling in the sediments and will make an important contribution to

Figure 2. (a) Myrmidon Creek sewage plume (photo courtesy of Emily Saeck, Griffith University). (b) Hypereutrophic event in Buffalo Creek (photo courtesy of Jodie Smith, Geoscience Australia).

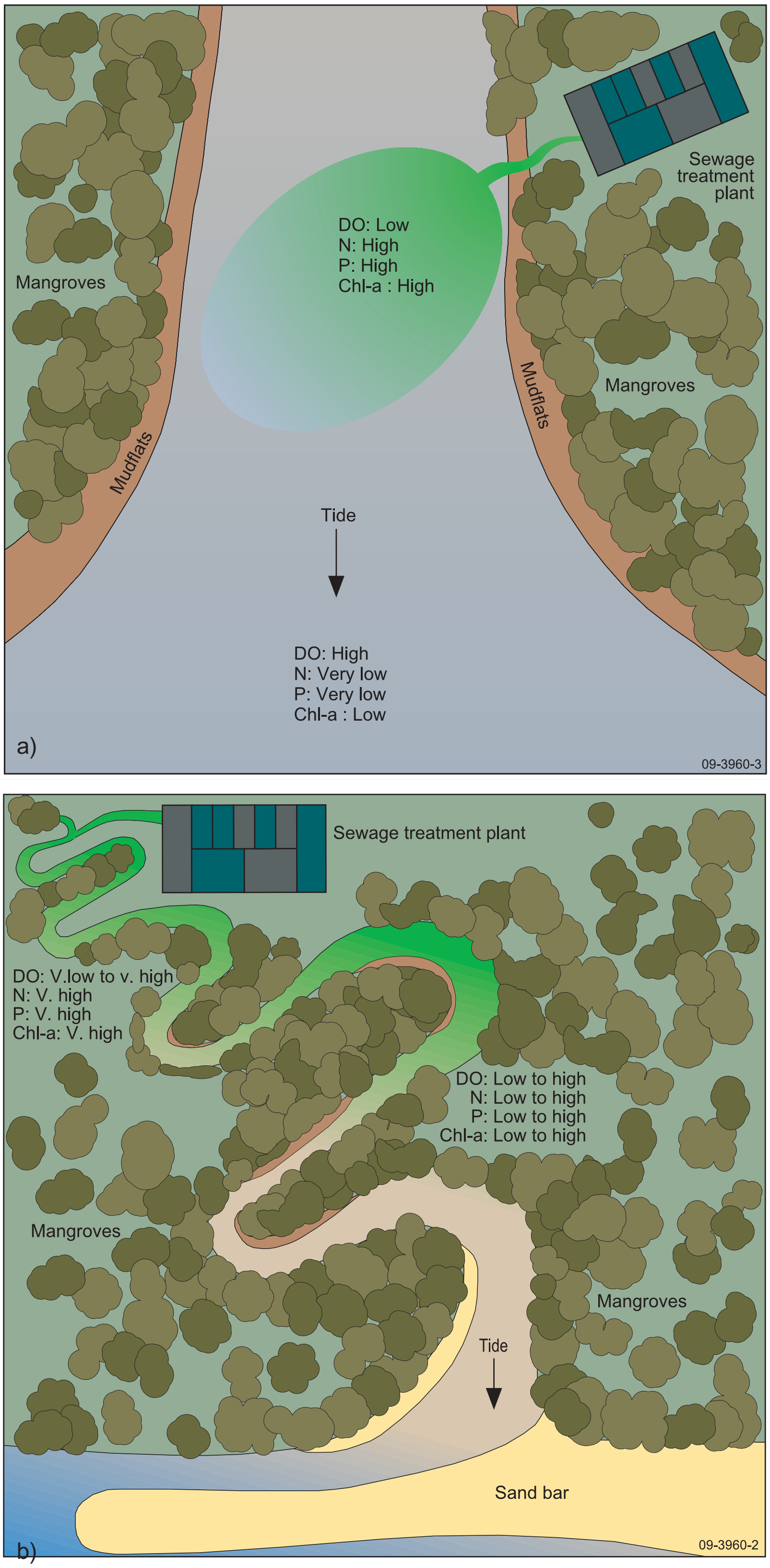

Figure 3 (a) and (b). Conceptual diagrams of Myrmidon and Buffalo Creeks showing geomorphology, sewage discharge points and nutrient and oxygen conditions.

refining the water quality model for Darwin Harbour.

Nutrient cycling in the intertidal mudflat sediments

The intertidal mudflat sediments are highly heterogenous and heavily bioturbated by crustaceans, polychaete worms and other infauna. This results in a large natural variability in nutrient cycling processes within each sampling site. However, there were marked differences in a range of nutrient cycling processes in Buffalo Creek compared to Myrmidon Creek and the reference creek which were far greater than any natural variability.

Benthic nutrient fluxes (the release of nutrients from the sediments to the overlying water column) were up to 100 times higher in Buffalo Creek compared to Myrmidon Creek and the reference creek. Additionally, porewater nutrient pools indicate the sediments in Buffalo Creek contain a large source of dissolved nutrients. This is significant because it indicates the sediments would continue to release nutrients to the water column for a long period even if sewage discharges were ceased. There were no marked differences in benthic nutrient fluxes between Myrmidon Creek and the reference creek or between the wet and dry seasons, despite additional nutrient inputs during the wet.

Denitrification is a process which occurs in sediments whereby inorganic nitrogen is converted into dinitrogen gas. Denitrification was measured in the sediments as an indication of the efficiency of nitrogen removal from the system. It provides a useful indicator of ecosystem health. In Myrmidon Creek and the reference creek, denitrification efficiency was very high (80 to 90 per cent) indicating that most nitrogen is released from the sediments back into the atmosphere. Conversely, denitrification efficiency in Buffalo Creek was low and the majority of nitrogen is released back into the water column (as ammonium and nitrate) where it is bioavailable.

The degree to which the sediments have retained additional phosphorus from sewage inputs was assessed by determining the different phosphorus fractions in the sediments. Initial results indicate that concentrations of phosphorus in surface sediment are up to three times higher in Buffalo Creek compared to Myrmidon Creek and the reference creek. More importantly, over 50 per cent of the phosphorus in Buffalo Creek is in the exchangeable and redox-sensitive fraction. This fraction is a bioavailable source for phytoplankton and microbenthic algae growth. Moreover, there is potentially a risk of phosphorus release into the overlying water column under anoxic conditions, which are known to occur in Buffalo Creek.

The low benthic nutrient fluxes and high denitrification efficiencies measured in the intertidal sediments of Myrmidon Creek and the reference creek provide a clear indication that the ecological health of these two creeks is intact, despite additional nutrient sources from wet season runoff and sewage outfalls. The geomorphology and hydrodynamics of Myrmidon Creek allow for a short residence time with efficient flushing and rapid export of sewage discharges. This research indicates that the effect of sewage inputs in Myrmidon Creek is only temporary and localised, with the effects principally measured in the water column rather than sediment processes.

On the other hand, residence times in Buffalo Creek are longer, particularly upstream where the sewage outfall is located. A larger nutrient load, low denitrification efficiency and poor tidal flushing have resulted in large sediment nutrient pools and poor ecosystem health in Buffalo Creek.

Conclusions

The effects of treated sewage effluent on ecosystem health in Darwin Harbour are localised. In Buffalo Creek, a range of nutrient cycling processes is impacted by high nutrient loads from sewage effluent. In Myrmidon Creek, the impacts are temporary and limited to the water column. This project provides an understanding of the predominant nutrient cycling processes and the fate of nutrients in the intertidal mudflats of affected areas. It provides information about the assimilatory capacity of the ecosystem to cope with increasing pollution loads.

This knowledge will contribute to the development of a conceptual model showing the effect of nutrient and sediment loads on the health of mudflats and mangroves and identify a suite of potential bio-indicators for assessing ecosystem health. This research will provide valuable input into the development of an optimal monitoring program for Darwin Harbour. The research on the impact of biogeochemical

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processes in intertidal mudflats will provide key information needed to validate a mathematical model simulating and predicting water quality in Darwin Harbour.

The outcomes of this research will enable water managers to make better informed decisions when considering issues such as sewage treatment options when planning expanded urban development. There will also be more effective targeting of future investments to maintain or improve water quality or to upgrade sewage treatment.

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Related websites/articles

Tropical Rivers and Coastal Knowledge (TRaCK) research hub
www.track.gov.au

Aquatic Health Unit, Department of Natural Resources, Environment, The Arts and Sport
www.nt.gov.au/nreta/water/aquatic/index.html

Water Quality Protection Plan for the Darwin Harbour
www.nt.gov.au/nreta/water/quality/wqpp.html