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Nutrient and sediment concentrations in the Pagsanjan–Lumban catchment of Laguna de Bay, Philippines

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ABSTRACT

The off-site transport of nutrients and sediments can have detrimental effects on water quality and ecological health of waterways. This study was conducted to determine the concentrations of nutrients and sediments in surface waters contributing to Laguna de Bay, Philippines. Four sites representing various land uses and non-point and point sources of contamination (rice, vegetable and coconut production systems, and piggery) were selected and instrumented with automated water samplers for time weighted collection of water samples. Total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and total carbon (TC) were determined in unfiltered samples. The effluent from piggery farms (a point source) had the highest TSS, TKN, TP and TC concentrations. For the other three sites, the dominant land use upstream of the sampling sites greatly influenced the concentrations of nutrients and sediment. Among the croplands, the site associated with rice as a dominant land use in the Pagsanjan–Lumban catchment contributed more suspended sediments and higher concentrations of TKN and TP as compared to the vegetable (Lucban) and coconut dominated (Cavinti) sites. In the majority of cases at all sites the TKN and the TP concentrations exceeded the Australian trigger values for freshwater quality for total nitrogen of 0.35 mg/L and TP of 0.10 mg/L. In addition to land use, TKN was correlated with TSS particularly in the Majayjay (R^2 = 0.28), Pagsanjan (R^2 = 0.51) and Lucban (R^2 = 0.36) sampling sites. The relationship between TP and TSS was also significant at Lucban (R^2 = 0.29) but not at the other sites. Rice paddies are subjected to wet cultivation (puddling) and have loose topsoil and are kept flooded most of the time which allows larger amounts of suspended sediments and nutrients to leave with the drainage water.

1. Introduction

Nitrogen (N) and phosphorus (P) are essential nutrients for healthy lake ecosystems. However, excessive concentrations in water bodies can cause eutrophication with excessive growth of algae and noxious aquatic plants which can lead to depletion of dissolved oxygen and consequently fish kills. Excess nutrients are the most common abiotic pollutants in lakes of the Philippines (Zafaralla et al., 2005), USA (USEPA, 2000) and other countries. In the USA alone, 1.52 million ha of lakes are impaired by nutrients and agriculture is the principal source of these nutrients (USEPA, 2000). Numerous studies have been carried out on the effects of agricultural practices on water quality in temperate environments (e.g. Daniel et al., 1998; Haygarth and Jarvis, 1999; Dougherty et al., 2004; Heathwaite et al., 2005). While studies have been conducted in tropical northern Australia, particularly catchments adjacent the Great Barrier Reef, (e.g. Freebairn et al., 1986; Smith et al., 1992; Bramley and Roth, 2002; Cox et al., 2005; Mitchell et al., 2005; O'Reagain et al., 2005; Bainbridge et al., 2009; Packett et al., 2009) there are limited studies in other tropical environments (e.g. Kress et al., 2002; Kwong et al., 2002; Goni et al., 2006; Olarewaju et al., 2009; Golbuu et al., 2011). However, the majority of the studies in other countries in tropical environments have focused on water quality in coastal estuarine environments (Golbuu et al., 2011; Goni et al., 2006; Kress et al., 2002) rather than further inland at the headwaters of catchments (Kwong et al., 2002).

Moreover, most catchments in northern Australia are now used for agricultural (sugar, horticulture, grains and cotton) or pastoral purposes (Brodie and Mitchell, 2005) and these land uses and the agricultural practices employed are quite different from those practiced in the Philippines.

Laguna de Bay is the largest freshwater lake in the Philippines and one of the five largest in Southeast Asia. It occupies a total surface area of approximately 900 km^2 with an average depth of 2.5 m and a maximum water holding capacity of about 2.9 billion m^3. The main land use in the catchments that drain into the

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eastern bay of the lake are mainly agricultural and water quality in the eastern bay is relatively less polluted than in the western and central bays. The Pagsanjan–Lumban catchment in the south-eastern bay is the second biggest and contributes about 35% of the freshwater inflow of the lake. Further information about the catchment is given in Cruz et al. (2012). Since the eastern bay is being considered as a source of potable water for Metro Manila in the near future, it is important to protect water quality in this part of the lake from agricultural activities in the catchment. While the Laguna Lake Development Authority (LLDA) is mandated to manage the lake, there are limited data on nutrient and sediment concentration and loads in the Pagsanjan–Lumban catchment. The concentrations of N and P in river waters depend on a number of catchment characteristics and activities such as land use, fertiliser application rate, soil type and hydrological flow pathways linking the land to the stream (Heathwaite and Jones, 1996). Information on where the nutrients are coming from is also important since the management actions focus on controlling nutrient source (Young et al., 1996).

This study was conducted over a three year period to identify and quantify sources of nutrients (particularly N and P) and sediments at four sites representing the major land uses in the Pagsanjan–Lumban catchment. The data presented here will assist in identifying where management actions need to focus in order to minimize off-site transport of nutrients and sediment to rivers in the catchment and, eventually, the lake. The study will also provide benchmark data about concentrations of nutrient and sediments in surface water under current land management practices.

2. Materials and methods

2.1. Pagsanjan–Lumban catchment

Background information about the Pagsanjan–Lumban catchment is given in Cruz et al. (2012). The Pagsanjan–Lumban catchment has an area of approximately 45,445 ha, is the second biggest catchment surrounding Lake Laguna, and produces the largest flow of water into the lake (Hernandez, 2006). The catchment is composed of four major sub-catchments, namely: Balanac (23,224 ha), Bombongan (11,588 ha), Caliraya (9751 ha), and Lewin (883 ha). The catchment has a relatively flat to moderately sloping to rolling topography, starting from the lakeshore and moving towards the mountains. About 90% or 40,900 ha has a slope of ≤18%. The steeper areas with >18% slopes in the mountainous parts constitute only about 4544 ha, or 10% of the total area (Cruz et al., 2012). Based on the 1998 land use map (S. Godilano, pers. comm.) the dominant land uses are coconut plantations (approximately 15,029 ha, or 33%), cropland mixed with coconut plantation (12,003 ha, or 26%), and cultivated areas mixed with brushland/grassland (10,043 ha, or 22%). The coconuts in this area are under-planted with fruit trees such as rambutans (*Nephelium lappaceum*), lanzones (*Lansium domesticum*), jackfruit (*Artocarpus heterophyllus*), bananas (*Musa acuminata*) and some citrus (*Citrus* spp.). These crops are not fertilized or sprayed with pesticides and weed control is by manual slashing. Further details about land use are given in Cruz et al. (2012). There are three main soil types in the catchment: Inceptisols in the less steep regions around the Lake's edge, Alfisols further inland between the regions close to the Lake's edge and the more mountainous area; and Ultisols in the steeper section that is close to Mt. Banahaw (Mariano and Valmidiano, 1972).

Briefly, four sites were selected for installation of automatic water samplers to sample water representing that draining from the major land uses in the sub-catchment – coconut agroforestry (Cavinti), rice production (Pagsanjan), vegetables (Lucban), and piggeries (Majayjay). The Majayjay sampling site was at the end of Initian Creek near where it flowed into the Balanac River. The Initian Creek ran behind the piggeries located in the township of Majayjay and was used by all piggery owners for the disposal of wash water when the piggeries were hosed out each morning. These sites were chosen since they were representative and integrated all the contributions from the upstream catchments.

2.2. Sampling and laboratory analysis

At Cavinti, Pagsanjan and Lucban water samples were collected every 6 h by an auto-sampler and the daily samples were composited to provide a weekly sample. At Majayjay water samples were collected daily when the majority of piggeries were washed out and then composited to provide a weekly sample. This was done to obtain a representative sample for the whole week. In addition weekly grab samples were also taken from February to May in 2009 at the Balanac and Bombongan Rivers which meet in a confluence at Pagsanjan River, just before the river drains into Laguna de Bay.

The daily water samples were stored at 4 °C until they were composited and transported every week to the laboratory for analysis. Collection of water samples started in 2007 in Lucban and Cavinti while in Pagsanjan and Majayjay collection started in 2008 and continued until 2009.

Total suspended solids (TSS) were measured by filtering a known volume of water through Whatman glass fibre filters (1.2 μm) that had been conditioned by wetting with high quality water, dried at 40 °C then weighed. The filter and retained sediment was then oven dried at 40 °C and re-weighed and the mass of sediment in the known volume of water was determined (APHA, AWWA and WEF, 2005).

Total Kjeldahl nitrogen (TKN) was determined in unfiltered samples by digesting a known volume of sample in sulfuric acid with selenium as a catalyst followed by colorimetric determination of ammonium using an autoanalyser. Total P (TP) was determined by digesting a known volume of sample with sulfuric acid and ammonium persulfate followed by colorimetric determinations. Total C was determined on the unfiltered subset of water samples from all sites collected from mid March to late October 2008. These analyses were made using the Skalar Formacs High Temperature TC/TN Analyser.

3. Results and discussion

3.1. Total suspended solids

Total suspended solids (TSS) varied greatly among sites as shown in Fig. 1a. Over the monitoring period, TSS ranged from 6 to 544 mg/L and median was 54.5 mg/L at Cavinti (coconut), from 13 to 312 mg/L and median was 60 mg/L at Lucban (vegetable), from 81 to 2936 mg/L and median was 327 mg/L at Pagsanjan (rice) and from 12 to 7728 mg/L and median was 1300 mg/L at Majayjay (piggeries). The results reflect the predominant land uses upstream of the sampling sites influenced TSS concentration. Among the croplands, the rice-dominated system in Pagsanjan–Lumban catchment produced greater suspended sediment concentrations than the coconut (Cavinti) and vegetable (Lucban) dominated sub-catchments. Rice paddies have loose topsoil and are kept flooded most of the time. They are also connected and water flows between them. These management practices may allow suspended sediments to leave with the surface drainage water that drains into the Salasad River, Pagsanjan. Also, Inceptisols are generally more erodible soils (Krishnaswamy et al., 2001) and this was the dominant soil type in the rice growing region (Pagsanjan). At these sites another source of TSS may have been stream bank erosion but since all the monitoring was done in stream and no edge-of-field measurements