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Nutrient Load Estimates for Manila Bay, Philippines using Population Data

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Abstract – A major source of nutrient load to periodically hypoxic Manila Bay is the urban nutrient waste water flow from humans and industries to surface water. In Manila alone, the population density is as high as 19,137 people/km^2. A model based on a global point source model by Morée et al. (2013) was used to estimate the contribution of the population to nitrogen and phosphorus emissions which was then used in a water transport model to estimate the nitrogen (N) and phosphorus (P) loads to Manila Bay. Seven scenarios for 2050 were tested, with varying degrees and amounts for extent of sewage treatment, and population growth rates were also included. In scenario 1, the sewage connection and treatment remains the same as 2010; in scenario 2, sewage connection is improved but the treatment is the same; in scenario 3, the sewage connection as well as treatment is improved (70% tertiary); and in scenario 4, a more realistic situation of 70% primary treatment achieved with 100% connection to pipes is tested. Scenarios 5, 6, and 7 have the same parameters as 1, 2, and 3 respectively, but with the population growth rate per province reduced to half of what was used in 1, 2, and 3. In all scenarios, a significant increase in N and P loads was observed (varying from 27% to 469% relative to 2010 values). This was found even in scenario 3 where 70% of the waste water undergoes tertiary treatment which removes 80% N and 90% P. However, the lowest increase in N and P load into the bay was achieved in scenarios 5 to 7 where population growth rate is reduced to half of 2010 values. The results suggest that aside from improving sewage treatment, the continued increase of the human population in Manila at current growth rates will be an important determinant of N and P load into Manila Bay.

Key words – nutrient load, Manila Bay, anthropogenic pollution, watershed, population

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1. Introduction

Manila Bay is an important water body at the southwestern part of Luzon Island in the Philippines and serves as a major port and source of livelihood for many coastal communities along its 190 km coastline (PEMSEA and MBEMP-MBIN 2007). It has a 19,268 km^2 catchment area populated by 31 million people or 34% of the total population of the Philippines (BSWM 2012; NSO 2010) (Fig. 1). Results from five completed bay wide surveys in Manila Bay from 2010-2012 show the presence of hypoxia in the bay, which worsened through time especially during the wet season with near bottom bay-wide averages falling to as low as 2.10 mg/L. Eutrophication was also observed with elevated chlorophyll-*a* and inorganic nutrient levels (Jacinto et al. 2011; Sotto et al. 2014). To start looking at the dynamics of hypoxia and eutrophication in Manila Bay, the amount of land-based pollution from anthropogenic activities that flow into the bay was investigated.

Urban activities, though concentrated in small areas, dramatically alter regional and global nitrogen (N) and phosphorus (P) cycles especially in places near the coast (Svirejeva-Hopkins et al. 2011; Van Drecht et al. 2009). In Metro Manila alone, the population density was as high as 19,137 people/km^2 (NSO, 2010). Wastewater from urban areas is emitted as point sources with large nutrient loads from domestic sewage (including excreta from humans and animals), P-based detergents, agriculture, and industries (Morée et al. 2013). Detrimental effects of excessive nutrient loading into an ecosystem include eutrophication, oxygen depletion (hypoxia), harmful algal blooms (HABs), and fish kills.

In the Manila Bay watershed, the nutrient load problem is aggravated by the fact that in Metro Manila, only about 20%

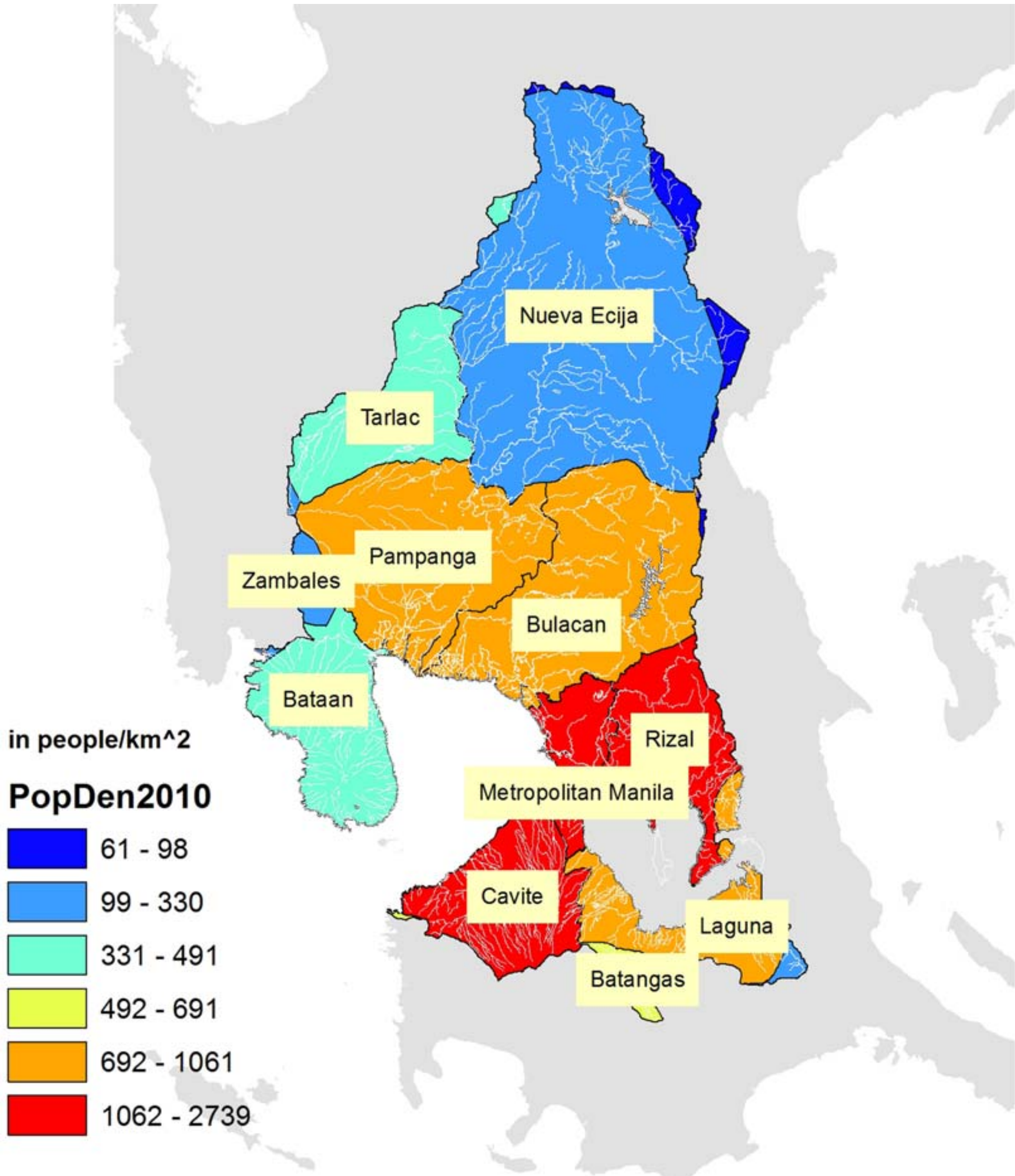

Fig. 1. The Manila Bay watershed, its rivers, provinces, and corresponding population density for 2010

of the population has sewerage services (The World Bank 2012). In 2005, only 8% of sewage was fully treated (up to secondary) (GEF 2005). Generally, industrial and commercial wastewater is discharged with very little or no treatment and most of the waterways in Metro Manila are heavily contaminated. Residential sewage constitutes about 65 - 75% of pollution in Metro Manila while the rest come from industries and solid waste dumped into drainage systems or into rivers and coastal areas (GEF 2005). In effect, most of the wastewater that drains out into the bay contains untreated sewage.

This study is a quick estimate on the effect of population alone on the nutrient flow from the watershed of Manila Bay using a point source and water transport model patterned after the global country scale inventory of urban nutrient flows in waste water of Moreè et al. (2013) but on a smaller scale. Since the sewage system in the Philippines is still largely underdeveloped, scenarios that tackle the effectiveness of sewage connections and treatment were investigated to help assess the significance of interventions related to sewage treatment. Results from this study will help in the management and rehabilitation efforts in the Bay and will be incorporated into a water quality and hydrodynamic model for the bay.

2. Methodology

General description of the model

The nutrient load model is composed of two parts: a point source (urban wasteflow) model and a water transport model, both calculated over a 10 km resolution grid. The point source model calculates the amount of N and P emission in a grid cell based on the land area and the number of people residing in that area. The emission is then fed into the water transport model, which then gives the nutrient load per cell based on a digital elevation model and a runoff model forced by annual precipitation. Different scenarios (Table 1) with varying degrees of sewage treatment and population growth rate are then tested and projections for the future are made.

The nutrient loads were calculated based on the flow chart shown in Fig. 2. Population data and other statistical data per province are used to calculate N and P emissions based on rates from the Food and Agriculture Organization of the United Nations (FAO). The N and P emissions per province are then distributed onto the grid, after which a water transport model, using digital elevation maps, annual precipitation, and flow direction, calculates the nutrient load flowing into Manila Bay.

A 5 × 5 minute (~10 × 10 km) grid was created with the limits in decimal degrees: 16.5 N 120 E and 13.N 122 E, which includes most of Luzon Island and the whole of the Manila Bay watershed encompassing 11 provinces listed in Table 2. A flow direction map was generated using a digital elevation map from SRTM (Shuttle Radar Topography Mission) at a 90- meter resolution (Jarvis et al. 2008).

Population data was obtained from the 2010 census by the National Statistics Office (NSO 2010) at the provincial level and was used as the baseline. Published NSO growth rates were used to project the population into future scenarios. The fraction of the population per province considered as urban was based on the definition by the NSO. A barangay/town (smallest political unit) is considered urban if it meets any of the following criteria: has a population size of 5000 or more, has at least one establishment with a minimum of 100 employees, has five or more establishments with 10 to 99 employees, and five or more facilities within a 2 km radius from the barangay hall. Otherwise, it is considered rural. Many barangays make up a province (NSO 2010). Coastal populations were identified as people living within 2 km from the coast whose emissions were considered to flow directly into the bay.

Sewage treatment

The percent connection to sewage pipes per province used was arbitrary with the default being 15% connection to sewage pipes representing a baseline scenario. Pampanga and Metro Manila, having slightly better sewage connections, are assigned 20 and 30% connection to sewage pipes respectively. Connection to pipes and subsequent sewage treatment was considered separate since construction of treatment plants often lag behind the construction of sewage systems by several decennia in many industrialized and developing countries (Van Drecht et al. 2009).

Treatment of population data

The population data was treated according to the schematic diagram shown in Fig. 3. Population data was separated into three categories: urban, rural, and coastal. Coastal people are classified as those living 2 km from the coast. Waste from people classified as living in urban areas either goes through sewage pipes or not while those living in rural areas have waste that either goes through sewage systems or is temporarily stored in septic tanks. Waste from those living along the coast goes directly to Manila Bay. Waste that goes through sewage systems undergoes N and P reduction due to treatment. For those without connections, the waste undergoes some nutrient retention as it passes through land and rivers. For waste that goes through septic tanks, there is retention of N and P in the tanks.

Gross Human N and P flows

N and P flows from humans come from human excreta and P in detergents. N estimates in human excreta are based on protein consumption from FAO data (preliminary) (FAO 2010). For this model, P content in detergents was considered uniform for all the provinces due to lack of available data, and therefore P emission is based on population density. For most countries for the period 1961 - 2000, country data on retail stage per capita protein consumption are available. N content in protein was set at 0.16 (Block and Bolling 1946) with the P consumption estimated from N using the N:P ratio of 10:1 based on a twentieth century N and P consumption data set for the United States by the US Department of Agriculture in 2012. Excretion is in the form of urine (80% of intake for N and 62% for P is lost) and feces (17% for N and 35% for P); 3% of N and P intake is also lost via sweat, hair and blood (Morée et al. 2013).

Table 1. Detailed description of the different experimental scenarios tested

Scenario name	Description	% connection to pipes	% primary treatment	% secondary treatment	% tertiary treatment
Baseline (2010)		30% for Metro Manila, 20% for Pampanga, and 15% for the rest of the provinces	15% for Metro Manila, 10% for Pampanga, and 5% for the rest of the provinces	10% for Metro Manila and 5% for the rest of the provinces	No tertiary treatment
Scenario 1 (2050)	Baseline conditions but with population increased according to the published NSO growth rates	30% for Metro Manila, 20% for Pampanga, and 15% for the rest of the provinces	15% for Metro Manila, 10% for Pampanga, and 5% for the rest of the provinces	10% for Metro Manila and 5% for the rest of the provinces	No tertiary treatment
Scenario 2 (2050)	Increased connection to sewage systems	100% connection to sewage systems	15% for Metro Manila, 10% for Pampanga, and 5% for the rest of the provinces	10% for Metro Manila and 5% for the rest of the provinces	No tertiary treatment
Scenario 3 (2050)	Improved sewage treatment	100% connection to sewage systems	10%	10%	70%
Scenario 4 (2050)	Improved sewage treatment but less tertiary treatment	100% connection to sewage systems	70%	10%	10%
Scenario 5 (2050)	Population increased using half of the published growth rates	30% for Metro Manila, 20% for Pampanga, and 15% for the rest of the provinces	15% for Metro Manila, 10% for Pampanga, and 5% for the rest of the provinces	10% for Metro Manila and 5% for the rest of the provinces	No tertiary treatment
Scenario 6 (2050)	Population increased using half of the published growth rates	100% connection to sewage systems	15% for Metro Manila, 10% for Pampanga, and 5% for the rest of the provinces	10% for Metro Manila and 5% for the rest of the provinces	No tertiary treatment
Scenario 7 (2050)	Population increased using half of the published growth rates	100% connection to sewage systems	10%	10%	70%

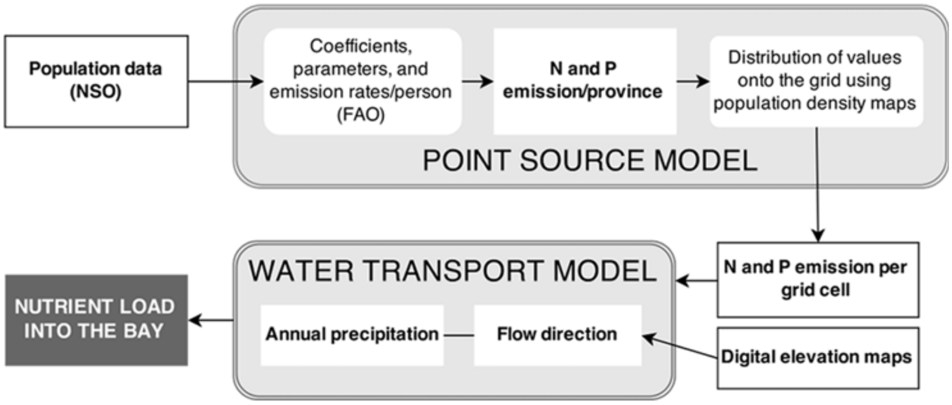

Fig. 2. Point source and nutrient load model flow chart

Table 2. Population data for 2010, % urban, % connected to sewage systems, and projected population for 2050 for the provinces considered to be in the Manila Bay watershed (2010 data from the National Statistics Office)

Province	Population (2010)	% Urban (2010)	% Connected to sewage (2010)	Population (2050)
Rizal	2,484,840	95.79	15	9,800,177
Laguna	2,669,847	83.49	15	10,529,842
Cavite	3,090,691	86.81	15	12,189,645
Batangas	2,377,395	44.35	15	9,376,415
Bulacan	2,924,433	77.80	15	7,463,625
Pampanga	2,014,019	78.61	20	5,140,101
Bataan	347,357	59.72	15	886,511
Zambales	534,443	82.43	15	1,363,985
Nueva Ecija	1,955,373	49.03	15	4,990,427
Tarlac	1,273,240	32.50	15	3,249,514
Metro Manila	11,796,873	100.00	30	26,253,044

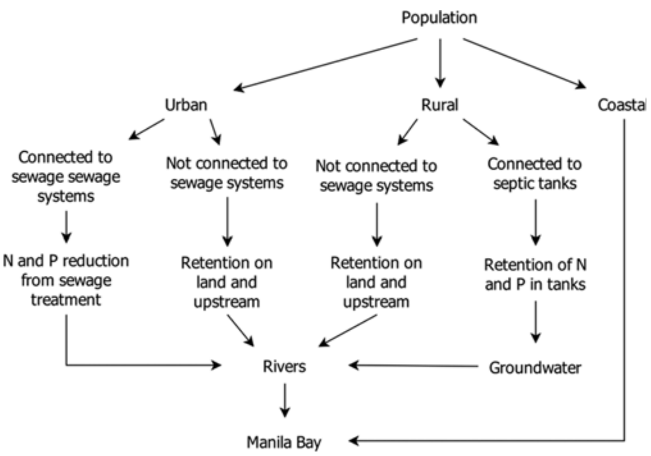

Fig. 3. Schematic diagram of the treatment of population data in the model

Losses of N and P and sewage treatment details

Estimated sewer leakage, biological degradation, nutrient particle settlement, and volatilization processes are 10% for both N and P (Morée et al. 2013). Primary treatment indicates 10% N and P removal, secondary treatment has 35% N and 45% P removal, while tertiary treatment has 80% N and 90% P removal (Morée et al. 2013).

Scenarios tested

Seven scenarios (Table 1) for 2050 were tested wherein the population increased according to the published growth rates by the NSO. In scenario 1, the sewage connection and treatment remains the same from 2010; in scenario 2, sewage connection is improved but the treatment is the same; in scenario 3, the sewage connection as well as treatment is improved (70% tertiary); and in scenario 4, a more realistic situation of 70% primary treatment achieved with 100% connection to pipes is tested. Scenarios 5, 6, and 7 have the same parameters as 1, 2, and 3 respectively, but with the population growth rate reduced to half of what was used in 1, 2, and 3.

3. Results and Discussion

Human activities are becoming an increasingly common source of heavy nutrient loading and in large well known systems like the Baltic and Black sea, aggravate the natural tendency towards eutrophic conditions which may lead to hypoxia. Nutrient loading from land to the coast can be separated into two broad categories: biogeochemical reactions from the land itself and materials corresponding to human production. In detail, human production includes domestic and industrial sewage, domestic animal waste, fertilizer, and atmospheric fallout from vehicular and industrial nitrogen emissions. Products like domestic and industrial sewage can be scaled more or less directly with the population density of the area (Smith et al. 2003). As a first estimate and to work with data that was readily available, population numbers were used in the model as a major input of nutrient loading and to represent the domestic sewage fraction.

In all scenarios, an increase in N and P load was observed even in scenario 3 where 70% of the waste water undergoes tertiary treatment. This shows that the increasing human population, sewage treatment, and pollution management in the Manila Bay watershed are important factors for the nutrient load to Manila Bay.

A map of the N and P load per grid cell is shown in Fig. 4 with the highest loads coming from Metro Manila, Bulacan, Pampanga, and the central part of the watershed. These coastal provinces may have a big impact on the bay since the waste generated from the people along and near the coast directly flow into the bay. Though Metro Manila has better sewage connections and has some degree of sewage treatment, the population density is very high making it a hotspot for nutrient loading.

Table 3 summarizes the total N and P load that can drain into the bay for the different scenarios as well as the percent increase from the baseline scenario. All the scenarios result in an increase in the N and P load into the bay. A greater increase is seen after connection to sewage pipes since these

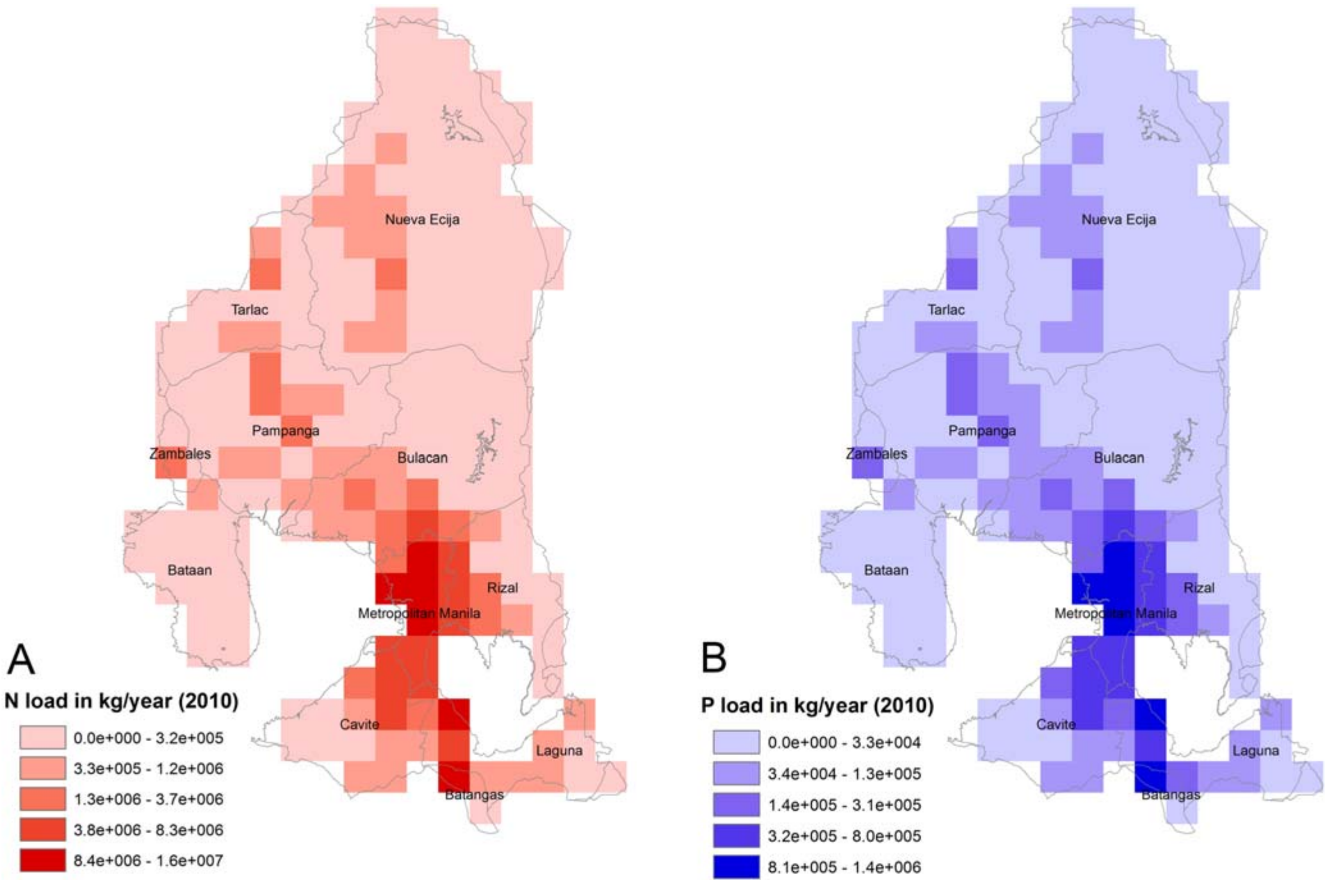

Fig. 4. (A) Nitrogen load and (B) phosphorus load map for the year 2010 (baseline scenario) for the whole Manila Bay watershed in kg N or P per year

Table 3. Total N and P loads and corresponding N and P increase for the different scenarios tested

Scenario name	Total N load (kg/yr)	Total P load (kg/yr)	% N increase	% P increase
Baseline (2010)	4.67E+07	4.54E+06		
Scenario 1 (2050)	1.64E+08	1.62E+07	250	257
Scenario 2 (2050)	2.66E+08	2.47E+07	469	444
Scenario 3 (2050)	1.22E+08	9.62E+06	161	112
Scenario 4 (2050)	1.67E+08	1.36E+07	288	232
Scenario 5 (2050)	9.83E+07	9.66E+06	110	113
Scenario 6 (2050)	1.58E+08	1.46E+07	238	222
Scenario 7 (2050)	7.29E+07	5.75E+06	56	27

go through a more direct route into the rivers and eventually into the bay. The least increase was observed for the scenario where 70% tertiary treatment is achieved at half of the projected population increase. Though this model is still under development, this first estimate shows that the current pollution and nutrient loading in Manila Bay will not decrease with better sewage connection and treatment mainly because of the expected high population growth.

Conclusion and Recommendations

These results, albeit preliminary, show that the current pollution and eutrophication problem in Manila Bay will not decrease with better sewage connection and treatment mainly because of the expected high population growth. This is relevant information for policy makers, stakeholders, and the national government. There may be a need to distribute the population growth centers by, for example, making living in the provinces more attractive in addition to measures that address the poor sewage system in Metro Manila and the surrounding areas of Manila Bay. Better nutrient use and recycling practices in agriculture can also be pursued. This study, however, does not address how agriculture and aquaculture derived inputs affect nutrient loading in the bay, which may be quite significant as well. Also, the fate of these nutrients and how they affect the dynamics of eutrophication and hypoxia in the bay should also be investigated.

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