Journal of Environmental Science and Management Special Issue 2-2016: 58-70 ISSN 0119-1144

Ecological Integrity of Pasonanca Natural Park: The Sustainability of Water Supply Under a Policy of Protected Areas

ABSTRACT

This study establishes the optimum thresholds and rating scales to evaluate the ecological integrity of Pasonanca Natural Park protected area in Zamboanga City, Philippines. Six indicators representing four key eco-hydrological attributes of sustainable water supply namely vegetation and soil at the riparian buffer zone, the hydrology and water quality of the stream, were assessed. Tree basal area was found to be high ranging from 56.08 m^2 ha^{-1} to 65.46 m^2 ha^{-1} in undisturbed sites. These values are higher than other tropical forests in Southeast Asia. Total organic carbon and total nitrogen were at critical levels. Mean streamflow was significantly declining at 0.101 m^3 s^{-1} yr^{-1} ($p<0.001$) suggesting the possibility of diminishing water supply in the coming years. The annual mean water turbidity was significantly increasing at 2.572 NTU yr^{-1} or 22.48% yr^{-1} ($p<0.001$) hinting at higher frequency of chemical treatment and increasing risk of exposure to disinfection by-products in drinking water. Annual high turbidity day count occurred more than 90 days from 2007 to 2013 with the highest at 181 days in 2011. The overall ecological integrity rating of Pasonanca Natural Park is poor. The withdrawal of the riparian buffer zone from strict protection status and its reclassification to special use zone to pave the way for active management should be considered.

Key words: *old growth forest, turbidity, water treatment, disinfection-by-products*

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INTRODUCTION

The National Integrated Protected Areas Systems Act of 1992 (RA 7586 or the NIPAS Act) defines protected areas as "portions of land and/or water set aside by reason of their unique physical and biological significance, managed to enhance the biological diversity and protected against destructive human exploitation." While multiple-use zones are allowed in protected areas where human settlements or indigenous cultural communities exists, undisturbed old growth forests with high biodiversity values are generally placed under strict protection status, i.e. where all forms of human activity is prohibited except those related to scientific studies (5.23, Rule 5, DENR Administrative Order 2008-06).

A number of studies have reported the ecological risks posed by the absence of human influence in the management of protected areas as well as the rational justification for and the implications of non-use of the abundant natural resources to in relation to social justice and economic development of the region of the protected area (*Wilshussen et al. 2002; Ervin 2003; Dudley and Stolton 2005*). Although traditional belief still holds that human interference is not important in the management of old growth forest ecosystems on the assumption that energy inflows and outflows are balanced, current researches provide evidence to support the existence of a dynamically unstable complex forest ecosystem; thereby debunking as scientifically flawed the traditional static equilibrium theory usually ascribed to old growth forests (*van Eeten and Roe 2002*; *Calder et al. 2007*; *Jorgensen et al. 2007*; *Chakrabarti and Ghosh 2009*). These same studies have shown that in the absence of human intervention, the accumulation of forest vegetation is limited only by the amount of energy available to the ecosystem. In this respect, vegetation, especially those in tropical forests, have been known to exhibit exceptional productivity owing to the abundant sunlight and rainfall throughout the year.

This evolving knowledge and understanding of the existence of a complex forest ecosystem raises serious questions regarding the relevance and effectiveness of placing large areas of undisturbed old growth forest under strict protection status (*Ervin 2003; Dudley and Stolton 2005; Spieles 2010*). As the debate for or against absolute protectionism continuous to rage to this day, the profound impacts of a degraded ecosystem because of neglect continue. This brings to fore the urgent need for facts-based assessment of the effectiveness of the protected areas strategy in order to provide guidance on how to rectify scientifically flawed practices and unfounded traditions especially if these have been embedded in environmental conservation policies.

One of the most significant outcomes in the discussion of issues relating to the sustainability of water supply is how to determine the effectiveness of the protected areas strategy as it is applied to natural parks assigned with multiple objectives such as that for biodiversity and as a source of drinking water. The emerging trend during the last decade is to assess the ecological integrity of the area of interest. *Mangold* (*1998*) defines ecological integrity as "a concept that expresses the degree to which the biophysical components of an ecosystem i.e., their structure, composition and processes, are present, functioning and capable of self-renewal." From a utilitarian perspective, an ecosystem possesses ecological integrity if it is able to sustain its provisioning, regulating and supporting services (*Millennium EcosystemAssessment 2005*). Ecosystems lose their ecological integrity if the structure or pattern of essential biophysical components are degraded. Consequently, the persistence of human life is threatened.

Many ecological integrity assessment tools have been developed to evaluate biodiversity programs (*Young and Sanzone 2002; Unnasch et al. 2009; Albano 2012*). Unfortunately, these reports seldom extend to the investigation of the status of the biophysical elements associated with other ecosystems services such as water supply and purification or the supporting services rendered by the soil horizon. This study addresses this gap by presenting an indicator-based ecological integrity evaluation tool that is easy to use, simple, cost effective, analytically sound and relevant to policy and lawmakers alike. The primary purpose is to provide a protocol for monitoring important changes in the ecological states using critical indicators that may signal potential concerns.

After more than two decades of absolute protectionism under the policy of protected areas, there appears no comprehensive literature on the ecological integrity of Pasonanca Natural Park in Zamboanga City, Philippines. The ecological integrity evaluation is significant in providinginformation on severity, prevalence, scope and distribution of problems that hamper the water supply objectives, if any, in the watershed. Moreover, it presents an opportunity to assess the far-reaching social and economic implications of the current ecological state of Pasonanca Natural Park with the intension that critical gaps between policy and realities in the ground are revealed and addressed based on the resulting scientific facts.

The specific objectives of this study are to select key eco-hydrological indicators, develop the metrics of optimum thresholds and their corresponding rating scales and use this tool to determine the ecological integrity of the Pasonanca Natural Park. Thus, four key ecological attributes are biotic condition or the status of vegetation; chemical concentration influencing the formation of and contributing to the structural stability of soil; the hydrology for the occurrence, distribution and circulation of water indicating availability of surface water at any given time; and water quality- pointing to the suitability of the drinking water source area for public water supply. These attributes are represented by six indicators of sustainability namely: status of tree basal area; status of soil total organic carbon; status of soil total Kjeldahl nitrogen; trend in streamflow; trend in water turbidity; and frequency count of high turbidity days. The status, trends and frequency are compared to optimum thresholds established for this study derived either from available literature or from conventional industry practice.

METHODS

Description of the study site

Pasonanca Natural Park (6°57'-7°9'N; 122°00-122°08'E) in Zamboanga City, Philippines is primarily an undisturbed old growth watershed (12,107 ha) with high biodiversity (**Figure 1**). It is a protected area by operation of the NIPAS Law and the core watershed is classified as strict protection where any form of human activity is regulated, except those related to scientific studies. It is a mixed dipterocarp forest similar in phylogeny to all other mixed dipterocarp forests in the *Malesiana* region (*Maury-Lechon and Curtet 1998*). More than half of the area of the Pasonanca Natural Park is old growth and basically remain undisturbed although a section at the northernmost area had been subjected to indiscriminate logging prior to the establishment of the protected area status in 1999.

Pasonanca Natural Park protected area is a river basin sitting along the north-to-south direction and the water is drained by Tumaga River. It is composed of two major sub-watersheds locally referred to as *Misoloy* (68-830 meter above sea level) located on the eastern side of the basin and Tictipun (70~1300 masl) on the western side. Approximately 21 km from its northernmost tip to the dam outlet, Tumaga River has been the primary source of drinking water for Zamboanga City (pop. 807,129 in 2010) since 1914. The local water utility abstracts raw water by run-of river scheme. Water treatment by conventional method i.e., coagulation, sedimentation, filtration and chlorination, is performed when water turbidity exceeds 5.0 Nephelometric Unit (NTU).

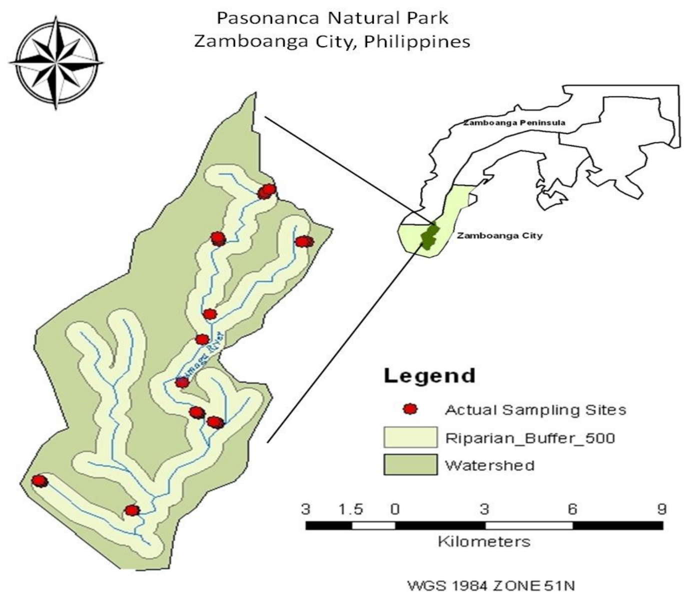

Figure 1. The location and distribution of the sampling plot at the Pasonanca Natural Park.

Sustainabily Metrics and Rating Scales

The developed ecological integrity evaluation tool was patterned after the work of *Young and Sanzone* (*2002*). The recommended optimum operating points were summarized from available literature applicable to tropical conditions or industry practice. The indicators were selected for their intrinsic value including availability, cost-effectiveness, policy relevance, measurability and analytical soundness. To determine the ecological integrity of the Pasonanca Natural Park, the numerical values of each key eco-hydrological indicator was compared with the values (**Table 1**). The final rating for each parameter was expressed using stoplight symbology such as green for good, yellow for caution and red for poor ecological integrity status (*Tierney et al. 2009*). The overall ecological integrity rating was determined by applying the one-out-all-out principle (*European Environmental Bureau 2005*). This means that the ecological integrity status of the subject area is assessed by its worst performing indicator.

Although there are many other eco-hydrological indicators that can be used to assess the current status of the protected area, the application of the one-out-all-out principle may render other correlated indicators redundant. In this study, each of the four key eco-hydrological attributes was evaluated using only one but significant indicator for each. The determination of their optimum operating thresholds is explained in the following:

Biotic Condition. This biophysical component of pattern is represented by tree vegetation. The indicator is the number of trees per unit area of land. The metrics selected is total basal area of all trees with girth diameter ≥5.0 cm at breast height (1.30 m above the ground). Basal area is the cross-sectional area of a tree trunk calculated assuming a circular

Table 1. Assessment Tool for Evaluating the Ecological Integrity of a Riparian Buffer Zone.

Type	Ecological Attribute	Indicator	Unit	Ecological Integrity Rating		
				Good (green)	Caution (yellow)	Poor (red)
Pattern	Biotic condition	tree biomass	$m^2 ha^{-1}$	15.65 - 21.91	> 21.91; ≤ 31.0	< 15.65; > 31.0
Pattern	Soil Quality	total organic carbon	%	≥ 4.5 %	2.0 - < 4.5 %	> 2.0 %
		total Kjeldahl nitrogen	%	≤ 0.225%	> 0.225; < 0.45%	≥ 0.45%
Process	Hydrology	streamflow	$m^3 sec^{-1}$	stable or increasing	decreasing but not significant (p > .05)	significantly decreasing (p < .05)
Pattern	Water Quality	turbidity	NTU	stable or decreasing	increasing but not significant (p > .05)	significantly increasing (p < .05)
		high turbidity day	days	> 30	31-90	> 90

bole. Tree basal area is computed at scale of a stand. Although tree biomass would be a better measure under current circumstance, the difficulty lies in the comparative power of this indicator because of many different allometric equations and assumptions in their calculations. Converting to biomass in terms of mass dimension is not possible in the absence of species data. Thus, the researchers revert to basal area measurement as it is species-independent. Nonetheless, tree basal area is significantly correlated to tree biomass (S*lik et al. 2010*), thus any of the two indicators may be a suitable measure of vegetation in the future.

The biotic condition is significant in the ecological integrity evaluation for three main reasons: First, trees are major conduits of the hydrologic cycle through the processes of evapotranspiration. Studies show for instance, that the average water loss by evapotranspiration in a tropical undisturbed rainforest in the Philippines could be as high as 41-52% of rainfall (*Combalicer et al. 2010*) and up to 72% of rainfall in a Malaysian forest (*Kumagai et al., 2005*). The root systems provide the conduit to facilitate plant-soil dynamics through the mechanisms of hydraulic lift and redistribution. These mechanisms have been known to reinforce transpiration by 30-50% during normal and below normal precipitation (*Domec et al. 2010; Neumann and Cardon 2012*). The impact of tree biomass on water loss is mutually reinforcing i.e., more trees means more water is lost through the combined processes of evapotranspiration. Second, the canopy of trees play a vital role as interceptors of rainfall, thus reducing their erosive capacity and attenuating overland flow. Intercepted water is returned to the atmosphere by evaporation and therefore does not contribute to surface water supply in the watershed. Finally, vegetation contributes to the the stock of organic material on the land. Soil organic matter (SOC) contributes to the formation of soil organic carbon, the basis for structural stability of the soil horizon. However, SOC in surface water can interfere in the treatment process and risk the production of carcinogenic disinfection-by-products during the chlorination of drinking water (*USEPA 2010*).

There is no exact quantity of tree basal area that is considered optimum for any specific forest type even if voluminous studies have been undertaken on stocking density in many forests elsewhere in the world. It is commonly agreed in silviculture that stocking control is primarily an exercise in space allocation with respect to crown closure and competition-induced mortality (*Powelson and Martin 2001*). Stocking refers to the quantity of trees per unit area. This follows that the ideal stocking level is species-specific and site-specific. *Kassim* (*2001*) noted that trees in dipterocarp forests require more space than those in non-tropical regions. Trees in many old growth forests even in temperate and other tropical regions vary greatly but measurements of density in the vicinity of 30-35 $m^2 ha^{-1}$ is common (*Rice et al. 1998; Foli et al. 2003*). Forests with basal area higher than these values tend to self-organize by self-thinning or resort to density-induced mortality *Cochran et al.* (*1994*) and *Williams* (*2003*) recommended an optimum stocking density between 15.65 $m^2 ha^{-1}$ and 21.91 $m^2 ha^{-1}$ with maximum at 31 $m^2 ha^{-1}$. These calculations converged with those of *Rice et al.* (*1998*), *Foli et al.* (*2003*) and *Schmid and Mata* (*1992*); with the latter having observed the natural outbreak of mountain pine beetle in stands if tree biomass beyond this limit.

On the other hand, stands below this optimum level may exhibit canopy gaps (*Calder 2001; Hoshizaki et al. 2004*). The break in the tree crown may be beneficial if it provides opportunity for sunlight to penetrate the understory but detrimental if raindrops erode loosely aggregated and uncovered topsoil. In production forest terms, stands with thin canopy cover are classified as understocked while those that exceed the maximum level are overstocked (*Long and Daniel 1990; Corlett, Naylor and Pinto 1998*). Overcrowding could result in self-thinning and mortality of trees. For this study, the ecological integrity rating is poor (red) for vegetation density outside the lower and upper limits. Fully stocked stands are good or desirable (green). Fully stocked stands are good or desirable. Stands basal area between 21.91 $m^2 ha^{-1}$ and 31 $m^2 ha^{-1}$ may indicate warning or caution (yellow).

Chemical Concentration in Soil. The structural stability and water-holding capacity of the soil are influenced by the quantity of soil organic matter (SOM) measured in terms of total organic carbon (TOC) (*Carter 1992; Amacher et al. 2007*). The physical, chemical and biological functions of SOM are important for soil formation but natural organic matters transported into raw water are precursor of carcinogenic disinfection by-products (*USEPA 2010*). There is a need to delicately manage TOC so that these are not leaked into water bodies during overland flow.

The quantity and condition of SOM is influenced by climatic variables, topography, geology and soil, as well as the amount and character of the organic material from vegetation (*Bronick and Lal 2005*). Loosely aggregated soils are vulnerable to the erosive effect of raindrops. They contribute to accelerated erosion. With the limited literature on optimum TOC for forest soil, this study relied on information recommended for agricultural soils because both have similar management objectives. The recommended optimum operating points for TOC is 4.5-5% for efficient soil development and structural stability (*Carter 1992; Amacher et al. 2007)*. Howard and

Howard (1990) suggest at least 2.0%. Management target is towards maximizing TOC. Hence, ecological integrity rating for TOC $\geq$ 4.5% is good (green); between 2-4.5% is caution (yellow) and below 2% is poor (red).

Nitrogen in the soil is beneficial to plant growth only in its transformed state as nitrates (*Bai et al. 2012*). Nitrification is the conversion of ammonium nitrogen, generated from the decomposition of SOM, to nitrates. Nitrates (NO_3-) are highly labile inorganic form of nitrogen that are easily leached to groundwater supplies or transported to surface waters by overland flow (*Skipton et al.2008*). Excessive nitrates in drinking water have been known to cause blue baby syndrome in infants and was associated with some form of cancers in adults (*Self and Waskom 2008; Zhang et al.2012*). Reducing the incidence of nitrogen saturation, particularly in hydrologically sensitive areas such as the riparian zones, increases the chance that these are not leaked to contiguous water bodies (*Walter et al. 2000; Agnew et al. 2006*).

Total Kjeldahl nitrogen (TN) measures the amount of nitrogen in the soil. While it is important for vegetation growth, their presence in streamflow is undesirable. The balance between desirable TOC and TN is expressed in terms of C:N ratio. Values between 20-25 have been noted to aid in the proper soil development while keeping in check the tendency for soil nitrogen saturation (*Ohta and Syarif 1998; Yoh 2001*). Hence, TN less than 0.225% is good (green); TN greater than 0.225% but less than 0.45% is caution (yellow); and TN greater than 0.45% increases the risk of nitrates deposition in water bodies thus a poor(red) rating is appropriate.

Hydrology. Streamflow, the most important hydrology indicator, refers to the quantity of surface water passing a given point in time. Streamflow is influenced by rainfall and the condition of groundwater in the watershed (*Burn and Hag Elnur 2002*). It possesses two components, namely: stormflow which reflects the immediate contribution of runoff to streamflow after a rainfall event; and baseflow which represents the groundwater contribution to streamflow (*Ojha, Berndtsson and Bhunya 2008*). Streamflow trend is determined using quantitative techniques of regression applied to seasonally-adjusted mean monthly data covering a period of at least 20 years (*Raghunath 2006*). At .05 level of significance, the coefficient of regression may either signify an increasing, decreasing or stable trend. Streamflow will persist in watersheds with good ecological integrity, thus a stable or increasing streamflow is desirable or good (green). A decreasing trend although it may not be significant, should already signal caution (yellow) while a significantly decreasing trend is poor (red) ecological integrity.

Water Quality. Turbidity is an important water quality indicator because it is sensitive to changes in the biophysical components and processes in the watershed. Turbidity indicates murkiness– a physical property indicative of the quantity of suspended colloidal particulates that are is carried in suspension in water . Sediments and particulates influence color, odor and taste. Safe drinking water must be colorless, odorless and tasteless (*PNSDW 2007*). Sediment inflow to rivers is essential to aquatic ecosystems but frequently occurring high sediment deposition can be ecologically suffocating and unacceptable to water supply.

Evaluation of turbidity trend is determined using quantitative techniques of regression. At .05 level of significance, a stable or decreasing trend is good (green); an increasing trend although not statistically significant is caution (yellow); a significantly increasing trend is poor (red) ecological integrity.

In the water industry (*DEQ 2010*), high turbidity day (HTD) count not exceeding 30 days per year is tolerable. High turbidity day occurs when mean daily turbidity exceeds 5.0 NTU. .The HTD occurring more than 90 days per year is not economically acceptable, or hence a poor (red) rating. More high turbidity days means increasing requirement for of chemical for use in the water treatment, longer treatment hours, lesser production and more treatment residues to dispose. HTD between 30-60 days yr^{-1} signals caution (yellow). Signifying At this condition, the growing persistence of disturbances could be originating in the riparian buffer zone or from other hydrologically sensitive areas in the watershed (*Agnew et al. 2006*).

Data Gathering and Analysis Techniques

Primary data for trees and soil were collected from May to September 2013. A stratified random method was applied to determine the location of potential sampling plots in three elevational gradients of Pasonanca Natural Park namely: lowland (96- 350 masl); middle (350-750 masl) and high elevation (750-1200 masl). Forests in the lowland and middle elevations are old growth and undisturbed. High elevation is characterized as secondary forest following almost two decades of strict protection. A 250-m riparian zone was delinated along the 21 km stream reach and pre-identified the location of 21 points distributed uniformly in increasing elevation gradients within the riparian zone using GIS. Three sites located above 800 masl were not visited due to safety and security concerns. The rainy season prevented us from identifying substitute locations. Within the time frame to conduct the study, only 18 macroplots were accomplished (lowland elevation, n=6; middle elevation, n=7; high elevation, n= 5).

One macroplot (15-m radius) constitutes a stand (**Figure 1**).

A direct inventory of live trees ≥ 5.0 cm diameter at breast height (dbh) were conducted in a 15-m radius diameter macroplots (n=18). The basal area of each tree trunk was calculated assuming a circular bole. The total basal area per unit ha was calculated computed using the an appropriate expansion factor (*Pretzch 2009*). A total of 792 trees were inventoried. The means and standard deviations were used to describe the data.

Composited soil samples (15 cores) were taken within 2-m diameter plots along the riparian zone (n=27) in four hillslope gradients namely: flatlands, lower slope, midslope and upper slope (*Carter and Gregorich 2008*). Soil samples were analyzed for total organic carbon (TOC) using the Walkley-Black dichromate method and total Kjeldahl nitrogen (TN) at the Regional Soils Laboratory of the Department of Agriculture. The TN represents the total of organic nitrogen (N), ammonia (NH_3) and ammonium (HN_{4+}). The mean and standard deviation of TOC and TN were used to describe the data.

Streamflow (1983-2008) and water turbidity data (2007-2012) were obtained from the Zamboanga City Water District, the local water utility that secures the Pasonanca Natural Park. Measurements were taken at the dam (control station) and at the water treatment plant for streamflow and turbidity, respectively, for the purpose of estimating production volumes and rates of chemical dosages. Monthly mean streamflow and monthly mean water turbidity were summarized from hourly observations. Mean monthly streamflow refers to the arithmetic mean of 30-day mean streamflow. Mean daily turbidity refers to weighted average of hourly turbidity (*Holder 1985*). Daily mean turbidity which exceeded 5.0 NTU was counted as high turbidity day (HTD). The trend of the time series of seasonally-adjusted monthly mean for streamflow and turbidity were obtained using simple linear regression evaluated at .05 level of significance.

RESULTS AND DISCUSSION

Comparing the results with the optimum operating thresholds in **Table 1**, the ecological integrity of vegetation, water quality and hydrology were all evaluated as poor (red) whereas soil quality was caution (yellow) (**Table 2**). The biotic condition is poor in all the three elevations. The chemical concentration in the soil shows that there is a need to balance the requirements for soil organic matter (SOM) as it is a vital component in the stability of the soil. Under saturated conditions, SOM could be carried into the stream during overland flow. Moreover, SOM in water interferes with the treatment process and is a precursor of disinfection-by-products.

Tree basal area, streamflow, water turbidity and HTD were worst performing indicators. Because the rates of material flows and processes in the watershed are inextricably linked, it is inevitable that the poor ecological integrity status of the Pasonanca Natural Park could suggest that the sustainability of water supply as well as and the other associated ecosystem services such as biodiversity are at risk too.

Biotic Condition

Within the boundary classified as strict protection zone of Pasonanca Natural Park, vegetation dominated the forest structure from the understory to canopy. The result of mean tree basal area at the lowland undisturbed old growth stand (n=6) is was more than twice the optimum limit at 56.08 $m^2 ha^{-1}$ (±31.07SD). This represented a mean of 328 trees ha^{-1}. One stand was found to have a good status (basal area = 19.48 $m^2 ha^{-1}$). The other stands were overstocked by 73-300%. At the middle elevation, the mean tree basal area of at the hill undisturbed old growth stand (n=7) was 65.46 $m^2 ha^{-1}$ (±35.89SD). Mean trees ha^{-1} was 536. The high variability indicated the presence of a few large or very large trees in the macroplots. Stands were overstocked by 50-186%. At high elevation secondary forest stand (n=5), the mean tree basal area was 39.40 $m^2 ha^{-1}$ (±8.59SD) or 771 trees ha^{-1}. The stands were overstocked by 34-142%. The relatively uniform girth dimensions of young trees at this elevation suggest a forest successfully recovering from the degrading effects of illegal logging of the 1990s. Unfortunately, However, the steady accumulation of organic matter for young trees could put more pressure on water supply in this stratum as more young trees will require more water for growth and maintenance.

Comparatively, tree vegetation at the undisturbed sites of the Pasonanca Natural Park was highest among several dipterocarp old growth forests under protected area status in Southeast Asia. For instance, Lambir Hills in Sarawak, Malaysia registered 43.3 m2/ha for trees greater than 1 cm dbh (*Lee et al. 2002*). At the Ulu Temburong in Brunei, tree basal area for ≥ 5 cm dbh declined from 41.2 $m^2 ha^{-1}$ in 2000 to 39.18 $m^2 ha^{-1}$ in 2007 *(Hedl et al. 2009*).

Chemical Concentration in Soil

The chemical attributes of soil indicates its quality. The mean TOC and TKN were homogeneous across all hillslope gradients. Mean TOC was 3.11% (±0.84 SD) to 3.54% (±1.09) in the flatland to midslope areas, respectively.

Table 2. Status and trends of key eco-lydrological attributes of the of the Pasonanca Natural Park.

Ecological Attribute	Indicator	Scale of Observation	Status and trend	Ecological integrity status
Biotic Condition	tree biomass	stand	56.08 - 65. 46 m^2 ha^{-1}	🔴
Soil Quality	Total organic carbon	stand	3.11 - 4.31 %	🟡
	Total nitrogen	stand	0.24 - 0.29 %	🟡
Hydrology	Streamflow	river basin	Significantly decreasing ($p<0.001$) at 0.101 m^3 s^{-1} yr^{-1}	🔴
Water Quality	Turbidity	river basin	Significantly increasing ($p<0.001$) at 22.48% yr^{-1}	🔴
	Annual high turbidity day	river basin	> 90 days	🔴

Note: Based on the "one-out-all-out principle," the overall ecological integrity of the area is determined by the worst performing indicator(s)

The mean upland TOC was 4.31% (±1.21% SD). The TOC values were 4-31% below the optimum threshold indicating mild to moderately disaggregated soil. The ecological integrity status of soil with respect to TOC is was rated caution (yellow). Total Kjeldahl nitrogen is was in the range 0.24% (±0.6% SD) to 0.29% (±0.11% SD) at the midslope and upper slope, respectively, with flatland and lower slope TN values in between. There is was no significant difference in the TN across the gradients but this also to points to potential N saturation which could increase the risk for nitrate leaching. Based on these findings, the ecological integrity status of Pasonanca Natural Park with respect to TN assessment is caution (yellow).

Hydrology

Trends in hydrology reflect the rates and efficiency of the hydrological processes. Streamflow for the 26-year period of record is significantly decreasing ($p=.0001$) by 0.101 m^3 sec^{-1} annually suggesting poor (red) ecological status (**Figure 2**). The decline in streamflow could be exacerbated by the extremes of rainfall and drought. The increasing frequency and severity of fluctuations could cause the ecosystem to "flip" irreversibly to an altered state unfavourable to water supply. *Lindenmayer et al.* (*2011*) warned about a "landscape trap"- a condition where ecosystems retain their structure but lose out on their functionality due to ineffective hydrological processes, among other. Under this circumstance, restoration can be tedious, costly or and even impossible (*Osborne and Kovacic 1993; van Eeten and Roe 2002*).

It is difficult to explain the factors directly contributing to decreasing streamflow at the river basin scale of Pasonanca Natural Park, however, the continuously accumulating vegetation at the secondary forest could impact on demand for groundwater in the higher elevation. Subsequently, contributory effluent streams in the middle and lowland elevations that rely on groundwater could dry up due to the receding the water table.Studies have shown a direct relation between trees and streamflow. For instance, *Locatelli and Vignola* (*2009*) observed that decreasing baseflow in a stream was directly attributed to the presence of trees, despite the good infiltration capacity of the soil and sufficient rainfall inputs. *Davidson et al.* (*2011*) attributed the active water withdrawal by plants to the presence of roots in most levels of the soil horizon. They found that it took only 0.1g cm-3 of root biomass at 3-m depth to draw down significant water stocks. *Molnar and Ramirez* (*2001*) further noted that the decreasing streamflow in Rio Puerco Basin in New Mexico was induced by higher transpiration due to increased rainfall.

In his separate study of a forest ecosystem, *Bruijnzeel* (*2004*) attributed the decreasing baseflow to poor infiltration capacity of the soil, the presence of numerous young trees and accelerated erosion. In another similar study, *Razafindrabe et al.* (*2010*) suggested that regular tree density control can could improve baseflow and reduce soil loss. Under the current practice of non-human interference in the management of the biotic elements at Pasonanca Natural Park, setting a cap to water abstraction not exceeding 40% of streamflow at any time will allow the watershed to perform such other vital environmental services e.g., river flushing (*European Environmental Bureau 2010*).

Water Quality

Mean monthly water turbidity was significantly increasing ($p<0.001$) at 2.572 NTU yr^{-1} or 22.487% annually (**Figure 3**). The increase in water turbidity raises not only serious health and safety concerns to water consumers but could also imply financial instability of the local water utility because costs accruing to more chemical coagulants and water treatment time increase with increasing turbidity.

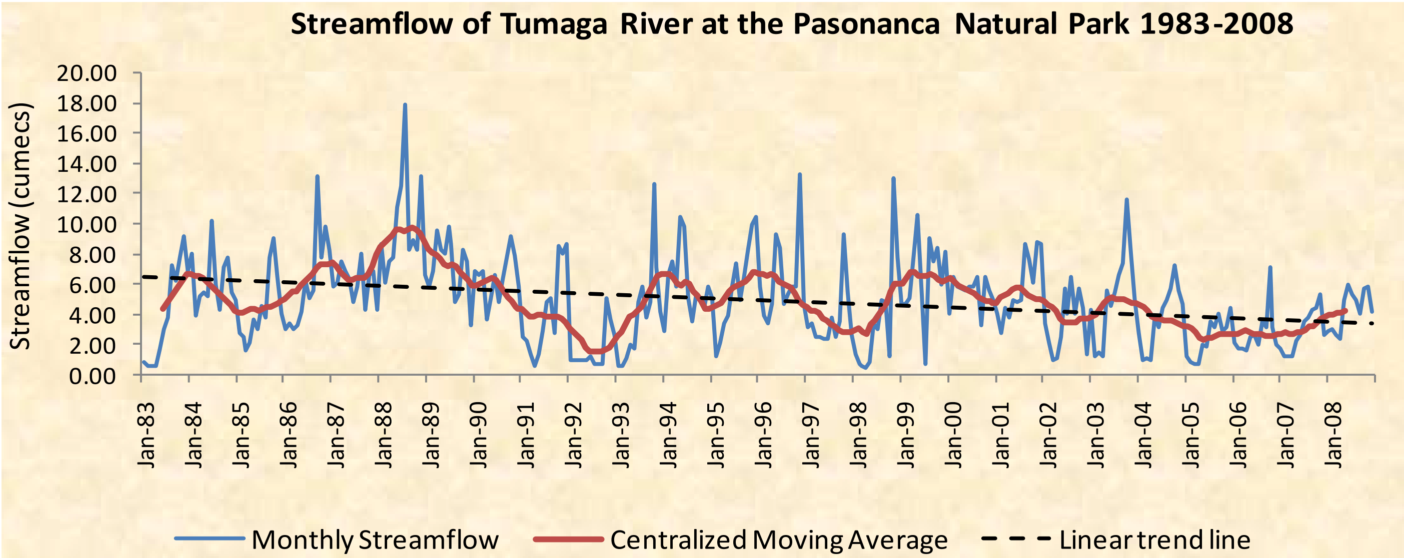

Figure 2. Streamflow trend is significantly decreasing ($p<0.001$) at 0.101 $m^3 s^{-1} yr^{-1}$.

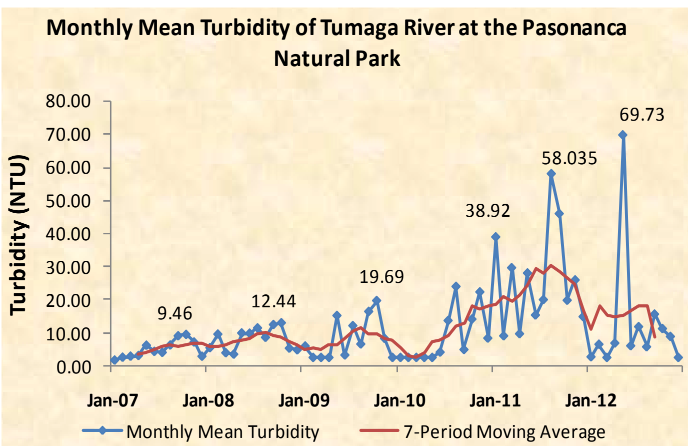

Figure 3. Mean monthly turbidity is significantly increasing ($p<0.001$) at 22.48% per year.

The non-linear increase was observed beginning late 2009 and continued through the rest of the years until 2012. High turbidity day (HTD) counts occurred more than 90 days with the highest count at 181 days in 2011 (**Table 3**). The highest single turbidity spike recorded in May 2012 was 2782 NTU.

Water Quality and Rainfall

It is difficult to explain these findings in the absence of on-site rainfall data and information on the location of hydrologically sensitive areas which are purported sediment sources (*Ziegler et al. 2006*). Subsequent interviews with watershed managers revealed that while background turbidity i.e. water turbidity on a clear day, is less than 1.0 NTU, the high turbidity day events were always induced by rainfall in the watershed.

Table 3. Annual frequency count of high turbidity day at the Pasonanca Natural Park.

YEAR	HTD*
2007	104
2008	171
2009	104
2010	133
2011	181
2012	135
2013	155

*HTD refers to High Turbidity Day, i.e., average water turbidity is greater than 5.0 NTU>

On the basis of water turbidity assessment, the ecological integrity status of Pasonanca Natural Park is poor (red). The implementation of corrective structural controls to mitigate sediment loading into the river is deemed necessary. Structural modification of stream banks and the design of appropriate buffer zones have been employed to improve water quality over time (*Reitner et al. 2009*). Meanwhile, in the absence of a costly structural remedy, timely public advisories with regards to water quality could empower people to make informed decisions with respect to their drinking water. In addition, the abstraction for public water supply should be withheld at some critical level of turbidity e.g. 1000 NTU, to avoid the health risks associated with treatment of highly turbid raw water and the formation of carcinogenic disinfection-by-products (*USEPA 2010*).

Rainfall is both a natural disturbance and a stressor. Climate change characterized by extreme rainfall and prolonged droughts threaten not only to water quality but to the ecological integrity of natural complex systems as well

(*IPCC 2008*). Hydrology and hydrochemistry attributes of the watershed are both affected by the magnitude, intensity, and timing of rainfall. Rainfall exerts a tight control on water supply as it affects vegetation, soil, streamflow and water turbidity (*Garbrecht, van Liew and Brown 2004*). Although rainfall provides recharge opportunities to the soil through the mechanisms of infiltration however, it has the potential to increase streamflow velocity to cause bottom sediments in stream channels to resuspend and impair water quality (*Zhang and Shi 2004; Wang, Edwards and Goff 2010*). Implementing structural barriers e.g. riparian buffers, to reduce the velocity of overland flow could confine sediments and other organic debris within the terrestrial domain (*Ziegler et al. 2006; Klapproth and Johnson 2009*). Rainfall, a distinct indicator of climate change, should be recognized and integrated in planning when ecological integrity is an endpoint objective. In the absence of innovative strategies to improve water supply sources, the run-of-river scheme of abstraction, as it is practiced at Pasonanca Natural Park, could be obsolete, economically infeasible and unreliable in the face of extreme rainfall owing to climate change.

Reliability of the Ecological Integrity Evaluation Tool

Evaluation tools are crucial to the determination of the success or failure of a program. Generally, the selection of criteria and their corresponding indicators or metrics of sustainability depend on many factors but analytical soundness, cost-effectiveness and policy relevance are among the major considerations (*Andreasen et al. 2001; Jorgensen et al. 2010*). These requirements offer wide latitude of choices to policy-makers. What sets ecological integrity (EI) evaluation tools from other environmental program evaluations tools is that EI tools are specific to the assessment of status and trends of patterns or processes of the biological and physical elementsin aquatic and terrestrial ecosystem (*Young and Sanzone 2002*).Their indicators are almost similar across different ecosystems. Moreover, the scale of application of the EI tool must be at the watershed level as it possesses the capability to integrate the contribution of each sub-systems into a whole (*Botkin and Keller 2000; Innis et al. 2000*). Building on the principle of environmental unity and systems theory, the ecological and hydrological attributes are interlinked in a way that events in a sub-system produce a synergistic reaction in another (*Ramo and St. Claire 1998*). The reliability or the degree to which the EI tool produces stable and consistent results, lies in the ability of each key attribute EI rating to confirm the others. The requirement for long-term streamflow and turbidity monitoring reinforces the robustness of the tool (*Raghunath 2006*). As applied to Pasonanca Natural Park, the EI tool shows poor rating for three eco-hydrological attributes- biotic condition, hydrology and water quality.

Active Management at the Riparian Zones of the Protected Areas

Active management generally refers to practices or prescriptions directly applied to conserve the resource. Active management is the antithesis of strict protection (also referred to as absolute protection, passive management or human non-interference) -practices that keep people out of the protected area. Although absolute protectionism have their benefits, *Wilshussen et al.* (*2002*) strongly argued against complete reliance on it for the reason that keeping people out of the protected areas will not achieve the desired end of nature protection or conservation. *Dudley and Stolton* (*2005*) pointed to the problem of scale in the application of the strict protection. Accordingly, small watershed (less than 100 km^2) will benefit immensely from strict protection but large watersheds could behave differently. The National Integrated Protected Areas System (NIPAS) Law of 1992 recognizes the “critical importance of protecting and maintaining the natural biological and physical diversities of the environment” when it aptly stipulates that the “use and enjoyment of these protected areas must be consistent with the principles of biological diversity, sustainable development and cultural heritage” (Sec. 2, RA 7586 or the NIPAS Law). The law further encourages the introduction of site-specific innovative structural strategies to achieve the objectives of maintaining the ecological value of the protected area in pursuit of sustainable development goals (Sec. 9, RA 7586). Thus, conservation rather strict protection or human non-interference should be the operative word in the management of Pasonanca Natural Park. Conservation is the “judicious, not total abstention from, exploitation of our natural resources... in order to ensure the perpetuation of the forest and its productivity (*Carlota 1985*). The delineation of the riparian buffer zone and the reclassification of this area as special use zone are plausible (5.21 Rule 5 DENR Administrative Order 2008-26).

The riparian zone or buffer zone – the interface between the stream and the land, are vital management units within the watershed. When actively managed, the riparian zones act as efficient sediment traps (*Lowrance and Sheridan 2005*) and increase streambank stability (*Simon and Collison 2002*). Active management prescriptions including controlled vegetation, grass vegetation as land cover and channelization are common. Controlled vegetation by means of tree cutting or thinning is a typical silviculture practice to maintain healthy, vigorous stands and improve streamflow (*Papadopol 2001; Pretzsch 2009*). Thinning usually refers to the removal of dead and dying trees, and slow-growing and unhealthy trees or those with irregularly formed crown and bole. Releasing certain number of trees by cutting or thinning means that the corresponding transpiration budget allocated to these trees is saved in the watershed (*D'Amato et al. 2011*). Grass vegetation acts as filters traps that break the velocity and transform concentrated overland flows into sheet flows (*Panku et al. 2012*). The reduced speed of flow facilitates the entrapment of sediments at the riparian buffer zone. Channelization or channel modifications to address over-spilling of river banks during high flows have reduced pollutant/nutrient loading to the streams resulting in improved water quality (*Viswanathan and Schirmer 2015*).

CONCLUSION AND RECOMMENDATION

An ecological integrity evaluation tool has been developed with subsequent application to Pasonanca Natural Park- the drinking water source area of Zamboanga City. Four key eco-hydrological attributes were identified namely biotic condition, soil structure, hydrology and water quality. Six indicators were chosen for their cost-effectiveness, analytical soundness and policy relevance. These are tree basal area, total organic carbon, total nitrogen, streamflow, water turbidity and annual high turbidity day. The ecological integrity status is poor (red) in three attributes namely biotic condition, hydrology and water quality. Under the policy of strict protection or human non-interference, the poor ratings of the eco-hydrological attributes are likely to persist. The sustainability of water supply cannot be guaranteed if the conditions persist. Immediate short term solutions may be implemented including setting a cap to water abstraction at 40% of streamflow; the withholding of water abstraction for treatment when water turbidity exceeds1000 NTU and the issuance to timely public advisory to inform water consumers of the state of their water quality.

The National Integrated Protected Areas System (NIPAS) Act of 1992 mandates the establishment of protected areas in sites of high biodiversity value. The law further allows for the reclassification of certain areas such as the riparian buffer zone as special use zones when necessary, to achieve the objectives of maintaining the ecological value of the protected area and to perpetuate valuable ecological services, e.g., water supply. The active management of the riparian buffer zone such as applying silviculture prescriptions in the form of controlled tree vegetation, the maintenance of grass vegetation as land cover and channel modifications could improve the ecological integrity status of the Pasonanca Natural Park.

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