Sedimentation dynamics of the Cagayan de Oro river catchment and the implications for its coastal marine environments

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Chapter 5:

General conclusions and key principles in the management of the Cagayan de Oro River catchment and its coastal marine environments
5.1. Conclusions and Summary of Results

5.1.1. Major Findings across the Ridge-River-Reef Continuum

Rainfall in the Cagayan de Oro River catchment is governed by a seasonal shift that is generally moderate all year round. However, a few extreme and prolonged rainfall events or typhoons also occur in the region, particularly during the rainy months and towards the end of the year. Therefore, the catchment is largely stable, but possesses a small number of erosion-prone sub-catchments (see Figure 5.1), which have a high potential to cause massive floods of water and mud during extreme rainfall events.

In both average and extremely high river discharge conditions, the sediment and associated materials were highest in concentration at the river mouth (see Figure 5.1). Regarding the dispersed offshore sediments, the flow direction was predominantly east and southeast, following the general coastal current circulation. In extreme discharge events with high-sediment volumes, sedimentation poses a direct threat to both corals and seagrass communities, but not to mangroves.

The distribution and abundance of mangroves, corals and seagrasses within the Cagayan de Oro River coastal environment indicates their response to the sedimentation dynamics they experience (see Figure 5.1). Therefore, this study acknowledges the need to conduct management interventions at different points along the ridge-river-reef continuum where sedimentation has become anomalous.

Four key management principles—integration, sustainability, precautionary and adaptive (Boesch, 2006)—are proposed here as overarching themes to address the ridge-river-reef continuum challenges in an integrated way. In particular, through this approach the study hopes to reduce the erosion-sedimentation process and its effects on the ridge-to-reef continuum (see Figure 5.1). These four principles serve as normative guides for every proposed management or rehabilitation activity.
5.1.2. Highlights of Ridge-to-Reef Sedimentation and Some Management Implications

The diagram below shows the entire flow and summarizes the highlights of methods, results, and outcomes of the three main chapters with recommended management measures.

**Figure 5.1:** Flow diagram of the three main chapters: each chapter contains the specific methods used and their corresponding results, and the key factors that have influenced or not influenced the outcome of the process. The brown arrows indicate the flow direction of sediments with river discharge. Final outcomes are the recommended management programs for the entire continuum.
5.1.2.1. Erosion and river sedimentation: key management challenges.

Erosion and sedimentation rates in the Cagayan de Oro River catchment vary from sub-catchment to sub-catchment, due to the diverse characteristics of HRUs comprising a sub-catchment. Catchment erosion-sedimentation dynamics are initially dictated by extreme rainfall input or typhoon events (see Figures 5.2a and b), as discussed in Chapter 4. However, more importantly for management intervention, catchment physical features, particularly steep slopes (≥30%) and vast areas of cultivated land/pasture land (>70%) or the lack of forest and dense vegetation, have largely determined the rain factor’s influence on soil erosion and subsequent sedimentation.

Generally, the model has assessed the Cagayan de Oro River catchment as mostly made up of slightly erosion-prone sub-catchments (107,014 ha or 76% of the total catchment). However, several moderately erosion-prone (28,798 ha or 20.5%) sub-catchments could become highly vulnerable to severe and widespread erosion during extreme rainfall events. Fortunately, the catchment has mostly average monthly discharges; however, extremely high discharge events do occur intermittently a few times during the year.

According to the SWAT model results, one key potential contributory risk to severe erosion in the catchment is the unstable ‘disturbed’ land cover. This instability may be exacerbated by extreme rains and continuing anthropogenic pressure. Thus, the foci of management intervention should be both the land cover component and destructive land-based activities. Another key risk factor for massive flooding in lowland areas is the increasingly shallow river water depth caused by the gradual deposition of sediments on the river bottom. This is due to the river’s sloping topography and unstable banks, where houses and human activities proliferate. Here, the focus is river rehabilitation from abnormally high-sediment deposition caused by both natural processes and human activities. The riverbanks and the human activities within the vicinity need to be well managed.
Figure 5.2a and b: Two scenarios: (top) strong rain and high discharge posing high-risk encroachment of river plume on both corals and seagrasses; (bottom) low and average rains and discharge resulting to high-sediment deposition at the river mouth and minimal encroachment on corals and seagrasses (base map from Google Earth, 2015).
5.1.2.2. Coastal sedimentation dynamics: key management challenges.

Comparison between river plume and ambient coastal waters for TSS and salinity values using the December 26 and April 22 sampling results revealed the presence, albeit limited, of river plume in the coastal sites. For salinity, freshwater intrusion into coastal sites was exhibited on both sampling dates. Thus, under average discharge conditions, river plume did encroach on some areas of the sampling plot close to the river mouth. It is expected that increases in river discharge and sediment load will result in a greater extent of plume coverage along inshore waters.

Based on the Delft3D modelling, the heaviest sediment concentration under all discharge conditions was within the river mouth and its vicinity. In fact, heavy sediment depositions on the river bottom have made the river mouth zone very shallow. Additionally, upland-derived sediments that have accumulated over time at the river mouth have formed into a large mudflat. Other coastal manifestations exhibiting the deposition of eroded catchment sediments included the accreted landmasses and dumped dredged materials. This particular issue necessitates a two-pronged remedy: rehabilitation of the affected sites and similar intervention measures for the erosion sites.

Finer river sediment particulates were dispersed on the east and southeast portions of the bay. With extremely high discharge from Typhoon *Washi*, model simulations suggest dispersed sediment concentration along inshore waters at 300 to 400 mg/L or 20% of the total TSS input value. Receding ebb tides carried more sediment materials seaward than did the flood tides. Thus, there is a looming threat to seagrass and coral communities from river-borne sediments during high and continuous rain events exacerbated by ebb tides and mudflat erosion. This issue must be addressed at the sediment source and along the banks where most terrigenous materials can be trapped and impounded.
5.1.2.3. Sedimentation, coastal changes, and the marine coastal habitats: key management challenges.

Through the years, river sedimentation has brought benefits to the coastal environment, due to the accretion and expansion of landmasses, and later the subsequent colonisation of mangrove trees. However, it has also paved the way for major physical modifications to the coast and riverbank, facilitated by human intervention at the expense of naturally growing mangroves.

Moreover, physical and vegetation cover changes demonstrate some influence on the extent and direction of river discharge and sediment dispersal in the bay. With the Cagayan de Oro River coastal environs, these changes have exacerbated river sedimentation, as well as plume dispersal off the river mouth. For example, the continued westward expansion of the mudflat inflicts a high-sediment encroachment on corals, particularly during erosion and the further transport of loose sediments to the reefs.

Coastal and bank changes may not have exacerbated the river plume encroachment and concentration on seagrass meadows. In fact, the prograded coastline of Macabalan has partly impeded the downstream flow eastward towards the meadows. However, coastal development, particularly of Macabalan, has also resulted in a much larger current coastal population and human activities close to the seagrass sites.

The issue here is the lack of integration of coastal habitats—such as mangroves, corals and seagrasses—as important components into the city’s coastal development program. This gap has led to the loss of mangroves and the continuing decline of corals and seagrasses, due to pressure from human-induced activities and other related stressors. This can be addressed by effort from the coastal communities themselves and by the local government prioritising its concern for coastal and marine ecosystems, even as the city’s coastal development continues.
5.2. Key Management Principles for Ridge-River-Coastal Challenges

Four key management principles are used to examine each management measure recommended by the present study (see Figure 5.3). These principles are important requirements for any ecosystem-based management and can be used to assess rehabilitation and management plans (e.g., Chesapeake Bay and Louisiana Coast) (Boesch, 2006).

Integration is understood as multi-dimensional: a management approach is interdisciplinary (science, management, sociology), the employed variables are inter-medium (land and water), and the stakeholders originate from different sectors (multi-sectoral and intergovernmental) (Knecht & Archer [1993]), as cited in Boesch [2006]). Sustainability is intergenerational, ensuring that the needs of the present generation are met without compromising the ability of future generations to produce enough for themselves (Brundtland et al., 1987). The precautionary principle is another management requirement; it prevents any potentially harmful action to proceed, even without an established cause and effect relationship. Finally, the adaptive management principle requires continuous learning and refining of management strategies, based on set goals while trying to reduce uncertainties by constant monitoring/assessment or experimenting (Lee, 2001).

In the present study, the scientific findings are crucial inputs for an effective management plan based on these four key principles. According to the integration principle, erosion-sedimentation as a common stressor must be addressed appropriately, while also considering human needs and uses. Therefore, any rehabilitation activities such as land use conversion, riparian vegetation, coastal clean-up programs and dredging should be assessed in terms of their impacts on the lives and needs of the affected human communities.
5.2.1 Sedimentation, its Factors and the Four Key Management Principles

Sedimentation as influenced by rainfall events and other factors is shown below.

Extreme high rainfall + very steep slopes + large cultivated areas + minimal forest cover → high river discharge and severe and massive erosion in the sub-catchments.

Normal and low rainfall volume + steeped slopes + reduced forest cover → average volume of river discharge and localized and slow soil erosion.

Heavy and prolonged rainfall in the upland → very high volume of river runoff and of suspended sediment concentration in the river.

Normal or low catchment rainfall input → average/low volume of river discharge and average/low sediment concentration in the river.

High discharge carries more sediment particles dispersed far out into the bay with initial route of river outflow is NW but net circulation effect is SE; highest sediment concentration is at the river mouth.

Normal river runoff results to sediments largely concentrated within the channel and at the river mouth; little sediments are dispersed with the E/SE current flow.

Extreme sediment runoff + mudflat erosion → increased river sediment encroachment on coral sites; extreme high sediment runoff + strong SE/E current flow → heavy sediment encroachment on the seagrass sites.

Sediment deposition mostly along banks and coast → land accretion → mangrove expansion OR sea floor or river bed siltation → dredging → coastal filling → human settlements or mangrove expansion.

Key management principles overarching the rehabilitation of the ridge-river-reef continuum
1) Integration
2) Sustainability
3) Precautionary
4) Adaptive

Figure 5.3: Sedimentation processes under two scenarios and the factors influencing each; the four key management principles proposed to mitigate erosion and sedimentation effects.
For sustainability, catchment rehabilitation initiatives should be able to lessen the vulnerability of each system and increase its resilience against stress from erosion-sedimentation effects. Regarding precaution, rehabilitation plans should include strict bans on activities that may increase erosion and sedimentation rates, such as steep-slope cultivation, large-scale plantation, near-bank human settlements, riverbank concreting and mangrove cutting. Finally, adaptive management calls for setting clear goals for rehabilitating the Cagayan de Oro River catchment and its river system. These goals must be revisited or revised if required. Such revision should be based on the results of constant sedimentation impact monitoring in relation to the coastal environment and habitats, and on the overall effectiveness of management strategies applied to the entire ridge-river-reef continuum.

5.2.2. The Cagayan de Oro River Catchment Management and Rehabilitation Measures as Guided by the Four Key Management Principles

The primary culprit for high soil loss in certain sub-catchments (from a management perspective) is the sub-catchment’s very low forest density, which is due mainly to large-scale plantations, logging and other destructive practices in the catchment.

Rehabilitation of the river catchment should include all moderate- and high-sediment yielding sub-catchments and their adjacent sub-catchments (see Figure 5.4). First, this should be applied on the identified ‘erosion hotspots’. Then, on the moderately sediment-yielding sub-catchments, with relatively low rainfall inputs (≤287 mm/day), but with characteristic very steep slopes, large cultivated areas and much-reduced vegetation cover.

Following the integration principle, on-going rehabilitation initiatives include the greening of sites, involving the organised communities who are co-owners of the commodities and beneficiaries of the fruits of their labour. Therefore, rehabilitation programs must take a multi-sectoral and interdisciplinary approach. Further, rehabilitation efforts
should consider the establishment of various conservation practices across all highly erosion-prone parts of the catchment.

**Figure 5.4:** High and very high sediment-yielding sub-catchments as ‘erosion hotspots’ (encircled) in Barangays Tagbak and San Miguel in Talakag, Bukidnon Province.
The sustainability principle means that each sub-catchment must be stable enough to withstand severe erosion and resilient enough to return to its normal functioning after physical disturbances. Therefore, catchment stability entails dense forest cover, particularly on steep slopes, effective conservation methods on large areas of cultivated lands and minimal destructive land-based activities. A dynamic, stable and less-disturbed catchment will be sufficiently resilient to withstand physical disturbances.

The precautionary principle in catchment management calls for the banning of any activity that is potentially destructive to the catchment’s physical landforms and its vegetation cover. This specifically includes deforestation activity in any part of the catchment, along with agricultural cultivation and human settlement on the slopes and sites near the riverbanks.

Finally, adaptive management requires constant monitoring of rain and river measurements to assess quantitatively the rainfall seasonality response of given sub-catchment land features and management practices. This may require more SWAT modelling in the future. Specific management strategies applied to sub-catchments should be constantly evaluated against established goals. New data from regular monitoring activities will be used to refine or readjust the present management plan for the Cagayan de Oro River catchment and for other study sites.

5.2.2.1. On-going rehabilitation activities in the Cagayan River Catchment.

The National Greening Project is an-going activity of the Cagayan de Oro River Basin Management Council (CDORBMC) for rehabilitating the river catchment. It is spearheaded by the DENR-Region 10 in partnership with various community-based organisations in the three local government units—Talakag, Baungon and Libona—within the catchment. The project, which started in 2011, includes planting of timber, cacao, coffee and rubber in selected sites within each municipality (see Figure 5.5).
The Greening Project also includes sub-catchments identified by the present study as being highly prone to erosion (encircled in Figures 5.4 and 5.5). However, it is not clear
within the project what contribution of site attributes to erosion risks (e.g., steep slopes, barren spaces) would be addressed by planting selected commodities. Further, greening activity could be limited to sites close to human communities for effective support and maintenance at the expense of ‘erosion hotspots’ in more isolated sites.

**Figure 5.6:** The Cagayan de Oro River catchment with locations of sites targeted for future greening projects. Encircled sites are ‘erosion hotspots’ (DENR-10).

Regarding the 2016 Greening Project, it is notable that the targeted areas for development (see Figure 5.6) are located within the same sub-catchments identified by the present study (see Figure 5.4) as very high in sediment yields. These sites are located at the foot of Mt Kitanlad and lie within the confluence zone of a tributary/stream network.
5.2.2.2. **Recommended management measures for the Cagayan de Oro River catchment.**

This study recommends the following concrete management measures, guided by the four key management principles. These measures are also recommended for incorporation into the Integrated River Basin Management and Development Master Plan for the Cagayan de Oro River Basin (see DENR-RBCO, 2015).

1) **Public education and awareness building.** This includes explaining the contextual perspectives on disaster risk and involving local people in the interactive process of awareness raising (Burningham et al., 2008). The present SWAT map of the sub-catchments’ sediment yield values (t/ha/yr), and their corresponding geographical locations within the barangay and municipality, should be made publically accessible. In this way, the local people can realistically appraise the gravity of the risk and their possible contribution to it.

2) **Banning large-scale cultivation in ‘erosion hotspots’.** The strict enforcement of prohibited plantation expansion in ‘erosion hotspots’ should be established. To reduce the impact of slope cultivation on food production (Pimentel et al., 1987), government should prioritise the farming of staple plants and high-value crops in available agricultural lands.

3) **Improve slope conservation efforts.** Appropriate conservation practices and planting systems (e.g., contour farming) (Mercado Jr et al., 2001; Poudel et al., 2000) should be enforced in cultivated lands along sloping or hilly areas (≤15%). Training and actual field demonstrations on conservation practices can be initiated by local government technical officials to help local farmers increase food production and minimise soil erosion. Soil conservation and food production must be carefully balanced for sustainability (Partap, 2004).

4) **Removal, transfer and resettlement of informal bank settlers (Kothari, 2007).** The identification of new safer resettlement zones through city mapping and land surveys is
vital, as is the preparation of resettlement areas through various activities such as construction of basic infrastructure facilities. Informal settlements should be removed from hazardous sites and a strict enforcement of a ‘no human settlements’ policy on these sites should be established. Finally, evicted informal settlers can be resettled in new homes.

5) **Implement land use conversion.** Appropriately sized ‘hotspots’ can be converted into forested areas. Appropriate soil conservation measures can be implemented. The proposed plan consists of tree planting/growing on bare or grassy portions of the following SCs:

   a) SC 66 (very high) = 470 ha of pasture land  
   b) SC 68 (very high) = 70 ha of pasture land  
   c) SC 63 (very high) = 557 ha of pasture land  
   d) SC 62 (high) = 761 ha of pasture land  
   e) SC 65 (high) = 1,122 ha of pasture land

6) **Immediate rehabilitation of mountain and bank slopes** (e.g., tree planting, bank reinforcement and bans on cultivation). All ‘priority’ sites for rehabilitation are within the vicinities of river/stream confluence zone at the base of Mt Kitanlad. This action should target ‘erosion hotspot’ areas, particularly the mountain and river banks with ≥30% slopes:

   a) SC 66 = 247 ha  
   b) SC 68 = 100 ha  
   c) SC 63 = 29.7 ha  
   d) SC 62 = 161 ha  
   e) SC 65 = 168 ha

7) **Dredging in shallow parts of the river channel.** A bathymetric survey of the entire river channel should be conducted to identify ‘priority’ parts close to human communities. Proper dredging guidelines should be followed (DPWH, 2000).
5.2.3. The Cagayan de Oro River Mouth and Its Coastal Marine Habitat Management Measures as Guided by the Four Key Management Principles

Major research findings have revealed that sedimentation exhibits different levels of association with each of the three coastal habitats. Sedimentation’s beneficial effect is through land accretion and land filling, which subsequently become new mangrove-colonised sites (e.g., Sonneratia sp.). With corals and seagrasses, sediment plume encroachment on the coastal habitats’ sites during heavy catchment rains may affect either community.

Based on the four key management principles, rehabilitation plans should sustain the ‘healthy’ condition and expansion of each coastal habitat. First, the coastal environment itself must be sustainably stable and resilient, which means it can receive sediments and other stressors but can later restore itself to normal functioning conditions. This means the ecosystem should have components such as mangrove trees to mitigate the harmful effects of sediments. Second, the coastal habitats themselves should be sustainably resilient and balanced to withstand disturbances adequately. Thus, there is a need to rehabilitate the three coastal habitats and their environs and then to manage their succeeding growth and development appropriately.

The principle of integration requires that rehabilitation of the coast and its marine habitats should first consider the needs of coastal human communities. It presupposes active participation of concerned stakeholders in both planning and execution phases. Important concerns such as resilience, coastal habitat diversity, human consumption and needs, coastal development, disaster preparedness, and financial/economic implications should be properly established for discussion and so that decisions can be made.

For the precautionary principle, it is imperative to ban certain human activities that are potentially destructive to the ecosystem and to its coastal habitats, such as waste production or disposal in coastal waters, using illegal fishing methods, converting mangrove
swamps into human settlement areas, direct deliberate disturbance of corals and seagrasses, and extensive upland land-based activities.

As for the adaptive management principle, this requires continuous learning about the river mouth and the coastal habitat conditions in response to sedimentation’s impact. This can be done through a constant assessment of the distribution, abundance and diversity of each major habitat, while also monitoring sedimentation flow patterns and where high concentrations are located in coastal waters. Tests for other limiting variables must also be undertaken to determine the sources of variation in the results. Overall management strategies should be evaluated based on the targeted goals. This knowledge can then be used to correct or refine present management plans or to apply strategies to other study sites.

5.2.3.1. Management plans and on-going rehabilitation activities for the Cagayan de Oro River mouth and its coastal marine environments.

1) Barangay Bonbon has implemented advocacy and education programs to raise awareness among the population. This includes regular rubbish collection, proper waste disposal, sanitation-related projects and a coastal clean-up drive (Barangay Peace and Development Plan, 2015–2020). The plan identifies certain limitations to the program’s success, such as the lack of funds and the minimal cooperation from local inhabitants. Monitoring and evaluation for a sustained effective program is not discussed in the plan.

2) The city government, in collaboration with the DENR-10, is undertaking a mangrove-planting project under its integrated coastal management project along the Bonbon coasts (Jose Reyes, personal communication, 19 Aug 2015).

3) Barangay Macabalan has planned and initiated a program for a clean environment, including solid waste management, a coastal clean-up drive, repair of existing drainage systems, and the installation of sanitary toilets for all residents (Barangay Development Plan, 2016). It also adapted, through a barangay resolution, a disaster-risk reduction
program that includes construction of a dike and a breakwater seawall, and the relocation of residents from identified danger areas. However, there is no mention of a plan or activity for the coastal waters and its marine resources under any of the barangay programs; namely, clean environment, healthy population and productive constituency.

4) Under the flood-risk management project for the Cagayan de Oro River (FRIMP CDOR), a 12 km flood control structure will be built from the Pelaez Bridge up to the river mouth (see Figure 5.7). The mega dike project is expected to mitigate risks in flood-prone areas along the CdeO River. The construction of the dike will affect 15 barangays and might displace over a thousand households. The P5-billion project was proposed by the Japan International Cooperation Agency (JICA) after Typhoon Washi (Sendong) devastated Cagayan de Oro City in 2011. The mega dike is expected to protect people and properties from large floods in the future. However, the dike will be detrimental to the river ecosystem, isolating it from the rest of the larger terrestrial ecosystem. It is also unfavourable to groundwater replenishment and storage. Finally, the sediment load dispersed into the bay will increase. Nonetheless, this present study suggests that natural buffers, such as dense riparian vegetation should be planted between the wall and the inland communities on both sides of the bank along the entire extent of the dike (Wolanski, 2006). The forest serves as a second barrier after the dike, in case the concrete wall gives way to large floods. The vegetation also maintains the bank’s soil stability and intactness against erosion.

5) Dredging activity at the river mouth continues up to the time of writing. Dredged materials (240 m³/hr; 80% liquid and 20% solid) (DPWH, 2000) are stockpiled on Bonbon coast and are supplied to the city for various purposes (DPWH engineer, personal communication, 27 Aug 2015). A pre-dredging report identified no corals or seaweeds at the dredging site; seagrass had only 2.57% cover, while fish species numbered six, with
*Bolinao* (*Stolephorus* sp.) as the most abundant. Given the flow dynamics of river discharge and bay currents, monitoring of potential sedimentation impacts should include the existing corals and seagrasses during the actual dredging phase. Regular assessments of dredging impacts on the Bonbon and Macabalan coastal population should also be conducted.

![Figure 5.7: Map showing the proposed 12 km mega dike straddling the Cagayan de Oro River from the Pelaez Bridge to the river mouth (Tolinero, 2014).](image_url)
5.2.3.2. Recommended management measures for the Cagayan de Oro River mouth and its coastal marine environments.

Based on the four key management principles and on-going programs, this study offers some concrete proposals on river mouth-coastal management that includes mangroves, corals and seagrasses:

1) **Public education and awareness building.** Owing to the lack of community concern for their coastal environment, the development plans of Barangays Macabalan and Bonbon should include: regular intensive education campaigns on the existing threats to their marine and coastal resources; the exact locations of high-TSS concentration sites; and the various benefits of healthy marine resources to human communities. Disaster risks should be presented and understood from the perspective of local inhabitants (Burningham et al., 2008). The city government should coordinate similar efforts with the Macajalar Bay Development Alliance (MBDA) and ensure that various stakeholders participate in the campaign. The MBDA, established in 2008, is composed of 14 coastal cities and municipalities within the bay. It hopes to forge collective efforts and resources with other stakeholders to rehabilitate and manage Macajalar Bay.

2) **Integrated urban and coastal development programs.** In view of the continuing urbanization of the city and its coastal areas, it is imperative that the city and local governments, following the integration principle, should incorporate sustained coastal and marine resource management strategies into their development plans for the barangays of Bonbon, Macabalan and Puntod. There should be no conflict between urban/city development and natural resource conservation and protection. The human population’s welfare and protection, situated in a specific natural environment, should be the government’s paramount concern.

3) **Implementation of action plans and public participation.** Accumulation of garbage on seagrass sites should lead to concrete activities that are initiated and monitored at the
barangay level with identified people in charge, and small target communities. Regular (from weekly to annual) activities should include the following: coastal clean-up programs, proper rubbish disposal, coastal water quality monitoring, mangrove planting and maintenance, seagrass (small- and medium-size scales, percentage cover, canopy height, composition and depth limit) (Neckles et al., 2012) and coral monitoring (small- and medium-size scales, percentage cover, composition, coral health condition and new recruits) (Muhando, 2008).

4) **Repair and reinforcement of river banks.** The repair of eroded riverbanks and levees within the city is vital. This can be done by replanting trees and enforcing natural erosion control measures to reduce considerably further erosion and sedimentation along the river channel and its mouth. Specifically, a natural buffer should be established between the Cagayan de Oro River and the houses alongside the channel (city proper to Macabalan) to reinforce the existing concreted river dike (see Wolanski, 2006).

5) **Increase mangrove cover along the banks.** Continuous land progradation but slow mangrove colonization needs planting of riverine mangroves along the river banks, which will serve as natural sediment traps and a buffer against floods caused by river swelling (see Ewel et al., 1998). The increased mangrove area will reduce the sedimentation effect on coastal waters and consequently increase the river mouth’s capacity to absorb pollutants, yet remain functionally stable (see Duke & Wolanski, 2001).

6) **Increase mangrove cover along the coast.** Expanding the fringe mangrove plantation along the foreshore will reduce shore erosion and protect coastal human communities from extreme wave impact (Ewel et al., 1998). Presently, the DENR-10 and coastal residents have planted *Rhizophora* on Bonbon’s lowest intertidal zone. However, previous studies have proved the high mortality rate of *Rhizophora sp.* in most planting sites (Primavera & Esteban, 2008; Samson & Rollon, 2008). This study strongly suggests
transplanting existing *Rhizopora* trees to sheltered coastal sites and planting the more locally adapted *Sonneratia alba* and *Avicennia marina* on the lowest coastal zones, based on recommendations in Primavera and Esteban (2008) and in Samson and Rollon (2008).

7) **Rehabilitation of coral reefs.** Corals on Plots B and C have a relatively high potential for survival, due to the dominance of massive and sub-massive coral life forms. Further research can be pursued to determine the best rehabilitation techniques (Yeemin et al., 2006) (see also artificial reefs, Rilov & Benayahu (2002) and coral transplantation (Clark & Edwards, 1995) for the remaining coral, with the given freshwater and sediment inputs at the reef site.

8) **Total ban of coastal waste disposal and other anthropogenic-based disturbances.** Due to the present poor conditions of corals and seagrasses, the city and *barangays* must enforce a ban against the disposal of any kind of waste from domestic households, ports, industries, agricultural farms and other sources into the coastal shore and waters (Islam & Tanaka, 2004). The ban should include any potentially destructive activities (e.g., dynamite fishing) threatening seagrasses and corals and associated fauna.

9) **Establishment of MPAs.** Further study can be done to determine the feasibility of establishing the coral and seagrass sites as MPA, to sustain coastal integrity and increase food production (Roberts et al., 2001; Weeks et al., 2010) within the overall context of an integrated ridge-to-reef rehabilitation and management plan (Cicin-Sain & Belfiore, 2005). As this will affect socioeconomic concerns, multi-sectoral interests should be considered and wide stakeholder consultations should be conducted before decisions are made (Klein et al., 2008; Pollnac et al., 2001). Concrete, alternative livelihood projects should be incorporated into the rehabilitation plan.
5.3. Some Recommendations to Further Improve the Present Study and Similar Research Initiatives

5.3.1. Chapter 2: Erosion-Sedimentation Process in the Catchment

Chapter 2’s strength lies in its concepts and modelling work. The field data collection provided initial insights into catchment rainfall-river dynamics and final evaluations of the closeness between the simulated results and the actual conditions. The SWAT model itself generated reasonably good estimations of discharge volumes and sediment yields from each HRU. The variability of discharge and sediment yield results across the catchment reflected the unique condition of each unit’s vulnerability to erosion. With these data, catchment rehabilitation measures became more direct and specific in their applications. However, the prescribed model data inputs, which were then limited, could be improved:

1) Increase the duration of rain and river gauge data collection to three years or beyond. The SWAT model simulations need adequate time to adjust to the changing performance of input variables. A longer period of simulation run will provide a better appraisal of the actual rain and river processes.

2) Increase the frequency of river data collection to an hourly rate, using an automatic data logger/s. A daily single-event measurement does not capture the complete pattern of performance exhibited by a river parameter during an entire day and night. Further, river dynamics, particularly during rainfall events, are characterised by high and low flows that must be accounted for in the study.

3) Enhance the prescribed data inputs for better representation of the entire catchment characteristics, especially the spatial heterogeneity of each unit being studied. In particular, these model data inputs should include rainfall, LUC, soil condition and topography.
5.3.2. Chapter 3: River-Suspended Sediment Distribution in the Bay

Using the Delft3D as the modelling tool, Chapter 3 demonstrated the general coastal surface current circulation (near the river mouth) as influenced by the bay-forcing factors in Macajalar Bay. The tool also kept track of the physical movement of river plume from the river opening to the site of persistent concentration and subsequent deposition under different discharge conditions. Simulated outputs helped locate the sites most likely affected by river-borne sediments in view of the presence of coral and seagrass communities within the river’s coastal environs. However, the results and analyses could still be further improved; hence, the following recommendations:

1) Extend the sampling period for both river and coastal data collections to include the southwest monsoon months of July, August, September and October. This may show variations in coastal surface current circulation and sediment-dispersal patterns with the prevalence of strong southwest winds in the bay.

2) Use a floater with an attached GPS to track the surface current flow from the river mouth towards the sea. This exercise will provide insight into the actual flow velocity and directional patterns of surface current circulation. Field results will be used to validate the Delft3D model’s simulated results.

3) Identification of river-borne sediments from bottom re-suspended ones. Proper classification of sediments, based on their immediate sources, can clarify the extent and concentration of river sediment plume in inshore waters during actual field sampling.

5.3.3. Chapter 4: Implications of River and Coastal Sedimentation for the Distribution, Composition and Abundance of the Three Coastal Marine Habitats

Chapter 4 included the three important existing coastal communities at the mouth of the Cagayan de Oro River, and their basic ecological conditions in relation to the extent and concentration of river sediment plume. Temporal and spatial variations in the distribution,
abundance and diversity of coastal habitats were accounted for in the case of mangroves. However, in relation to the coral and seagrass communities, their temporal variations were not included. This was due to the limited time for monthly sampling and the unavailability of previous studies and reports. Hence, the following recommendations are made to increase data inputs:

1) Establish monthly monitoring of the growth (morphometrics) and cover percentages of seagrass and of the health condition and recruitment rate of corals for one year or more. Monitoring results will show temporal variations in seagrass and coral growth and abundance due to sedimentation effects. Sedimentation rates in the site will also be measured monthly.

2) Conduct regular water quality monitoring of the sampling sites (seagrass and coral). Parameters of the seawater quality analysis should include the ff: salinity, temperature, TSS, water clarity, dissolved oxygen, nitrite, nitrate, ammonia, grease and trace metals. The results will give vital information about the level of coastal water pollution that may account for the limited distribution and low abundance and diversity of seagrass and coral habitats.

3) Use geochemical tracing method to identify and compare upland-derived sediment deposits in accreted coastal and bank landforms with the sediment types in eroded sub-catchments. This will confirm the specific upland sites as sources of sediments concentrated and deposited within coastal marine environs.

5.4. Relevance of the Study in International Context

This present study which investigated the erosion-sedimentation processes from the uplands down to coastal waters and its habitats, using different methodologies and models, is perhaps one of the few in the whole world. Most previous science studies, both local and
international, confined their scope within a single unit (catchment or bay) or two adjacent units of systems (river mouth and coastal waters) which inevitably exclude parts of the catchment-coastal connectivity.

The present study hopefully opens new interests and opportunities among researchers across the globe to do catchment to coastal investigation of the effects of specific stressor on the entire natural landscapes. Its main relevance lies in the fact that with the ridge-river-reef research framework, it is possible to conduct a science-based investigation on large connected landscapes and its complex systems with reasonably good results. The study highlighted the importance of a mixed yet integrated approach of analyses on various natural factors and their interplay for complete accounting of each effect on the others.

Applying the ridge-river-reef approach in local or in international contexts, important research and management initiatives are conducted at reasonably good accuracy level of predicted results. Thus, early appropriated intervention is specifically introduced at each affected part or component of a system. For example, in the uplands identified “hotspots” are priority sites for rehabilitation while other areas are placed under a protected zone. Rehabilitation and reforestation efforts will include priority sites along the natural continuum such as the river banks and the estuarine areas. In the river mouth-coastal waters, proper zoning is introduced as part of the integrated management plan of the area. Moreover, climate change effects on the local weather conditions are taken into account for better management of its adverse effects on the physical habitats and the ecosystems along the ridge-river-reef landscape and seascape. Finally, the integrated science approach has specifically identified (in the recommendations) ways to protect and promote the welfare and interest of human community vis-à-vis the natural and human-induced problems within the ridge-river-reef connectivity.