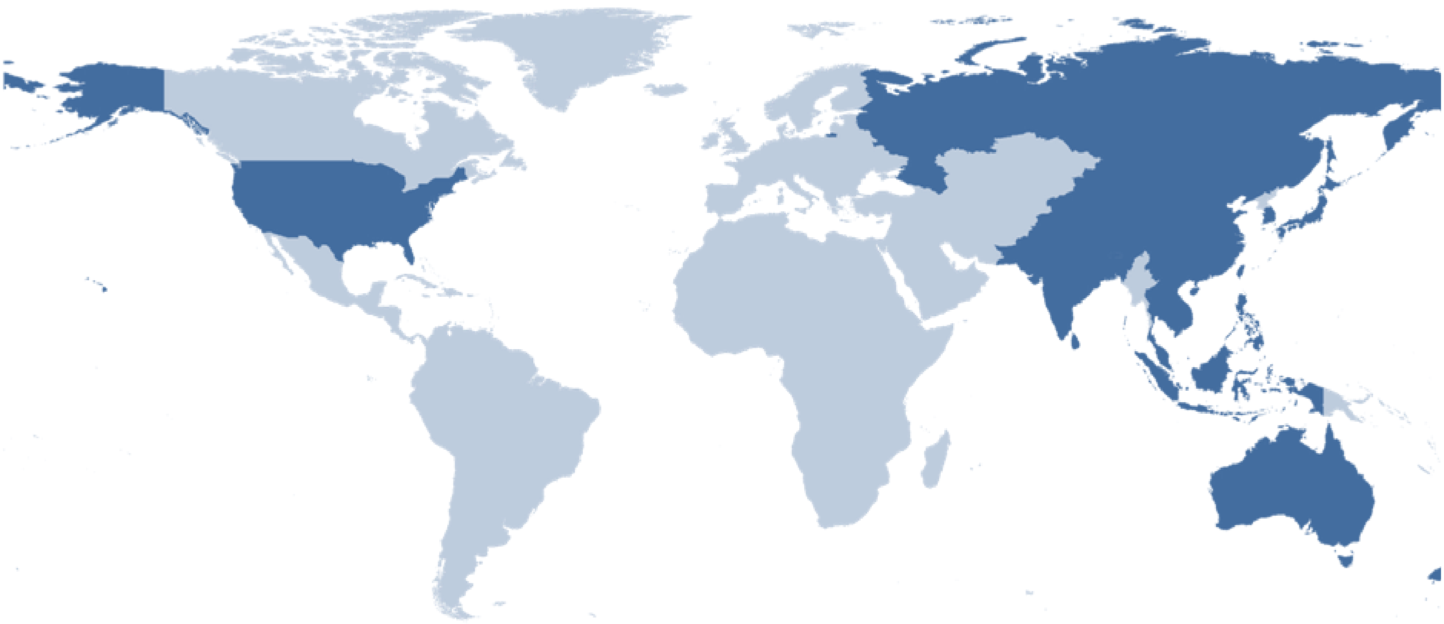
ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

Project Reference Number: ARCP2013-02CMY-Fortes

"Seagrass - Mangrove Ecosystems: Bioshields Against Biodiversity Loss and Impacts of Local and Global Change Along Indo - Pacific Coasts"



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"Seagrass - Mangrove Ecosystems: Bioshields Against Biodiversity Loss and Impacts of Local and Global Change Along Indo - Pacific Coasts"

Final Report Submitted to APN

Part One: Overview of Project Work and Outcomes

Non-Technical Summary

The Seagrass-Mangrove Bioshield Project (SMBP) aimed to address the gaps in knowledge and conservation of seagrass and mangrove resources. These gaps include area coverage, tolerance threshold particularly to nutrients and silt, comprehensive monitoring system, weak technical support, poor public appreciation of the ecosystems importance, and the small number of researchers trained in transdisciplinary seagrass-mangrove studies. The results are used as scientific advice to decisions in managing these ecosystems. They help provide a framework for policies formulated through an Integrated Decision Support System (IDSS).

SMBP established new scientific foundations for better resource area estimation, understanding source/sink dynamics of seagrass and mangroves and seagrass response to eutrophication, *Dugong* behavioral studies, water quality monitoring, proper mangrove forestation, and policies on fish cage operations, zoning plans, and for understanding resource-based community vulnerability.

Future works on seagrass and mangroves should adopt the transdisciplinary approach. They should include targeted research on trophic systems, monitoring of indicators of early signs of eutrophication, remediation of existing disturbed systems using natural means and making policies that identify and afford greater protection to seagrass and mangroves.

Keywords

Bioshield, eutrophication, ecosystem services, IDSS, CCVI

Objectives

SMBP aimed: (1) to identify and address the gaps in knowledge and conservation of seagrass and mangroves resources; (2) provide practical models enabling testing of scenarios of decisions regarding impacts on the bioshield functions of the ecosystems; (3) to develop a framework support for a local marine emergency contingency policy, anchored on a Conservation Zoning Plan and Coastal Community Vulnerability Index (CCVI); and (4) to develop a framework for an Integrated Decision Support System (IDSS) to support and enhance local conservation governance.

Amount Received and Number of Years Supported

The Grant awarded to this project was:

US$45,000 for Year 1:

US$45,000 for Year 2:

US$30,000 for Year 3 (To date, 80% of this total only):

Activities Undertaken

- **Science Establishment Phase (Years 1 and 2)** addressed the gaps in knowledge and in conservation of local seagrass and mangrove ecosystems. Field and laboratory activities were undertaken to gather data on area, distribution and community structure of seagrasses and mangroves, status and composition of biodiversity. To picture real world scenarios of impacts on ecosystem services, models were developed which synthesized data on trophic dynamics, water quality, stable isotopes, carbon fluxes, and ecohydrology.

- **Capacity Building Phase (Year 3)** focused on the science established in the first phase and translated the outcome into educational and advocacy materials to build the local stakeholders' capacity in conservation and management of their seagrass and mangroves. This was done primarily through more than 29 Focus Group Discussions, workshops, training courses, a national conference, and advocacy. The materials produced were used to help identify community vulnerabilities, enhance understanding and appreciation of the importance and services of the ecosystems, and provide the framework of a decision support system to enhance governance.

Results

1. The gaps in knowledge and management include: area of the resources, tolerance threshold to excess nutrients and siltation, comprehensive monitoring system in aid of legislation, weak technical support infrastructure, poor public appreciation of seagrass and mangroves, and the small number of researchers trained in transdisciplinary coastal ecosystem studies;
2. Area of seagrass beds and mangroves in the Gulf or Mannar Bioshere Reserve (India) and at the sites in the Philippines are now known. In Mayo Bay, seagrass cover was about 58% and dugong feeding trail cover was 6.7%.
3. Recruitment of mangrove seedlings was highest at the natural mangrove stations. The high density of planted trees excludes settlement by other species from nearby natural forests; hence, the planted forest remains mono-specific. Reforestation became habitat modification.
4. Lowest fractional seagrass cover (Blanco et al. 2016) coincided with the lowest seagrass density in Bolinao (Fortes et al. 2012) and correlated directly with the highest number of fish structures, implicating the negative impact of increased mariculture activities on the seagrass ecosystems.
5. Seagrass and mangrove habitats are highly diverse: at least eight of the total 19 seagrass species found in the Philippines; 17 macrobenthic seaweeds and nine macroinvertebrates. In Indonesia, fishes and crustaceans were abundant.
6. A prominent four-level food chain (epiphytic algae, mesograzers, juvenile fish, and piscivorous fish) in seagrass was observed. Dugongs open up the substrate in the process of feeding, exposing worms and other organisms, which become food for starfishes (ex. *Protoreaster nodosus*). In general, epiphyte and grazer densities were greater in developed catchments with higher nutrient loads than in less developed ones with less nutrients.
7. Salinity in the seagrass beds in Mati was always lower than that in Malita despite the fact that the former faces the Pacific Ocean and is without an inflowing river. (ground water source?); in the Gulf of Mannar (India), there was a significant change in the behavior of trace metals due to changes in salinity.
8. $\delta^{15}N$ values were constant regardless of the seagrass species present in the gulf. Majority of the samples exhibited little effect of nutrient load on their health. The picture is different in Bolinao (see No. 11 below);
9. Highest concentrations of trace gases (pCO2 and CH4) were observed in the northern sector of Chilika Lagoon (dominated by freshwater macrophytes e.g. *Phragmites*); concentration of both pCO2 and CH4 were at least 4 times lower in its southern sector (dominated by seagrass).
10. Spatial gradients in dissolved nutrients (N, P) and chlorophyll between sheltered waters with fish cages and 5 km away from these cages (in the Seagrass

Reserve) were very strong, producing graded negative impacts on the communities. Bolinao should focus more on conservation of seagrass and mangroves. If they want to retain mariculture in the sheltered waters, the fish structures over the seagrass should be removed. Sugimoto et al. (2016) propose a co-management scheme in order to improved governance of the industry.

11. Based on increasing sensitivity (decreasing resistance) to a combined effect of nutrients, chlorophyll-a and siltation, the following sequence of seagrass species results: *Enhalus acoroides* > *Thalassia hemprichii* >*Cymodocea rotundata* > *Halodule uninervis* > *C. serrulata* > *Halophila ovalis* > *Syringodium isoetifolium*. In using seagrass to shield the coasts from disturbances, the species occurring first in the series are more desirable.
12. Under scenario 0 (keeping present condition) and Scenario 1 (with 25% feed cut in both areas), the latter could bring about a drastic reduction in fish mortality (Tsuchiya et al. 2012). However, this reduction in mortality is limited if the neighbouring town does not cooperate.
13. Services of seagrass beds to humans are lesser known, when compared to mangroves. This results from minimal exposure of the population to the activities of local institutions and agencies dealing with coastal conservation. The vulnerability of the municipalities (CCVI, Orencio and Fujii 2012) is highly controlled by their dependency on fisheries for food and income, lack of knowledge and information from support institutions, and their low participation in environmental management activities. 80% of the stakeholders were very incompletely aware of the link between ecosystem services and human well being.
14. Bimodal peaks in dugong sightings occurred consistently around 9-11 AM and 1-3 PM. Dugongs appear to “like” more people although they do not “like” the presence of boats. The findings have direct implications to dugong and seagrass conservation and tourism (dugong watching) policies.
15. For the first time, the concept of ‘bioshield’ has been elucidated, backed by empirical project data; ‘bioshield is the ecosystem’s inherent biological functions to protect the coastal environment and its dependent populations by counteracting or mitigating the threats and negative impacts of both human-induced and natural forcing factors.

Relevance to the APN Goals, Science Agenda and to Policy Processes

SMBP has laid the foundation to predict impacts of eutrophication, unsound policies and climate variability on seagrass and mangrove ecosystem services. This is via a science-based understanding of the ecosystems’ and their users’ strengths and vulnerabilities. This knowledge was synthesized and is being adopted as a framework of capacity development and policy decisions to enhance governance and sustainable use of the ecosystems.

Self-evaluation

Unfortunately, those activities planned from mid-Year 2 and early Year 3 were done with less diligence and seriousness required of partners. This was brought about largely by a perception that the time and the resources allotted were not sufficient to produce ‘world class’ journal publications. In SMBP, ‘grey’ materials are more useful to local stakeholders than journal publications, which are too technical, generally inaccessible or expensive to come by. In Year 3, however, more quality publications were published and initiated.

Our self-evaluation considered four areas of competency: A. responsibilities, B. knowledge of subject matter, C. communication skills and service, and D. teamwork. Each competency is gauged either as an area to improve, achieved, or exceeded. Hence, we still need to improve especially on competences A and C. Happily, we did exceed three sub-areas and achieved many, in comparison to last year's self-evaluation. The main obstacle to effective teamwork appeared to be physical distance and personal priorities.

Potential for further work

The following **"Guideposts"** provides guidance in seagrass and mangrove conservation in the future:

1. More in-depth investigations are needed in plantation areas with direct effluent discharge to rivers and if the suspected freshwater source is groundwater.
2. The sensitivity ranking of seagrass species that resulted in relation nutrients and siltation may be used immediately where applicable to guide coastal developers and entrepreneurs.
3. Changes in the collective responses of seagrass communities to the gradients in nutrients and siltation, should be considered as indicators and be tested for a better understanding of fish farm effects on the coastal environment (Fortes et al. 2012).
4. The mono-specific plantation of *Rhizophora* significantly reduces the diversity of mangroves. This should be looked at more seriously by governments in the light of massive mortality rates of plantings despite huge financial support for mangrove reforestation (Philippines and Indonesia).
5. Together with metabolomics data, utilizing genomics, transcriptomics and proteomic data can lead to the development of impact assessment protocol and biological model for seagrasses in the future.
6. Future works on seagrass and mangroves should adopt the transdisciplinary approach and to include more targeted research on seagrass trophic systems, monitoring using indicators that alert managers to early signs of eutrophication, remediation of existing eutrophic systems through natural reduction mechanisms and policies that identify and afford greater protection to seagrass and mangroves.
7. In coastal management, the priority should be to enhance remaining seagrass and mangroves and recover key ecosystem characteristics and services of natural forests including sequestering excess nutrients and fine sediment.
8. As SMBP demonstrated, project data could help students and faculty members in local colleges to complete their graduate studies and enhance research. In addition, the institutional network developed by the project opens up opportunities for graduate studies and training in partner institutions abroad. This approach should be promoted.

Publications and Others

The table below summarizes the accomplishments of the project in terms of publications and other capacity building or appreciation materials. Details are in the Technical Report:

Publication type	No.	Status
Journal article	7	4 published, 2 under review, 1 submitted
Book	2	Published
Book Section	2	In press
Article in proceedings	5	2 in press; 3 in preparation
Oral/Poster presentation	14	Presented, all with abstracts
Poster for public display	2	Each 20 copies, distributed
Brochure	1	30 copies, distributed
CD video	1	10 copies for site distribution

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Preface

We are indeed glad to write and present this Terminal Report of our project, the Seagrass-Mangrove Bioshield Project, SMBP, keeping in mind the general weakness in understanding the fundamental concepts surrounding seagrass, mangroves, and their 'bioshield' function. This report covers aspects of seagrass and mangroves related to community structure, biodiversity, trophic dynamics, water quality, stable isotopes, carbon fluxes, ecohydrology, modelling and ecosystem services. Salient points emerging from the study are synthesized and translated into educational and advocacy materials useful in building the capacity of stakeholders and enhancing local decision-making process.

We acknowledge special thanks to APN for the funding support, encouragement, and the patience in dealing with our inaccuracies and slipups. To our local partners who, spending their simple lives in such simple lovely places, have always been our source of inspiration in our resolve to improve the state of our coastal environment.

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Introduction

In the Indo-Pacific region, coastal management vis-à-vis environmental change mitigation and adaptation overly focuses on control of Malthusian over-fishing in coral reefs. There have been few works that dealt with related concerns in mangroves, much less in seagrass ecosystems. It is well documented that among the coastal tropical habitats, coral reefs are the most popular, mangroves the most disturbed, and seagrass meadows, the least studied. This is despite the fact that each of these ecosystems are recently known to rival each other in coastal environmental and socioeconomic importance. A boost to this progressive thinking in scientific circles is the pronouncement made by UNEP-IUCN (2009) that "...when healthy, mangrove forests, saltwater marshlands and seagrass meadows are extremely effective at storing atmospheric carbon, thereby mitigating climate change". This is the reason why these habitats are currently referred to as "blue carbon ecosystems".

Along this line, seven respected scientists and a number of collaborators from five countries (Australia, Japan, India, Indonesia, Philippines) proposed to implement, for 3 years, the above project, with a shortened name, *Seagrass-Mangrove Bioshield Project*, SMBP. Six sites from the three latter countries have been selected to demonstrate that a seagrass bed and mangrove forest –singly or as interlinked systems, serve as natural 'bioshield', sustaining system goods and services against local and global human and natural stressors. Adopting the Integrative Science for Society and the Environment (ISSE) framework, SMBP is phased in a way to first establish the scientific base (Phase 1: Science Establishment, 2 years) and link this with academic programs and governance policies to ensure sustainability of the benefits gained (Phase 2: Capacity Building, 1 year).

Hence, in light of the old paradigm of coastal protection which overemphasize coral reefs, we argue in favor of a growing consensus, that places seagrass-mangrove system conservation as priority, developing models of the ecosystems' health and functions, which comprise their natural biological protector ('bioshield') role in mitigating local and global changes along the Indo-Pacific coasts. To be tested and promoted, these models will support decision-making and will be used to build capacity of stakeholder communities and governments so that they could utilize more efficiently and effectively ecosystem goods and services while adapting to environmental changes.

More specifically, SMBP aims: (1) to identify and address the gaps in knowledge and conservation of seagrass and mangroves resources; (2) to provide practical models enabling testing of scenarios of various decisions regarding human and natural impacts on the bioshield functions of the ecosystems; (3) to provide a framework support for a local marine emergency contingency policy, anchored on a Zoning Plan and Coastal Community Vulnerability Index (CCVI); and (4) to provide the scientific base for an Integrated Decision Support System (IDSS) to support and enhance local governance. The products include students trained in practical, state-of-the-art technique for water quality monitoring, acoustic telemetry and in trophic dynamics, peer-reviewed articles, and education and advocacy publications. Mentoring of students will ensure that, after training, expertise would be available to continue critical aspects of the project. The IDSS, zoning plan and the CCVI will be a key to formulating policy regulations, which will be developed in collaboration with stakeholders and other projects at selected study sites.

Methodology

The study sites of the project are categorized into two: primary and secondary. Primary study sites of the project are shown in Fig. 1, indicating the parameters under study at each of them. They are 'primary' in the sense that they are where the major activities of the project as originally proposed and approved were undertaken. The "secondary" sites are located only in the Philippines (Fig. 2). These are places which the project found it important to include in its activities because of their significance and contribution to project thrusts (e.g. municipalities in the provinces of Samar and Leyte, since these were hard-hit by the Super-Typhoon Haiyan, but which occurred after the approval of the project; Batanes, since it is the place most frequently hit by typhoons, and where seagrass and mangroves are practically unknown). These are also the sites where the project has been invited to share the highlights of its activities.

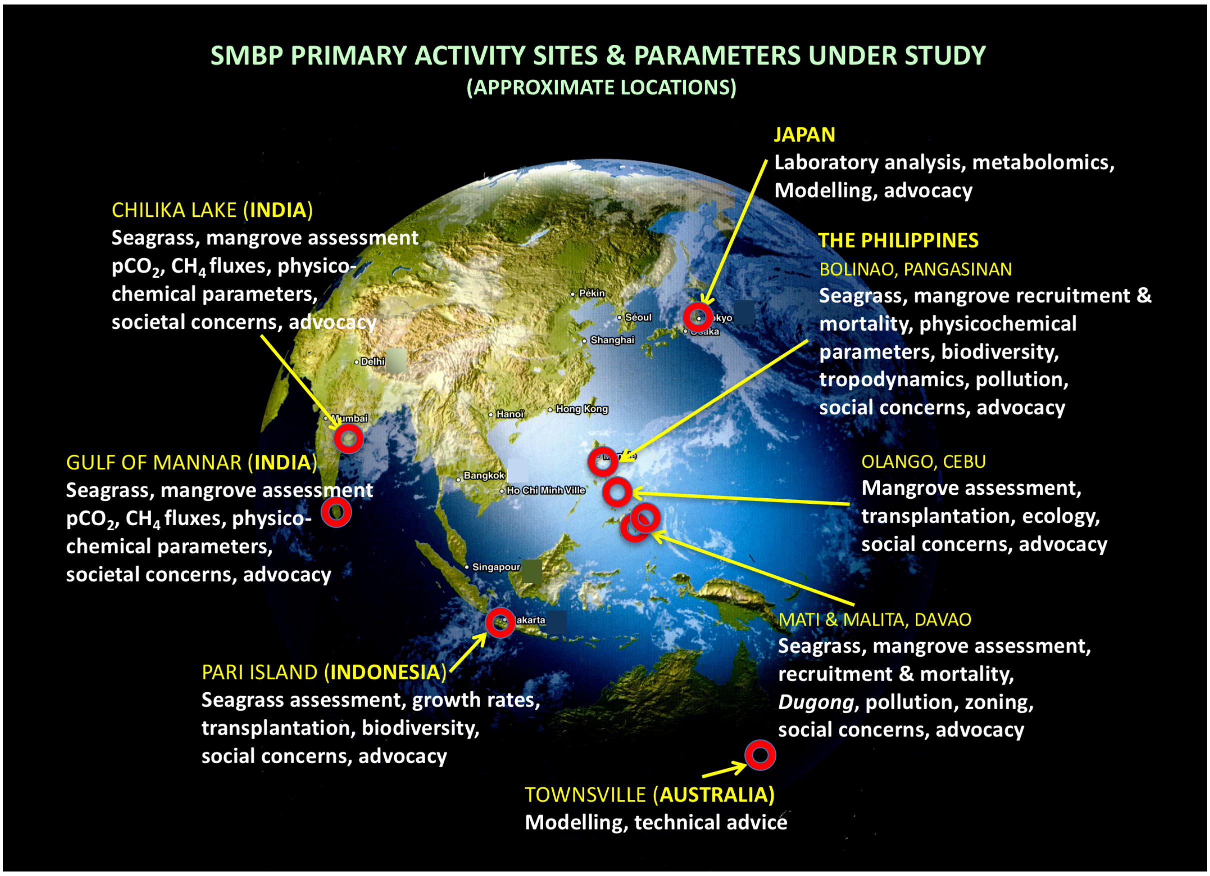


Fig. 1. The "primary" study sites of the project, indicating the parameters and member responsibilities under study at each of them.

Fig. 2. Primary and secondary activity sites of the SMBP in the Philippines. See text for definitions.

The project aims and details of how these were achieved are given below:

(1) To identify and address the gaps in knowledge and conservation of seagrass and mangrove resources – Even before the official start of the project, an initial Gap Analysis coupled with Training Needs Analysis was undertaken at the sites. This comprised both one-on-one interviews or structured questionnaires, depending on the accessibility of the place or availability of the interviewees. The activities were undertaken by hired project personnel, assisted by community facilitators from the Local Government Units and academe. The outcome of the activities are the objects of the trainings and Focus Group Discussions (FGD) or workshops in the subsequent implementation of the project.

Areal extent of seagrass and mangroves - Remote sensing (World View II, Landsat) for areal extent and distribution; In Bolinao, serial satellite images were used to estimate the fractional cover change of seagrass from 1989 – 2006 (17 years) and correlating these with the increase in fish structures in the channel in order to know the impacts on seagrasses;

a) Seagrass assessment and distribution of dugong trails - The transect-quadrat method was used to collect seagrass samples for identity and to quantify the biomass (g.m^{-2}) and cover (m^{-2} or ha) of the plants and the amount of the plants that go to grazing or feeding by dugongs. To cover the entire seagrass area underwater, acoustic video camera DIDSON (Dual Frequency Identification Sonar), concentrator lens and GPS receiver were integrated into the original measurement system for mapping seagrasses on the seafloor (Fig. 3). The system was equipped on the survey boat. Seamless images of seafloor had been captured as the survey boat cruised slowly along the planned survey lines, even in turbid or dark water.

Fig. 3. DIDSON deployed at depth and left for at least 12 hr. to capture dugong images

b) In Pari Island, Indonesia, data on the following biotic factors of *E. acoroides* at study sites include: percent cover, density, number of leaves, biomass (below-, above ground and total), growth, production and litter fall of leaves of *E. acoroides,* survival growth seedlings transplant of *E. acoroides,* total number-, total weight- and average total length of fishes and crustaceans in the natural and transplant sites.

Percent cover and density of *E. acoroides* were measured by using frame 50 x 50 cm of PVC pipe. The frame was randomly placed 30 times at each stations, percent cover and density of *E. acoroides* were measured in the PVC frame. Number of leaves was counted from each shoots of *E. acoroides*. Biomass was done from 1- 30 shoots. Growth and production of the leaves of *E. acoroides* were measured by using leaf marking methods (Zieman 1974). Litter fall of *E. acoroides* was carried out by using the method of Nojima et al. (1996). Biota in the natural and transplants sites were collected by using push net.

In addition, some environmental factors were also monitored:

- Temperature of surface water (ºC) was taken at all study sites by using thermometer. Depth of water column was measured by using scale from bamboo stake. Current speed of the water outside the transplant sites was measured by using a plastic bottle, a bamboo stake with a mark of 1 m length and a stopwatch. The plastic bottle was filled with seawater to 95 % submergence and a small bamboo stake was fixed to the top of the bottle. The travel of the plastic bottle over 1 m. The duration of plastic bottle washed away along 1 m was measured with a stopwatch. The current measurements were repeated 10 times.
- Sediment properties of the study sites were analyzed before the transplantation experiment is done. Wet sieving of sediment over 4 mm, 2 mm, 1 mm, 0.5 mm,

0.025 mm, 0.0125 and 0.063 mesh sieves was followed by drying and weighing the fractions. The sediment particles smaller than 0.063 mm is called mud (silt and clay), from 0.125 to 0.250 mm is fine sand, 0,5 – 2 mm is coarse sand and particles larger than 2.000 mm is gravel. Total organic matter in the substrate was measured by combustion of dried samples.

- Photosynthetically Active Radiation (PAR, 400-700 nm) was measured using LiCor Quantum Photometer type Li-250 with LiCor underwater-quantum sensor type Li-192SA between 10:00 – 14:00 h. Light readings were taken 50 cm above the water surface, just below the water surface, and in the water column every 10 cm down to maximum at 10 cm above the sediment. For each month the vertical extinction coefficient (k,m^{-1}) was calculated from the Lambert-Beer equation. This vertical extinction coefficient was calculated by exponential regression of the light-depth profile.

$$IH = I_o * e^{-kH}$$

where IH is light intensity ($\mu mol.m^{-2}.s^{-1}$) at depth H, Io is light intensity just below the water surface ($\mu mol.m^{-2}.s^{-1}$) and H is bottom depth (m). Water samples were collected for analizing the salinity (‰) which was determined using a salinometer Beckman RS7C.

- Water samples for nutrient (NH_3-N, NO_2-N, NO_3-N and PO_4-P) analysis were collected from water column and interstitial water by using rhizon and syringe. The water samples in the syringe were directly place inside plastic bottles (250 ml) and in the cool box with ice. They were placed in the freezer prior to analysis. Nutrients content in the water samples were analyzed in the Laboratory of Faculty of Fisheries and Marine Science, Bogor Agricultural University in Bogor, NH_3-N (APHA, ed. 21, 2005, 4500-NH_3-F), NO_2-N (APHA, ed. 21, 2005, 4500-NO_2-B), NO_3-N (APHA, ed. 21, 2005, 4500-NO_3-E) and PO_4-P (APHA, ed. 21. 2005, 4500-P-E) (Strickland and Parsons 1984).

c) In Mati, Philippines, a new methodology was developed to estimate the cover of seagrass and dugong trails using continuous optical images taken using water-proof digital still camera from the sea surface by swimmers. Using the software PhotoScan (Agisoft), 3D optical images were generated from the continuous photos. The resolution of 3D optical image is 2.96 ± 0.17 (SD) mm per pixel so that a leaf of *Halophila* is identifiable. In addition, the seagrass coverage rate and sizes of dugong trails were estimated in the image using simple image processing method.

d) Underwater acoustic observation on the behavior of dugongs – In Mati, we assembled the off-line acoustic video camera system for observing behaviors of the dugongs. The off-line system enables unmanned remote detection and identification of marine animals. The system consists of the acoustic video camera DIDSON, an acoustic lens-based sonar, which can substitute for optical system in turbid or dark water where optical systems fail;

e) In Bolinao, and to study seagrass response to the impacts of eutrophication and sedimentation, five 50 x 50 m quadrats were established along the 5-km gradient in nutrients (range in dissolved nitrogen: 17 $\mu mol.^{-1}$ at Stn A, the fish cage area, to 2 $\mu mol.l^{-1}$ farthest from it, in Stn E, the Seagrass Reserve); dissolved phosphate: 1.4 $\mu mol.l^{-1}$ to negligible amount and dissolved silicate: 9 – 5 $\mu mol.l^{-1}$, along the same sequence of locations) and chlorophyll-a (165 $\mu g.l^{-1}$ – 5 $\mu g. l^{-1}$). These gradients result from the extensive mariculture activities in Bolinao and environs which started in the 1980's. Biodiversity of macrobenthic algae, macroinvertebrates, infauna and fishes were also undertaken along these gradients.

f) Mangrove community classification and identification – This part of the study was conducted in Olango Island, in the central Philippines. The island has low topographic relief and with a maximum elevation of not more than 9 m at its highest point. A total of 4,482 ha of extensive sandy beach, rocky shoreline, inshore flats, seagrass beds, coral reefs, mangrove forest, mudflats, and salt marsh grass surround Olango and its satellite islets. The wetland is comprised of 424 ha mangrove, 33 ha mudflats, and some 53 ha of shallow areas that serve as a bird feeding grounds. In the northern tip of the island located the Olango Island Wildlife Sanctuary (OIWS) that covers an area of 1,030 ha and host large concentration of resident and migratory birds.

   The mangrove communities were classified into natural and planted forests with the help of local guide from the Peoples' Organization. Mangrove community structure analysis was conducted in several quadrats (5 m × 5 m) taken in natural and planted forests, respectively. True mangrove species inside the plot were identified following Primavera et al. (2004) and measurement of girth at breast height (GBH) of trees was taken approximately at 1.3 m above the ground. Saplings (girth less than 4 cm and height greater than 1 m) and seedlings (height less than 1 m) were identified and number of individuals by species was determined by actual count. Smaller subplots (5 m × 5 m) were established in the corner of the main plot if the density of saplings and seedlings was uniform and evenly distributed throughout the main plot. Height of trees and canopy width were measured using LASER Disto-meter expressed in meter. The community structure was analyzed using ecological parameters based on English et al. (1994). Mangrove distribution map was developed based on aerial observation and served as the basis for the establishment of sampling plots.

g) Mangrove recruitment/mortality and transplantation – Seedling tagging for growth (addition of internodes), density (no. per sq. m) inside permanent 5x5m quadrats and monitoring quarterly;
h) Biodiversity assessment ‑ Inside quadrats used to sample seagrass community parameters, assessment of the biota was undertaken using combined SeagrassNet ‑ NaGISA protocols (for seagrass) and inside permanent plots at selected sites (for mangroves);
i) Ecosystem services – Survey of the services provided by seagrass and mangroves, undertaken through use of structured questionnaires and Key Informant Interviews.
j) Metabolomics analysis of the seagrass *Halophila ovalis* – Involves sampling (in the field and cultivation of samples in the laboratory), extraction (of metabolites in a sample with a suitable solvent); instrumentation (Gas Chromatography coupled to Mass Spectrometry, GC-MS, Liquid Chromatography coupled to Mass Spectrometry, LC-MS, and Nuclear Magnetic Resonance Spectroscopy (NMR); metabolite identification, analysis (Multivariate Statistical Analysis: Principal components analysis and partial least squares), and Metabolic Pathway Analysis;
k) Stable isotope study and trophic dynamics – Seagrass samples for stable isotope ratio analysis, an analytical method used to determine the possible influence of land based nutrient load on marine plants, were frozen and shipped to Japan via air transport. Once retrieved, samples were subjected to stable isotope ratio analysis. In essence, samples were combusted at 1020 ˚C in an elemental analyzer (Fisons Instruments EA1108), and the combustion products (CO2 and N2) were introduced

into an isotope-ratio mass spectrometer (Finnigan Delta Plus) using a He carrier gas. The ratios of 13C/12C and 15N/14N were expressed relative to the Vienna Pee Dee Belemnite (V-PDB) standard for carbon and the N2 in air for nitrogen. The ratios of 13C/12C and 15N/14N were calculated using the following formula:

$$\delta^{13}C; \delta^{15}N = \left(\frac{R(sample)}{R(Standard)} - 1\right) \times 1000\ (‰)$$

where R = 13C/12C or 15N/14N.

The machine drift during the analyses was checked using L-a-alanine (δ 13C = 20.93‰, δ 15N = 7.61‰) for every six samples. The samples were measured twice with a S.D. ≤ 0.5‰ for both δ 13C and δ 15N.

An ‘observational’ aspect of trophic dynamics can be useful in relating the food web relationships in a seagrass bed. Offhand, among the major biological components in the bed are the following: seagrass (producer), urchin (grazer), siganids (herbivore), dugong (top herbivore), turtle (top omnivore).

l) Water quality – In India, water quality determination was carried out around four islands, where seagrass density was high and analyzed for various water quality parameters. *In situ* measurements were made using a multiprobe, after calibration with appropriate standards. The samples were collected in one-liter pre-cleaned acid washed polyethylene bottles and were preserved in an icebox, and transported to the laboratory for further analysis. The water samples were filtered through a 0.45 µm Millipore filter and were analyzed for nutrients. Standard procedures and methods were followed [Ramesh and Anbu (1996) and APHA (1995)]. The samples were analyzed for physico-chemical parameters such as temperature, salinity, conductivity, turbidity, total dissolved solids, pH, dissolved oxygen, biological oxygen demand and nutrients such as nitrate, nitrite, phosphate and silicate.

In Malita, Davao del Sur, Philippines, due to the accessibility to the river, we decided to set freshwater sampling stations in front of the villages along the river. Water from the fishpond and the banana plantation was monitored at the ditch, which directly flows into coast. Seawater sampling stations were set above the seagrass beds. Positions of the sampling points were recorded via GPS. Conductivity, pH, turbidity (freshwater only), temperature of the surface (25cm beneath the surface) was measured *in situ* with sensors (TOA DKK). Salinity was calculated together with conductivity and temperature. Depth of the water was measured with a metric ruler at freshwater sites and depth meter at ocean sites.

Water was sampled with an acid washed bottle that was rinsed thrice with the water sample at ambient temperature. It was kept one night in the refrigerator and used for pack tests the following morning. We used the pack tests (easy-to-use water quality checker) for chemical oxygen demand (COD), ammonium ion, nitrate ion and phosphate ion (Kyoritsu Co.).

Furthermore, water samples were also brought back to Japan for nitrogen and carbon analysis via standard laboratory protocols for further confirmation of results.

Dissolved nitrogen (DN) was analyzed via Total Nitrogen Analyzer (Mitsubishikagaku Analytec TN-2100W), and dissolved organic nitrogen was obtained by subtracting dissolved inorganic nitrogen (ammonium, nitrite and nitrate) from DN. Ammonium was obtained via the Indophenol Blue Method (TRAACS2000). Nitrite was obtained via naphthyl-ethylenediamine method via absorption spectroscopy (TRAACS2000). Nitrate was obtained via Copper-Cadmium Column, naphthyl-ethylenediamine method via absorption spectroscopy (TRAACS2000). DOC was obtained via TOC (total organic carbon) analyzer (Shimadzu TOC-V)

Turbidity profiles were made at 20 sampling stations. Five stations were made to represent potential impacts from Culaman River in the north, 11 stations were selected to represent the coastal waters of New Argao, and four stations assigned to represent the impacts from Lais River in the south.

m) Carbon and air-sea gas exchange (fluxes) of Ch4 and CO_2 (C mmol per sq. m per day) from the Chilika Lagoon, India

(2) To provide practical models enabling testing of scenarios of various decisions regarding human and natural impacts on the bioshield functions of the ecosystems – This included:

a) The ecosystem model developed by Wolanski (2009) as the base (Fig. 4), but emphasizing only the boxes enclosed by the broken line as these are the components within the scope of the project;

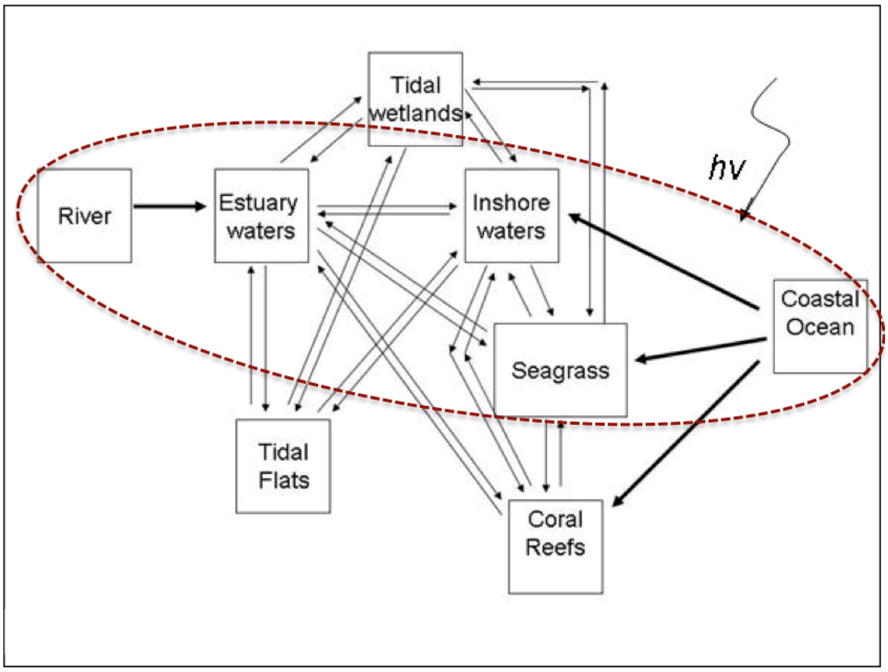


Fig. 4. The ecosystem model showing the major concerns of the SMBP (encircled) (After Wolanski 2009)

b) Hydrodynamic models (particle tracking simulations) for the temporal path of nutrients and pollutants predicting the likely impacts of varying degrees of protection (Tsuchiya et al. 2013); In India, a hydrodynamic model was carried out for the Gulf of Mannar Region (4 Islands) using MIKE 21. Input parameters include tide levels and/or wave climate.

c) A Coastal Community Vulnerability Index (CCVI), modified from Orencio and Fujii (2012), as indicator of the vulnerability of coastal communities;

d) A model of the framework of an Integrated Decision Support System (IDSS) which is based on selected data and information integrated through constant consultation with project partners and key community stakeholders;

In order to develop a model, data that are of direct relevance and use in order to meet the objectives should be available. For the most part, these data were obtained using the methods specified in Objective (1) above. Secondary data were secured from concerned agencies of government and other local agencies. In addition, community-based monitoring was also implemented to augment data with local knowledge and information. Here the following were undertaken:

a) Quarterly monitoring of certain parameters (sea level, sea surface temperature, salinity, rainfall, storminess, etc.);
b) Environmental impacts – Continuous for at least 1.5 yr. (subcontracted); quarterly undertaken by UPMSI and local partners, interviews of fishermen, coastal gleaners, entrepreneurs; photo-documentation;
c) Dugong sightings and ecosystem services ‑ Quarterly undertaken, consisted of interviews of fishermen, entrepreneurs; photo-documentation. Frequency of sightings correlated with the time of day (for at least 1.5 yr.), Sea surface temperature (SST), number of tourists and boats.

(3) <u>To provide a framework support for a local marine emergency contingency policy</u> – While the spirit of the objective remains, the methodology was partly modified. This was because of requests from local stakeholders to help them in their existing activities which overlap with those of SMBP. By law, all municipalities should formulate and implement programs and projects to address hazards and disasters –an offshoot of the recent calamities and disasters (e.g. Super-typhoon Haiyan which devastated most parts of the Philippines). What SMBP did was to undertake activities which complemented local efforts at the same time remaining aligned to its original objectives. Hence, the following were undertaken:

a) Helped the Municipality of Mati develop a Zoning Plan for Mayo Bay to conserve the rich biodiversity of its coastal and terrestrial protected areas;
b) Provided input into the Coastal Community Vulnerability Index (CCVI of the sites, collaborating with other local agencies and institutions;
c) Provided an assessment of the services of the seagrass and mangrove ecosystems as a base for planning and coastal development
d) Provided scientific inputs into the local Comprehensive Land Use Plan

(4) <u>To help develop a framework for an Integrated Decision Support System (IDSS) to support and enhance local governance</u> – In collaboration with prime stakeholders and other programs' officials, regular consultations were undertaken to come up with the best solution to issues. The general framework is shown below (Fig. 5)

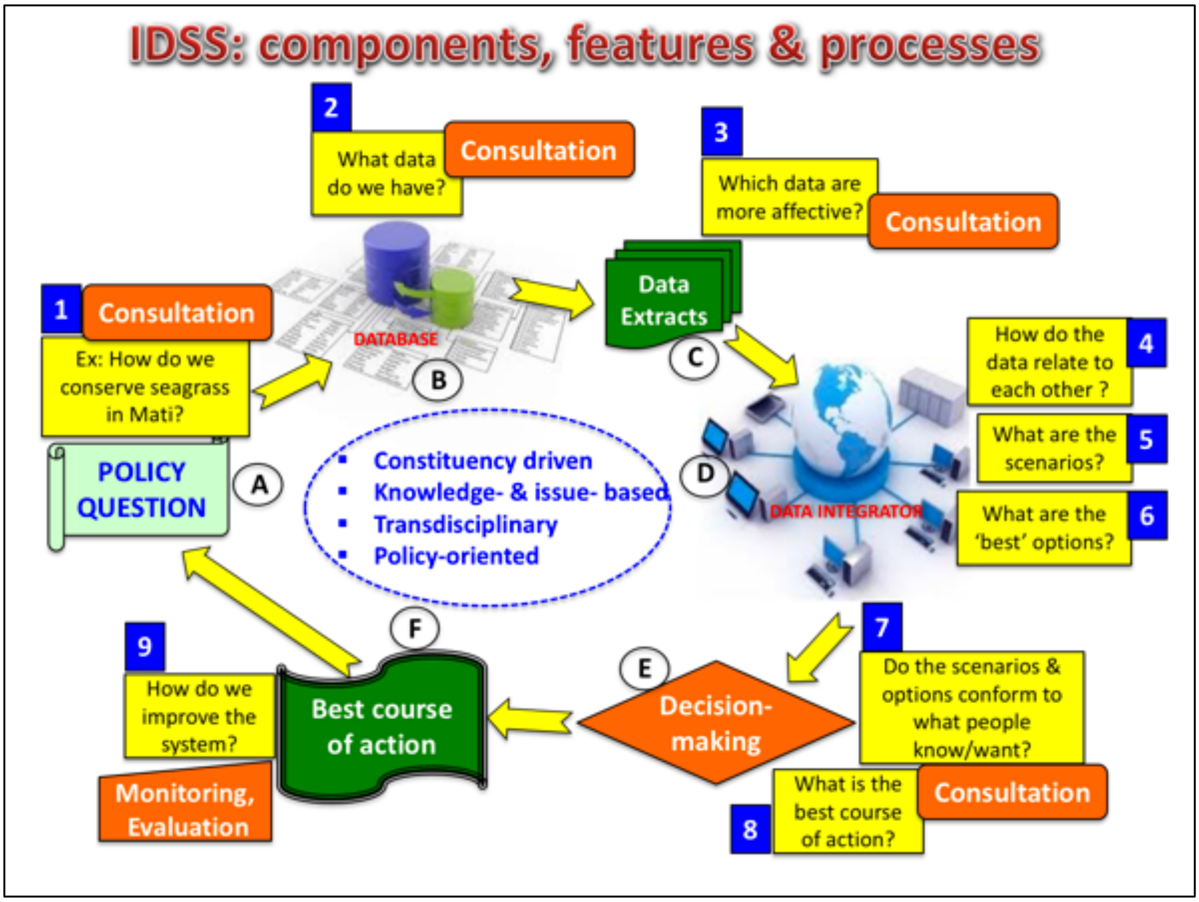


Fig. 5. A framework for an Integrated Decision Support System (IDSS) to support and enhance local governance

Results & Discussion

The Results and Discussion are given in the order they are presented above, sequentially in relation to the objectives:

(1) To identify and address the gaps in knowledge and conservation of seagrass and mangroves resources

Gaps in knowledge and conservation

The analyses identified gaps in knowledge and in conservation (management) specifically of the seagrass and mangrove resources. These gaps are between the allocation and integration of what is known about the resources and their requirements, and their current allocation-level or current capabilities to manage them. The data revealed areas of concern that can be improved or enhanced (Fig. 6). They indicate that majority of the respondents still do not have good knowledge about seagrasses, when compared to the mangroves. This is almost three decades after Fortes (1989) first reported on the state of knowledge on seagrass in southeast Asian region, concluding that the plants are relatively an 'unknown' resource. In the analyses, we took the "No Response" option as non-familiarity about the resource.

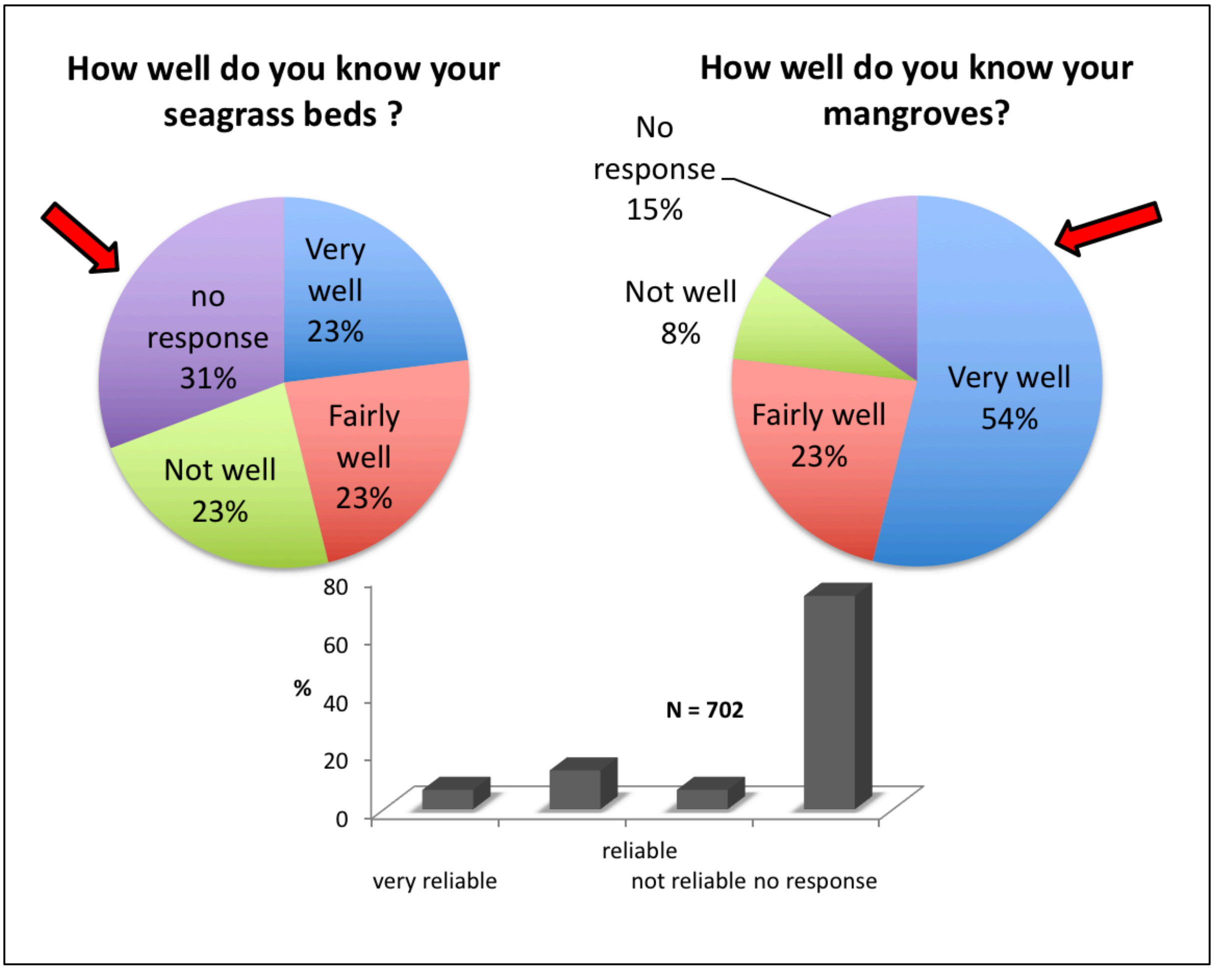


Fig. 6. Majority still regard seagrass beds as a relatively 'unknown' resource, in comparison with mangroves. Reliability Index is also included.

This 'pattern' is slightly different when the coastal communities were asked about the benefits they derive from the ecosystems. Their responses are shown in Fig. 7. Majority regard both ecosystems as important in terms of their environmental or ecological usefulness. However, none (regarding seagrass) or only a few (regarding mangroves) of them recognized their importance as a blue carbon source or as a factor in reducing the impacts of global warming. This is understandable since the concept in relation to the negative impacts of global warming has just been known and accepted in the global circles only in 2011.

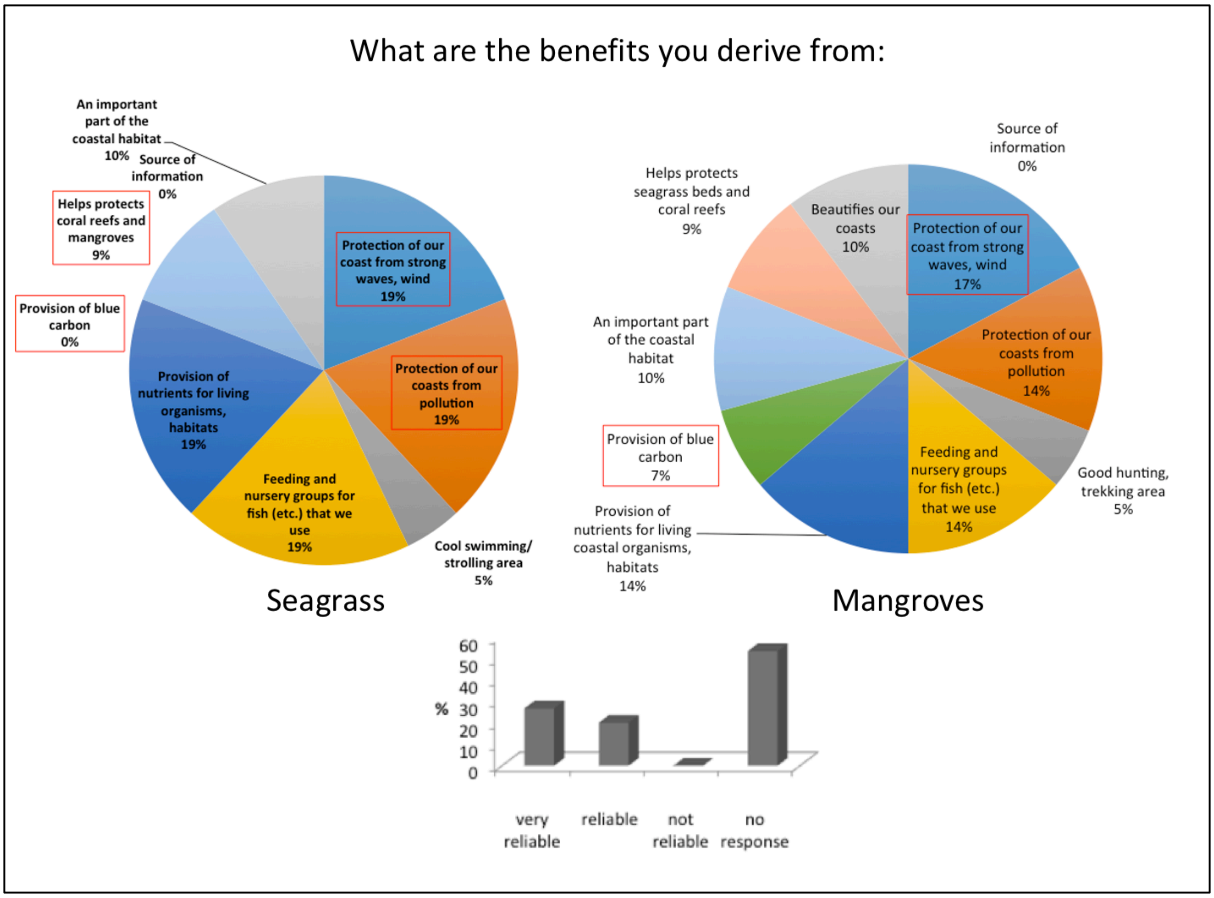


Fig. 7. Majority regard both ecosystems as important in terms of their environmental or ecological usefulness. Reliability Index is also included.

The outcomes of the interviews and analyses consolidated the topics for capacity building via implementation of our Focus Group Discussions (FGDs), workshops, training courses and the conference. These are reflected in the nature and intent of the community-oriented activities which are summarized in (Fig. 8) and whose details are given in Appendix 1. They do not include similar meetings aimed at improving project organization and performance (e.g. project planning workshop, organizational meeting re national conference). Hence, from the activities, three categories emerged (basic knowledge, methods, and communication and advocacy), dictated by the actual local needs for training and to understand the basic concepts of seagrasses and mangroves as 'bioshield' so that the outcome would be useful in addressing the issues. The activities were intended to train officials of the Local Government Units (LGUs), the academe, the environment, fisheries and education sectors, NGOs and media as beneficiaries. Seen from (Fig. 8), more basic knowledge and information were required at the early stages of the project in order to fulfil the stakeholders' responsibilities of protecting their coastal environment. The project understandably acceded to the request, since a strong scientific base should be the foundation of sound conservation and management practices. On the other hand, practical methods (e.g. sampling, water quality

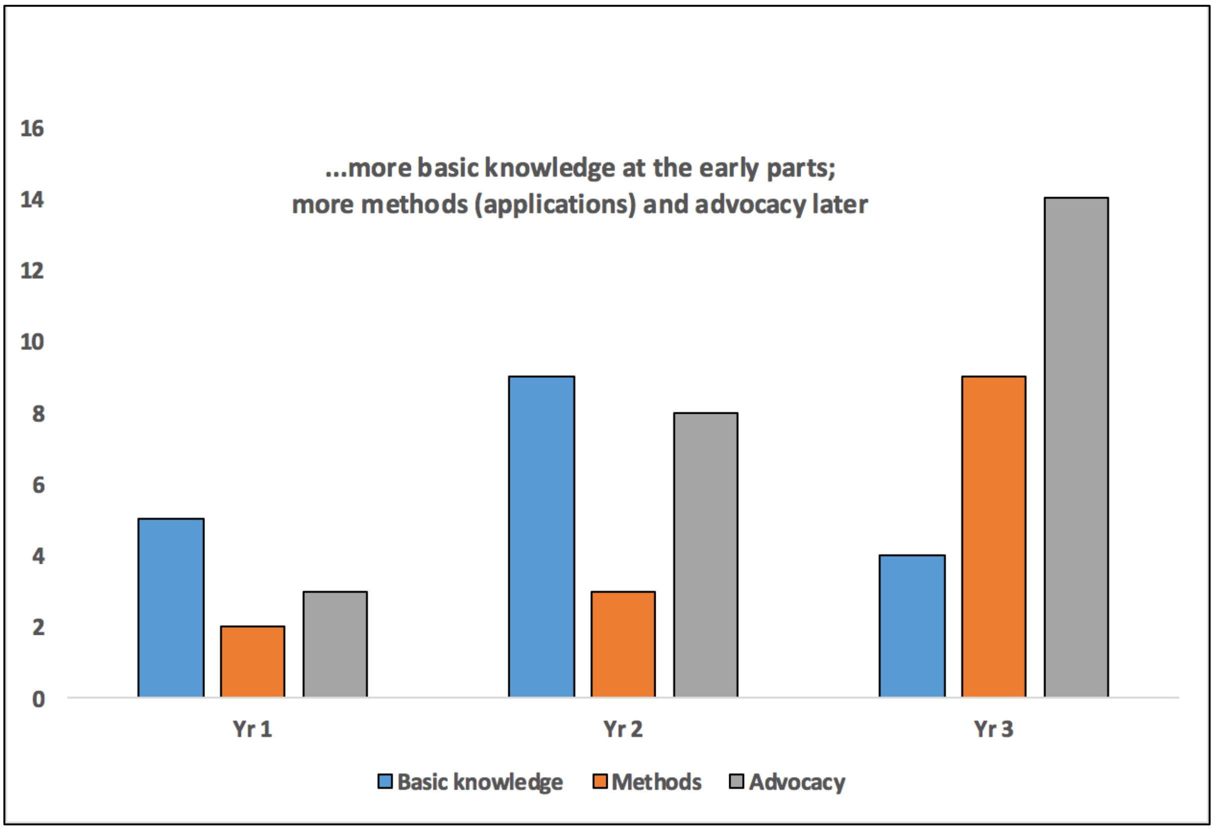


Fig. 8. Change in emphasis of the community-oriented activities from Yr. 1 to Yr. 3 of SMBP based on actual need and practicality.

monitoring) were necessary, going hand-in-hand with knowledge acquisition during these phases, increasing in number as these methods were translated into their application in addressing the issues (e.g. density sampling in seagrass and pack test to detect impact of eutrophication, as a science-base support for zoning ordinances). It should be emphasized that methods training of local personnel was only on topics most practical and relevant to local conditions of manpower, resources and actual use. Hence, training for non-academic personnel on the use of DIDSON, satellite and GIS, were not pursued for LGU and fisheries officials.

As was originally intended, more and more communication and advocacy oriented activities were undertaken as the project went on. The materials used here were mostly products of the earlier science-development phase of SMBP, catering to the actual need of communities for more people to be made aware and to understand more fully the need for concerted and integrated actions in order to solve directly their local concerns.

Area, distribution and community structure of seagrasses and mangroves

The area of seagrass beds in the Bolinao Seagrass Demonstration Site (Santiago Island only) totals 3,399 has or 33.99 km^2. This area comprises the highest single concentration of seagrass in the northern part of the Philippines. This total is categorized into: 1,600 ha (16 km2) of dense beds and 1,799 ha (17.99 km^2) of less dense beds (Fig. 9). Arbitrarily, "dense" seagrass beds means beds with 1- 3 dominant species (mostly *Enhalus acoroides, Thalassia hemprichii* and *Cymodocea rotundata*), having biomass of 500-1,200 gDW.m^{-2}; "less dense" seagrass beds means beds with 1-5 seagrass species having biomass of 0-499 gDW.m^{-2}. For all three dominant species biomass includes both aboveground and belowground dry weight. It is along the 5-km stretch in the eastern section of the northern

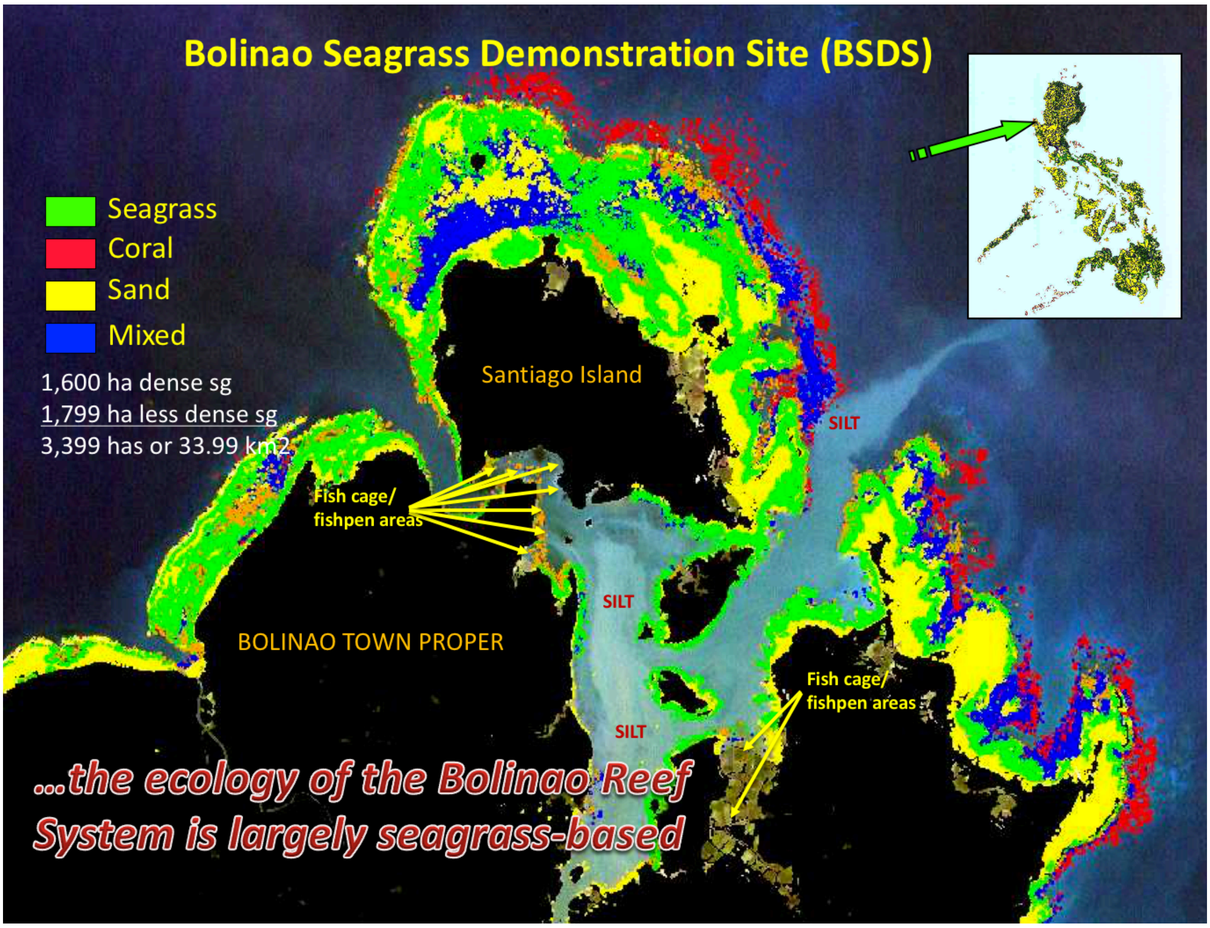


Fig. 9. Area of seagrass at the Bolinao Seagrass Demonstration Site (BSDS), primary study site in the northern part of the Philippines. Also shown are the major disturbance factors

island where the intensified studies of the project were undertaken. It should be noted that the values obtained are still in the process of refinement. ENVI 4.8's Maximum Likelihood Supervised Classification tool was utilized to classify the image. The highest overall classification result (88.3%) was obtained by applying the Simple Radiative Transfer Model and using Worldview-2's coastal, green, yellow and red bands (Tamondong et al. unpublished). Appendix 11 gives details of the distribution and area (km2) of mangrove, seagrass and coral reef ecosystems in the Gulf of Mannar Region, Tamil Nadu, India.

In Bolinao and in relation to the results of the analyses of seagrass response to gradients in nutrients and chlorophyll-a and sedimentation (silt), Fig. 10, shows a synthesized outcome. The sedimentation rates from near Station 1 (close to natural mangroves) to areas without seagrass going up north in the vicinity of Station 4 are shown in Fig. 11, Results show that some definite biological reactions along the gradient can be summed up in the following. From low levels of the 'stressors' ('less stressed' condition) to high levels ('more stressed' condition): (1) There was a marked decrease in the number of seagrass species; (2) In terms of cover and density, *T. hemprichii* and *E. acoroides* exhibited opposite responses, with *T. hemprichii*, showing marked decreases in both parameters, while *E. acoroides* showed increases; (3) In terms of biomass, ratios between the above- and belowground biomass in each of the two species showed general *(E. acoroides)* but a marked (*T. hemprichii*) increase; (4) In terms of leaf growth rate (cm day^{-1}), growth of both species was faster under ‘more stressed’ than in ‘less stressed’ conditions. However, under both conditions and regardless of the period, *T. hemprichii* consistently had much slower rate of growth than *E. acoroides*; and (5) In relation to season, both species exhibited similar bimodal peaks, which were generally higher in colder, wetter season than in hot, drier season. Based on increasing sensitivity (decreasing

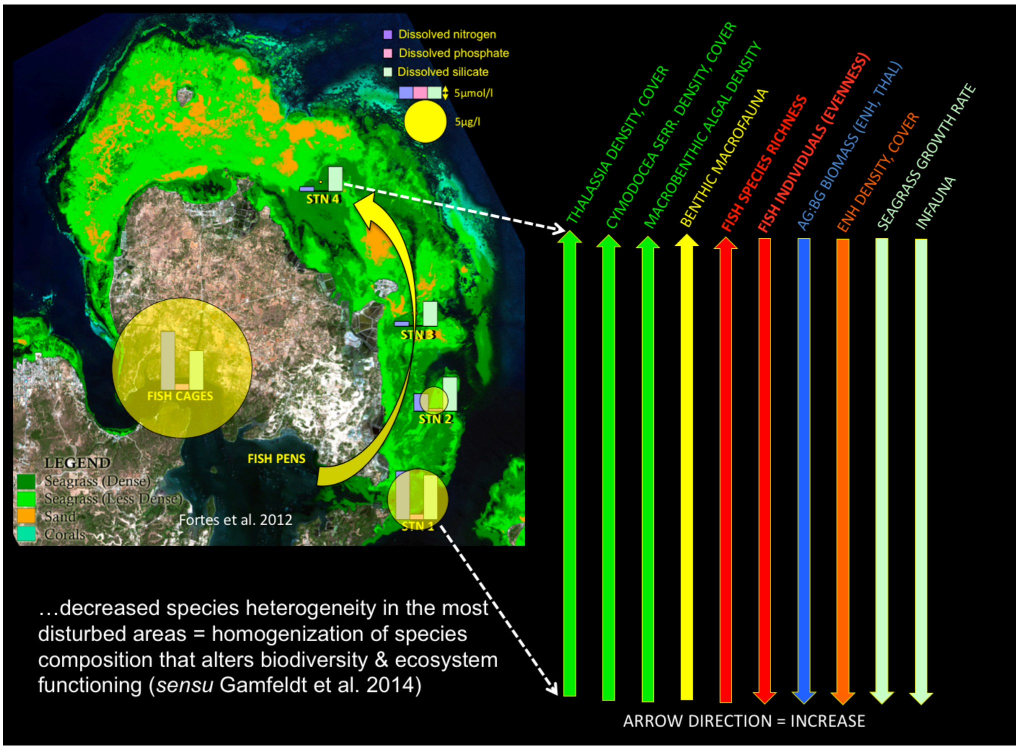


Fig. 10. Responses of seagrass and seagrass-associated communities to gradients in nutrients, chlorophyll-a and sedimentation in Bolinao.

resistance) to a combined effect of nutrients, chlorophyll-a and siltation, we propose the following sequence of the species:

Enhalus acoroides > *Thalassia hemprichii* >*Cymodocea rotundata* >

Halodule uninervis > *C. serrulata* > *Halophila ovalis* > *Syringodium isoetifolium.*

This sequence varies slightly from the initial findings of Terrados et al. (1999). We likewise propose that changes in the biological parameters in the study be considered in the search for indicators useful for a better understanding of fish farm and siltation effects on the coastal environment (Fortes et al. 2012).

A major deficiency in local efforts to understand the dynamics of species, communities and especially ecosystems, is their threshold response to disturbances or stressors. In Bolinao, we addressed this problem by studying the responses of major seagrass bed components to gradients in nutrients coming from fish cages and fishpens and silt discharged from rivers upstream.

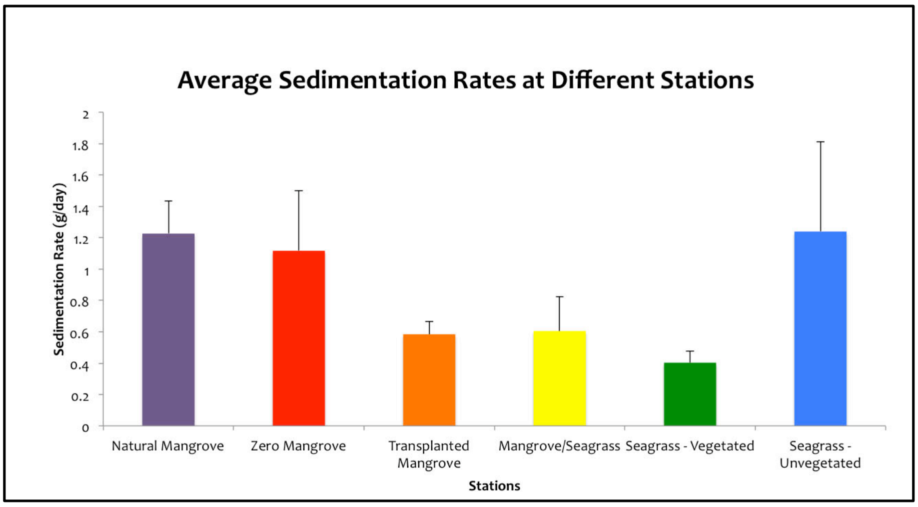


Fig. 11. Average sedimentation rates from a natural mangrove area, no-mangrove area, to seagrass and seagrass unvegetated areas. These areas generally follow the gradients in eutrophication shown in Fig. 10.

In New Argao (Malita, Davao del Sur), three sets of field activities were undertaken: (1) transect-quadrat sampling to determine the change in seagrass area and biomass; (2) sampling to determine the relationships between the area of seagrass grazed by dugong (DFT), the remaining seagrass and the gaps between the first two parameters; and (3) observations on the feeding behavior of dugongs. Fig. 12 shows the variations in species composition, area and cover of seagrasses at depth from 2007 to 2013 (Mukai, unpublished report). Species number was reduced from six to four and the area occupied by the plants

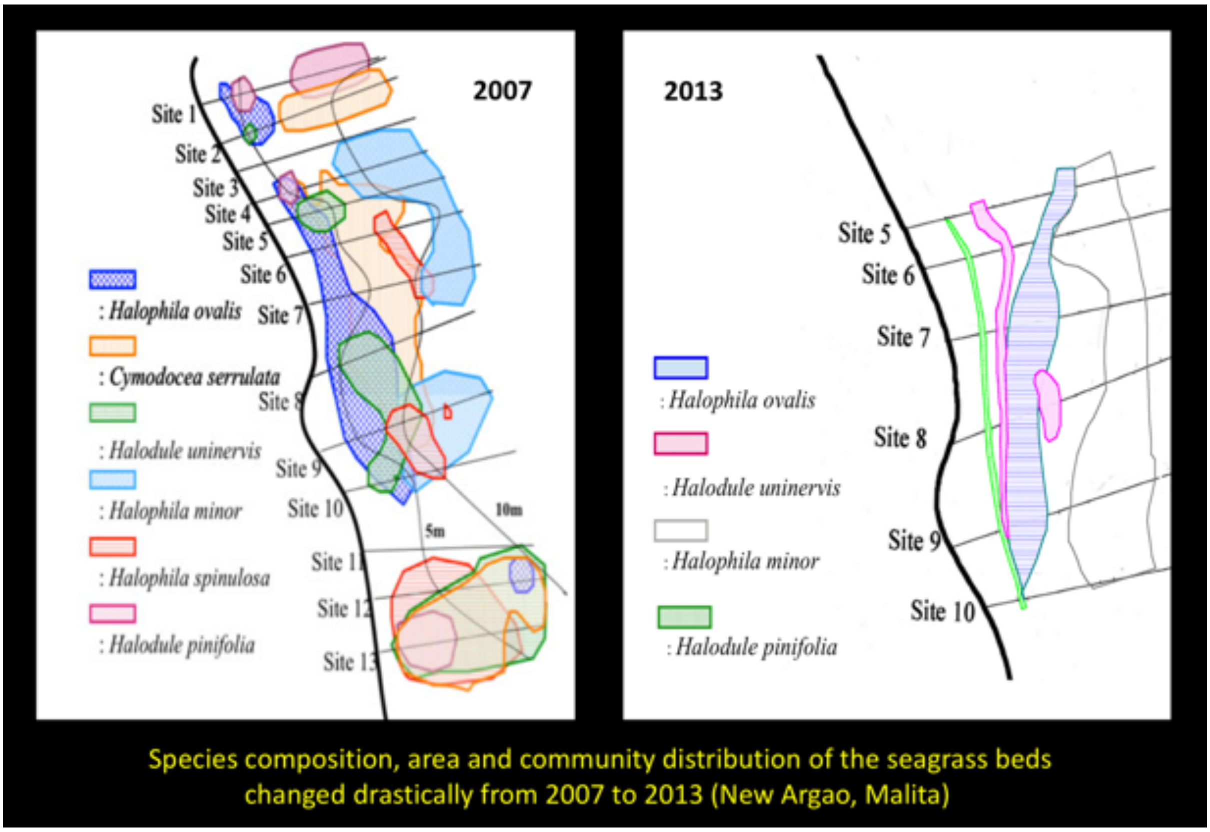


Fig. 12. Variations in species composition, area and cover of seagrasses at depth from 2007 to 2013 (Mukai, unpublished report).

was substantially diminished. In addition, the location of the beds generally changed, becoming more common at greater depths. In terms of biomass (g. m^{-2}) of the two dominant and primary food of the dugong, Table 1 shows the comparatively low values for Malita in December 2011. Later investigations undertaken showed that his 'pattern' of decreasing biomass did not change. This is exemplified by the change in biomass of *Halophila ovalis*, the 'favorite' food of dugongs, at sampling Station 9 from 2005 May and December (2005 M, D) to 2014) (Mukai, unpublished report, Fig. 13). From a mean of 27.4 g per sq. m in 2005, it was reduced to about 1 g per sq. m in 2014. It is interesting to note that the waters during the earlier sampling months, made close to the same months, were much clearer and less turbulent. In addition, for earlier sediment conditions were more conducive to seagrass growth: much less silted, the shell and other organic debris were also much less, and the substrate more consolidated and less shifty. In general, temperature was cooler and rainfall less during the earlier months.

Table 1. Comparative biomass (gDW.m^{-2}) of the two seagrass species in Malita

Quadrat No.	**1**	**2**	**3**	**4**	**5**	**Mean Biomass**	**gDW. m^{-2}**
Halophila ovalis	389	173	384	185	471 mg	320.40	14.24
Halodule pinifolia	0	0	0	14.8	22 mg	7.36	0.327
TOTAL						**327.76**	**14.567**

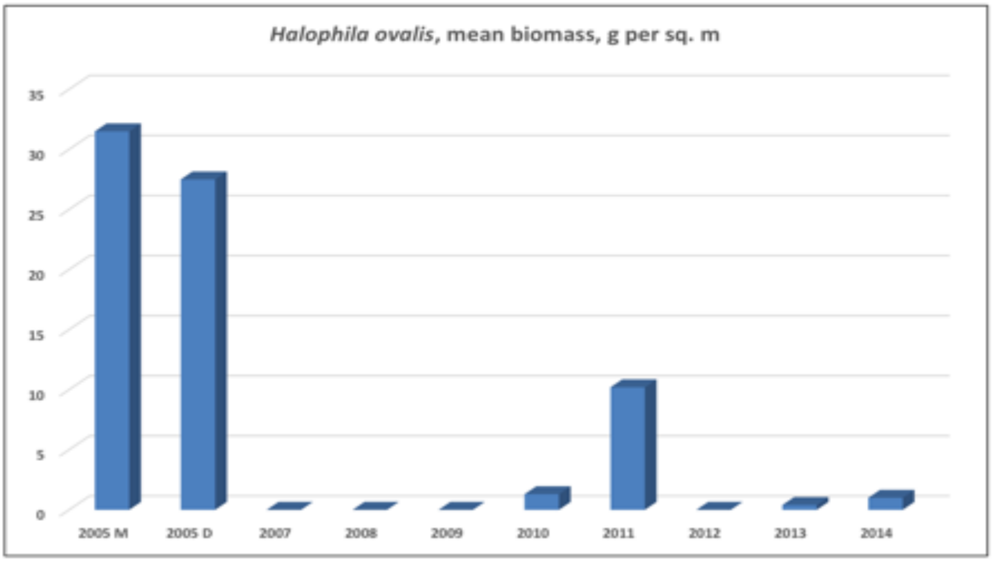


Fig. 13. Change in the biomass of *Halophila ovalis* (2005 – 2014) in New Argao, Malita, Davao del Sur.

Seagrass beds in Malita have changed drastically. These changes in the structure of the seagrass communities can only be surmised at this point in time, and that drastic fluctuations in the water and sediment conditions being the most influential factors in bringing about the changes.

To determine the relationships between the area of seagrass grazed by dugong (DFT), the remaining seagrass and the gaps, 38-43 quadrats were regularly sampled perpendicular the shore at a depth range of 3-17 m. Fig. 14 shows a representative quadrat sample at 10 m depth. Density of the seagrasses increased with depth, except at the depth greater than 17 m where no seagrasses were observed.

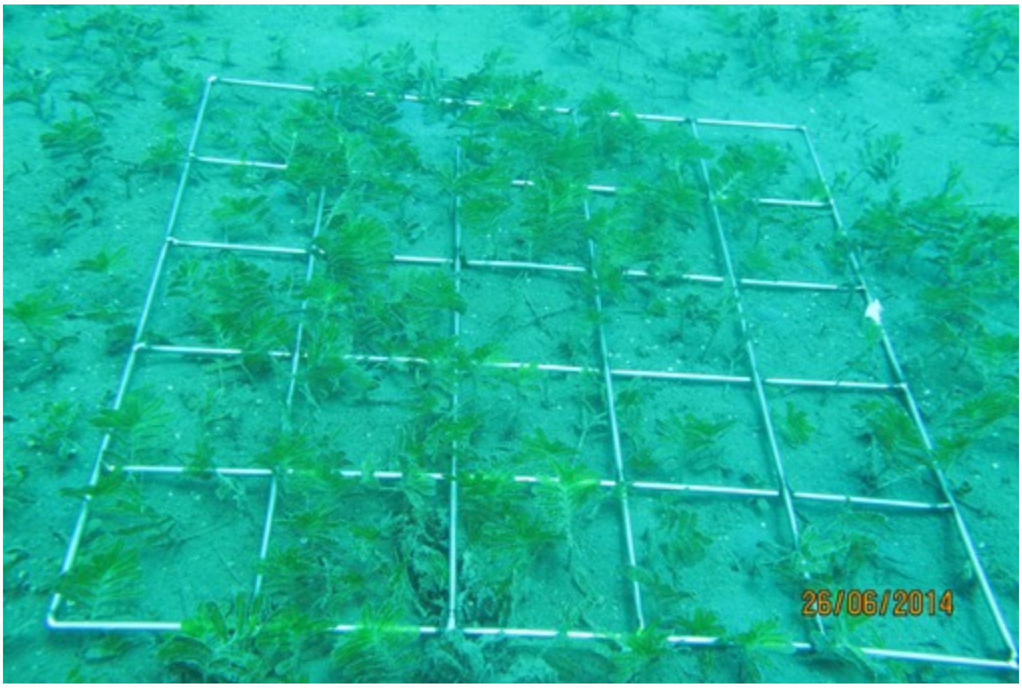


Fig. 14. Quadrat at 10-m depth in New Argao (Malita, Davao del Sur, 26 June 2014) showing a high % cover of an undescribed (?) or new (?) *Halophila* species

Fig. 15 shows a discernable trend in the temporal cover differences of the seagrass species and feeding trails in New Argao especially during the period November 2013 – June 2014. Worth noting are the following: (1) an increase/decrease in the cover of *H. ovalis* follows the increase/decrease in the area of seagrass grazed. This is consistent with the fact that while the seagrass is the primary and preferred food source of the dugong, grazing has apparently not affected the overall status of the seagrass bed; (2) on the other hand, the cover of the smaller variety of *Halophila ovalis* (HOVS (S), exhibited a decrease with an increase in the area of seagrass grazed; and (3) *Halophila spinulosa* (HSP) was not present from Nov 2013 to Feb 2014, but it appeared four months after in June 2014.

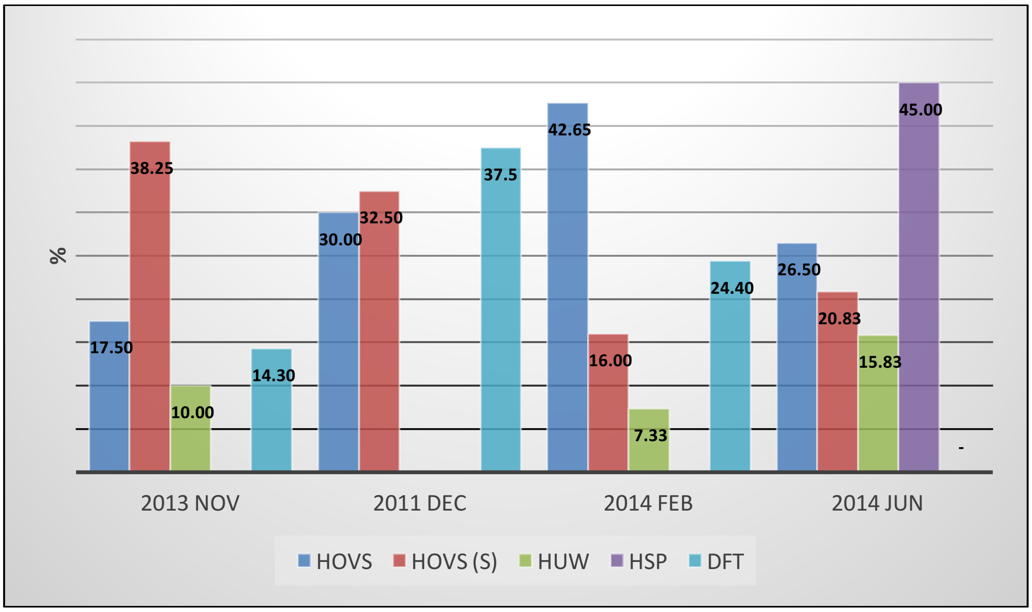


Fig. 15. Mean cover (%) of the seagrass and dugong feeding trails (DFT) in New Argao (Malita, Davao del Sur) in Nov 2013-Jun 2014; HOVS (S) is the smaller species of *Halophila ovalis.*

Fig. 16 supports the observations made regarding seagrass cover and dugong feeding trails in New Argao for the period. In Malita, 14.3% of the total of 3 ha area of seagrass was grazed or went into dugong consumption during the period.

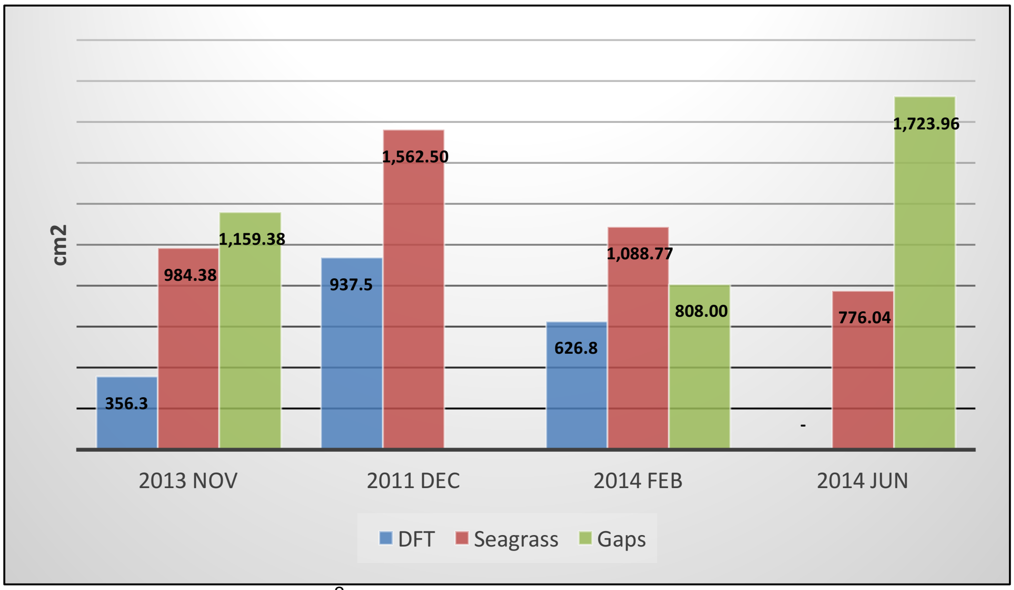


Fig. 16. Mean area (cm^2) of the seagrass and dugong feeding trails (DFT) in New Argao (Malita, Davao del Sur) in Nov 2013-Jun 2014

In the municipalities of the provinces of Samar and Leyte ravaged by the Super-Typhoon Haiyan last 8 November 2013, the area of seagrasses totals 329 ha (3.29 km2) (Fig. 17.). While we have the area of seagrass before the typhoon event in 2013, there is no sound basis of any explanation of the change in coverage (2013-2014), since seagrass can recolonize the same or nearby area after a month or so. In addition, the huge discrepancy in the two-year values indicate that other factors are more influencial in changing the dynamics of the plants. It should be emphasized that because of the generally turbid waters of the bay area, more mapping studies using refined methodologies are necessary in order to ascertain a more accurate estimate of the area covered by the seagrasses.

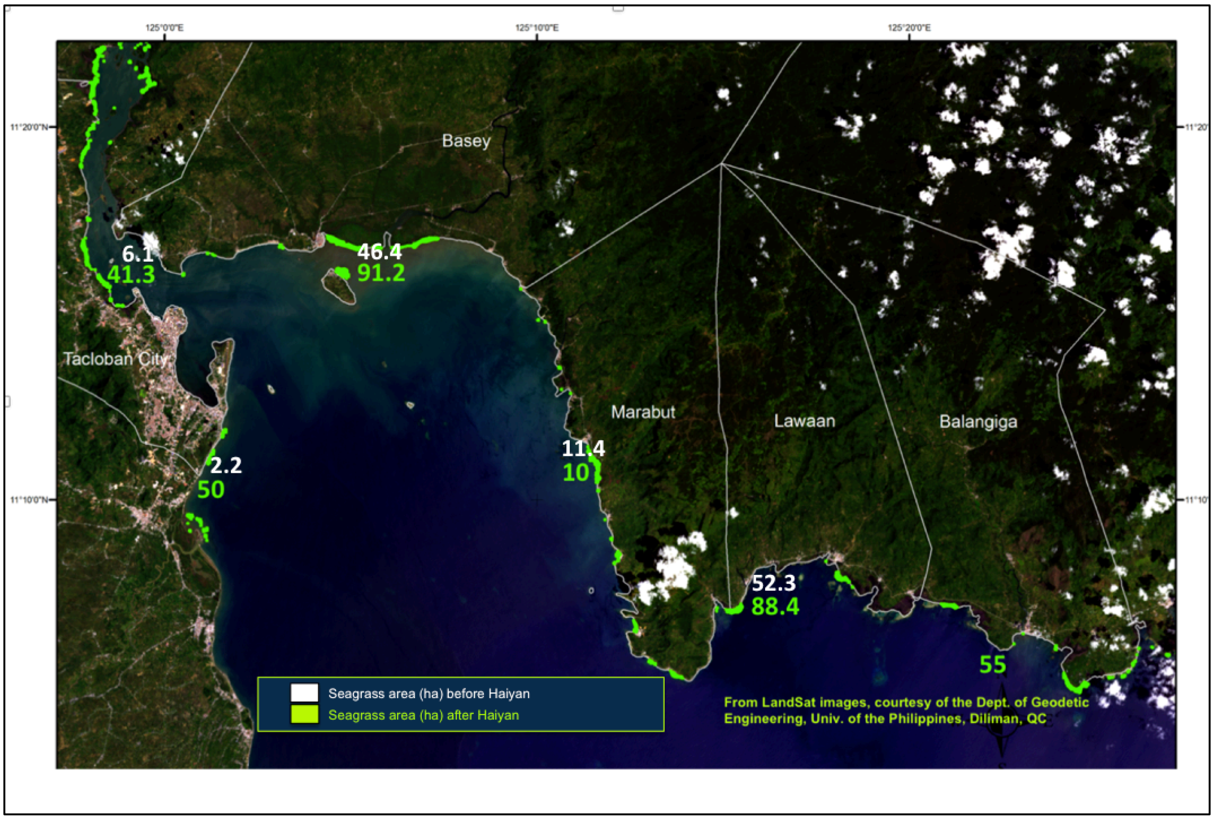


Fig. 17. Seagrass area (ha) before and after the Super-Typhoon Haiyan in 2013. The change cannot be correlated with its impact (see text for explanation)

In Indonesia, growth of young leaves *E. acoroides* varied from 1.06 to 1.87 cm.d^{-1} and growth of old leaves varied from 0.04 – 1.12. cm.d^{-1}. Production of above ground (leaves) varied from 2.32 to 2.39 g.DW.m^{-2}.d^{-1}. Litter fall leaves of *E. acoroides* in the water column varied from 0.49 to 4.96 g.DW.m^{-2}, lying on the substrate 0.26 – 4.99 g.DW.m^{-2} and total 0.75 – 9.95 g.DW.m^{-2} (Appendices 2, 3, 4, 5).

Percentage survival growth of seedlings of *E. acoroides* in the transplant unit 9 shoots.m^{-2} varied from 85.96 to 94.95 % and percentage survival growth of seedlings *E. acoroides* in the transplant unit 25 shoots.m^{-2} varied from 88.62 to 87.56. Percentage survival growth seedling of *E. acoroides* in the units 25 shoots.m^{-2} is higher than that in the unit 9 shoots.m^{-2} (Appendix 6).

Average number of new shoot in the seedling of *E. acoroides* after 6 months planting, one new shoot varied 7.00 to 13.33 shoots, two new shoots varied from 0.33 – 1.67 shoots and three new shoots 0.33 shoots (Appendix 7).

Kawaroe *et al.* (2008) reported that the area of seagrass beds lost in Pari Islands is 678,300 m^2 (25%) from 1999 to 2004. Decreasing area of seagrass beds at Pari Island was followed by reduction in its associated biota. Benthic animals such as giant clam, sea cucumber, mollusk, shells are still easy found on the reef flat in the period 1980 – 1990, also for fishes. But now they are very hard to find.

Seagrass ecosystem at Pari Island needs rehabilitation to restore the good condition. The technique for rehabilitation of seagrass is transplantation. Transplantation of seagrass was pioneered by Addy (1947), who used seeds of *Z. marina*. Fonseca *et al.* (1998) launched the protocol for transplantation in temperate seagrasses. Until now there is no guideline or protocol for transplantation of tropical seagrasses. Here, we try to develop baseline data of a protocol for transplantation of tropical seagrasses, using *Enhalus acoroides*.

Applying the new technologies mentioned above, seagrass areas in Masao, Pujada Bay were mapped with the acoustic video camera. Quantitative evaluation of seagrass vegetation in the area is needed in order to understand how they behave in response to disturbances. In addition, it is also useful in understanding the behaviour of the charismatic *Dugong dugon*, or sea cow (*dugong*), the most endangered among tropical marine mammals. Some earlier results of the activity are shown below (Figs. 20, 21, 22).

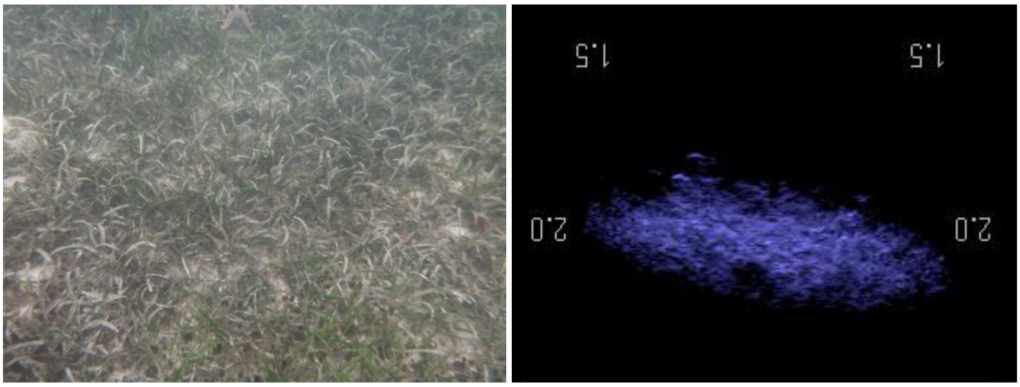


Fig. 20. Examples of the resulting optical (left) and acoustic (right) images of beds of the smaller seagrass species (mixed *T. hemprichii* and *C. rotundata*).

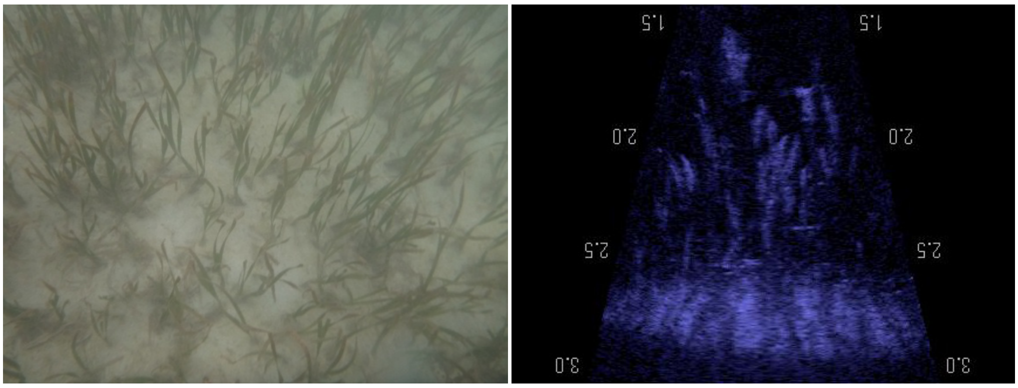


Fig. 21. Examples of the resulting optical (left) and acoustic (right) images of beds of the bigger seagrass species (*E. acoroides*).

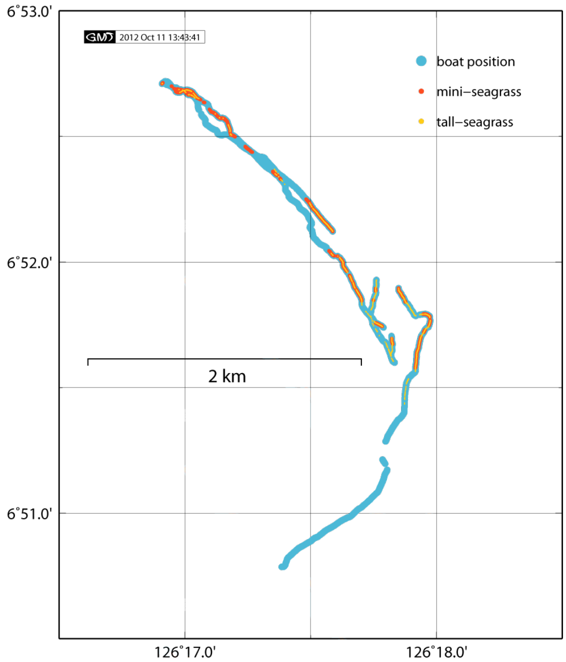


Fig. 22. Boat path showing the images created by DIDSON camera. Mini-seagrass, *T. hemprichii* and *C. rotundata*; tall-seagrass, *E. acoroides*

Hence, the earlier method of species classification of seagrass could not be done from the acoustic images alone. We need to collect more images of seagrasses and create a database in order to develop a method of seagrass classification based on the acoustic images. The outcome of this newer version of the technology is shown below (Mizuno et al. 2016. Through project partners from the University of Tokyo, this new method for making high-resolution seagrass map and quantification of dugong trail distribution was developed and field-tested in Mayo Bay. This method produces a clear and high-resolution database using both optical and acoustic devices (Figs. 23,24), respectively.

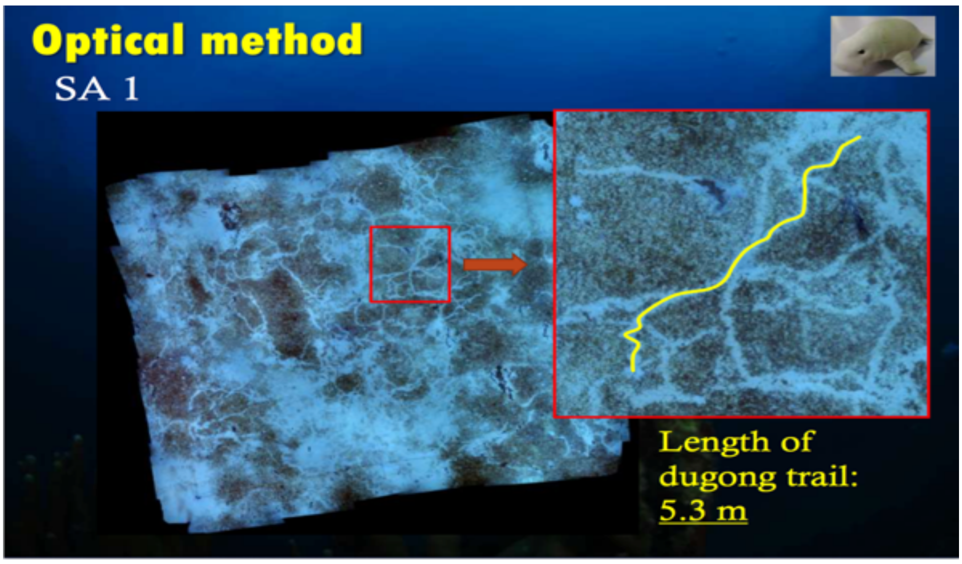


Fig. 23. Cover of seagrass (dark patches) and crisscrossing dugong-feeding trails at about 10 m depths in Mayo Bay, Mati, Davao Oriental.

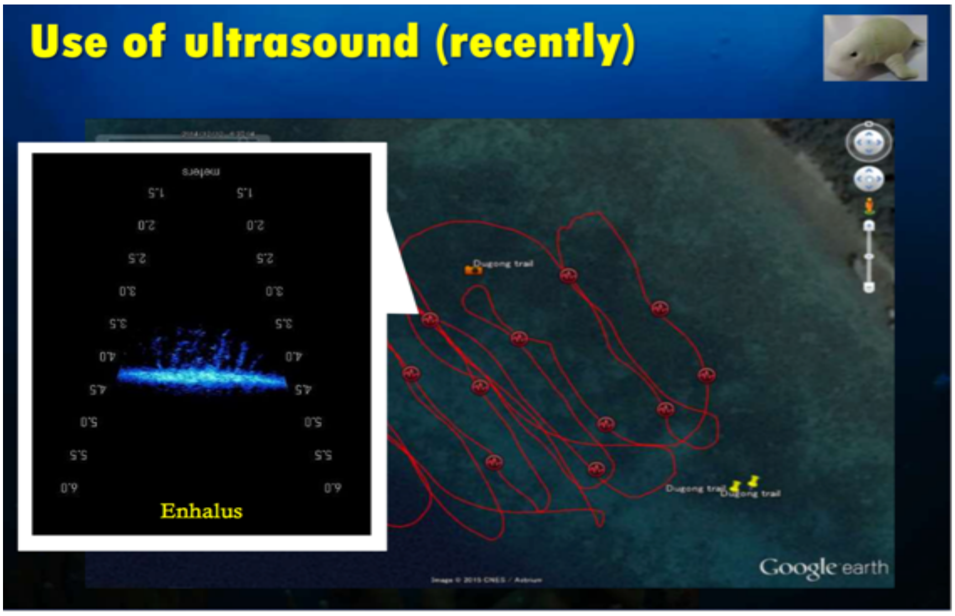


Fig. 24. Left: Patch of the seagrass, *Enhalus acoroides* (bright blue figure) detected by the DIDSON. The figure is one of the nodes along the path of the dugong feeding trails (red lines, about 10 depths in Mayo Bay, Mati)

This method has a strong advantage compared to the conventional method in that it needs much shorter time in the field, since it is easier to just take photos and the rest of the identification and analysis can be done at the laboratory. However, the data set is still small and some problems remain such as validation with the results measured by conventional methods (quadrat and transect tape), species classification, threshold definition, etc. This method could be useful in elucidating the relationship between dugong and seagrass. In addition, the high-quality image produced will contribute to local discussions on the current situation of the coastal environment among stakeholders. Moreover, the digitized data can be verified any time. Thus, this quantification method, based on high-resolution optical image generated by continuous photos, can be useful for assessing the status of the seagrass meadows and the distribution of dugong feeding trails.

In the case of mangroves, Fig. 25 shows the distribution and areal extent of the habitat at the sites for the Natural Resources Assessment Project (NRA) of the government (This writer is the leader in-charge of the Seagrass-Mangrove Sub-Module of the project). A total of 1,007 ha was estimated for both the provinces of Samar (the right land portion) and Leyte (the left land portion) sites, with Leyte having a slightly bigger area (566.5 ha) than those in Samar (440.5 ha). In Leyte, Abuyog has the largest mangrove area (295 ha, which includes a vast area of nipa), while Tolosa has the smallest (0.6 ha). In Samar, Balangiga has the largest mangroves (191.1 ha) and Marabut has the smallest (32.3 ha).

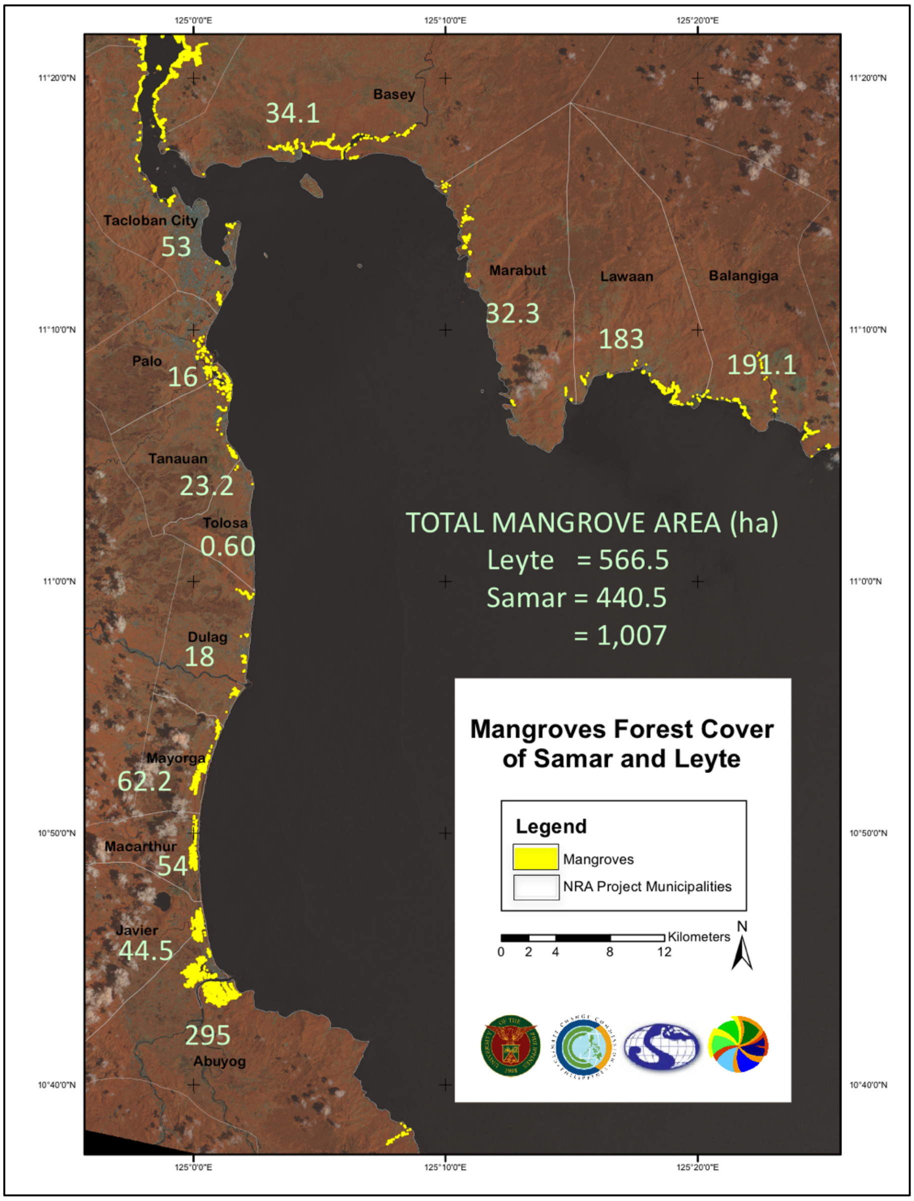


Fig. 25. Forest distribution and cover map of the mangroves at the Samar and Leyte sites (Courtesy of the RS-GIS Mapping and Database Module)

Table 2 gives the area (ha) of both ‘healthy’ and ‘damaged’ areas of mangroves at the 13 sites in Samar and Leyte. It should be noted that “**Healthy**” means recovered, showing no damage by Typhoon Yolanda. On the other hand, “**Damaged**” means affected by the typhoon, with few or no signs of recovery. It is interesting to note that after 3 years, at least 30% of the mangroves have not fully recovered. The mangroves at the Samar sites were heavily damaged when compared to the Leyte sites. This is because the path of the typhoon which packed the strongest winds directly hit the former; the latter, hit by the weaker typhoon part. Balangiga mangroves suffered the most; over 83% have not yet recovered after 3 years.

Table 2. Area (ha) of healthy and damaged mangroves at 13 sites in Leyte and Samar.

Municipality	Healthy mangroves	Damaged mangroves
Abuyog	295.00	0.00
Balangiga	32.10	159.00
Basey	34.10	0.00
Dulag	18.00	0.00
Javier	44.50	0.00
Lawaan	45.00	138.00
Macarthur	54.00	0.00
Marabut	22.00	10.30
Mayorga	62.20	0.00
Palo	16.00	0.00
Tacloban City	53.00	0.00
Tanauan	23.20	0.00
Tolosa	0.60	0.00
TOTAL	**699.70**	**307.30**
Percent	**70.00**	**30.00**

In Bolinao, practically all the mangroves have been removed to give way to fishponds. Those small patches that remain along coves are unhealthy, slowly being negatively affected by eutrophication. Some transplantation efforts have been made by the local coastal fishermen and the communities under the supervision of the environment and fisheries regional departments of the government.

In Mati, southeastern Philippines, the seagrass and mangrove resources have been mapped, but not as intensively as in the other project sites (e.g. Bolinao, Samar-Leyte). This is because of the non-availability of satellite images of the coastal portion of the area, which is of low priority compared to the terrestrial counterpart. Here, however, the project utilized new technologies to assess the distribution and abundance of the seagrasses. In addition, and in tandem with the seagrass activities, estimates of the number, length and distribution of dugong feeding trails were likewise assessed. Fig. 26 gives the distribution of both seagrass and mangroves in Mayo and Pujada Bays in Mati. The two bays have about 17 ha of shallow seagrass beds (to 5 m depth), distributed all along the fringes of Pujada Bay in the west. Mayo Bay, more and directly open to the Pacific Ocean, has much less seagrass although its abundant deeper-water beds (which exist), have not yet been fully and quantitatively assessed.

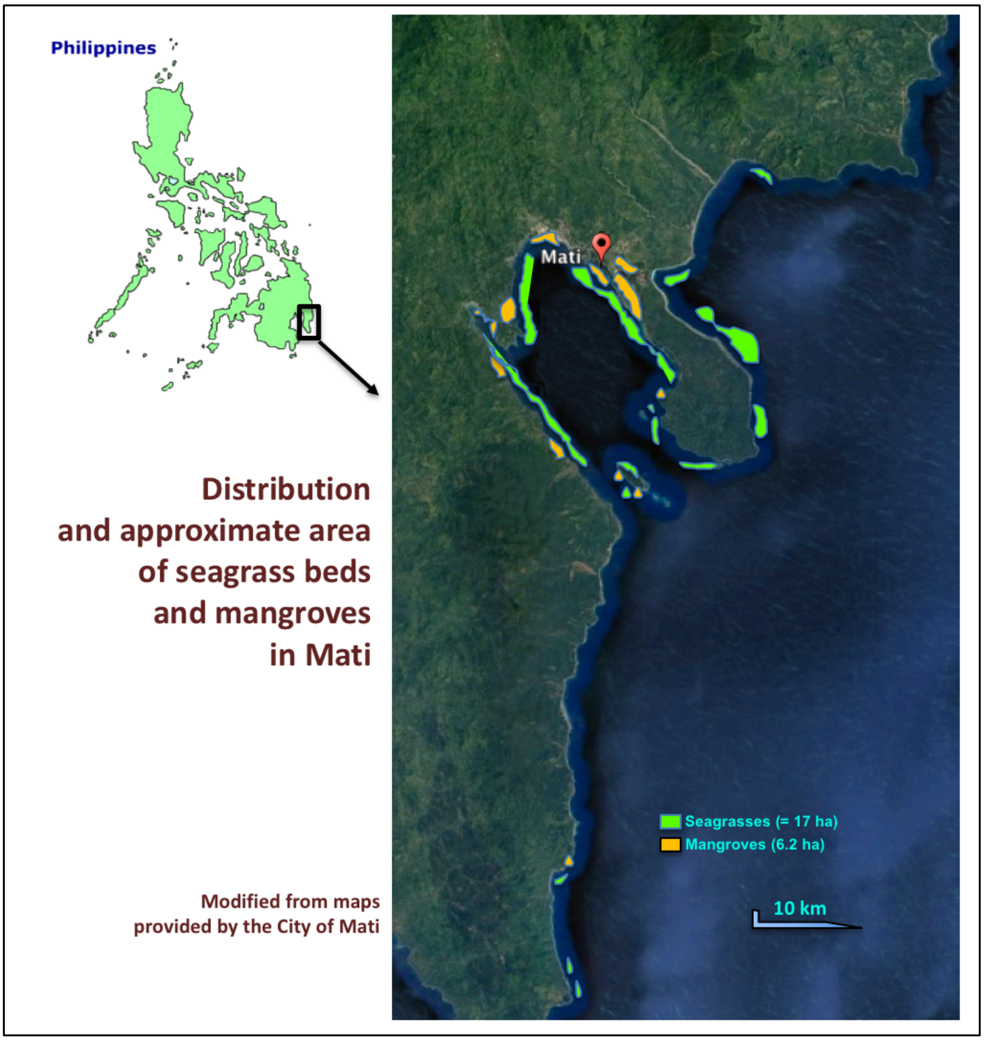


Fig. 26. Distribution (and approximate area) of shallow seagrass beds and undisturbed mangroves of Mayo Bay and Pujada Bay in Mati, Davao Oriental.

In Mati, only about 6.2 ha of relatively undisturbed mangroves remain. An object of intense development activities (fishponds homestead, and mining), the forest is diverse, thriving on varying types of substrates. Here, at least 3 students of the nearby Davao Oriental State College of Science and Technology (DOSCST) have wrote their theses, related to the thrusts of the SMBP.

In Olango, artificial planting of mangroves is a very popular practice at coast lines of tropical countries. The severe degradation of mangrove forest in the Philippines due to human encroachment in the past decades encouraged multilateral agencies to actively engage in the mangrove restoration. History of plantation efforts in many parts of the country was characterized with mixed success and failure stories (Primavera and Esteban 2008). For the economic benefits and the ease of the establishment of forests, the species of the highest survival rate is often chosen for the plantation, and planting density is usually far higher than that of natural stands. Therefore, at high survival rate of planted seedlings, where ecological disturbances are likely low, extremely dense mono-specific forests are formed. This study assessed the structural composition and extent of distribution of natural and planted mangroves in Olango Island, a Ramsar site in the Philippines.

The plantation was conducted in the 1st planted area at 15 years ago and the 2nd plantation area at about 60 years ago. Species composition of each quadrat of planted communities is shown in Fig. 27.

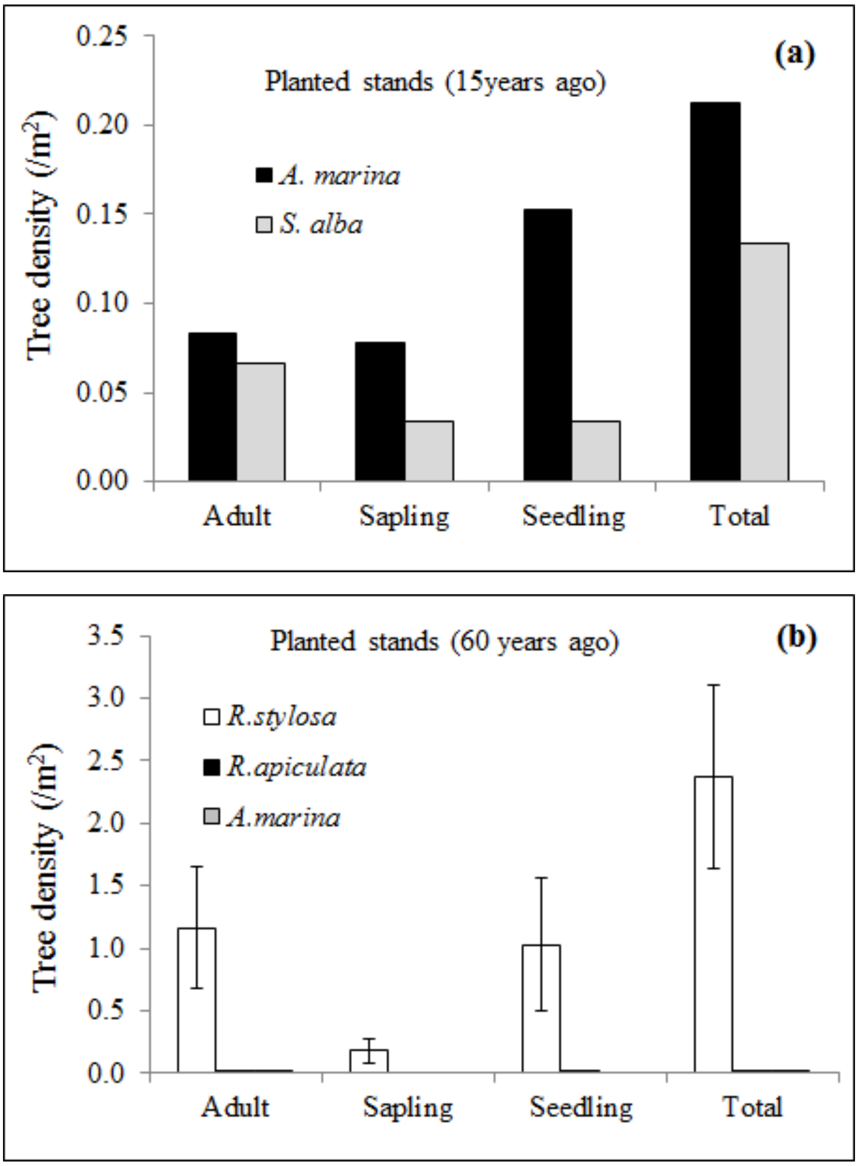


Fig. 27. Mangrove species composition at planted stands:
(a) 15 years ago, (b) 60 years ago

In planted quadrats, *Rhizophora stylosa* was far dominant compared with other species, *Avicennia marina* and *Sonneratia alba*, both in both 15 years and 60 years forests. Adult tree density was approximately 1.0 ind.m-^{2} in both communities. However, approximately twice as more young trees were growing in the 15 years community than 60 years community. DBH of adult trees in the 60 years community was 24.1cm +-4.1cm, compared with 13.9cm +-2.1cm in the 15 years community, with apparently darker climate than that of the 15 years community.

Fig. 28 shows the species composition of deep area of natural stands. In the natural stands, the largest composition was *A. marina*, followed by *S. alba*. They were originally dominant

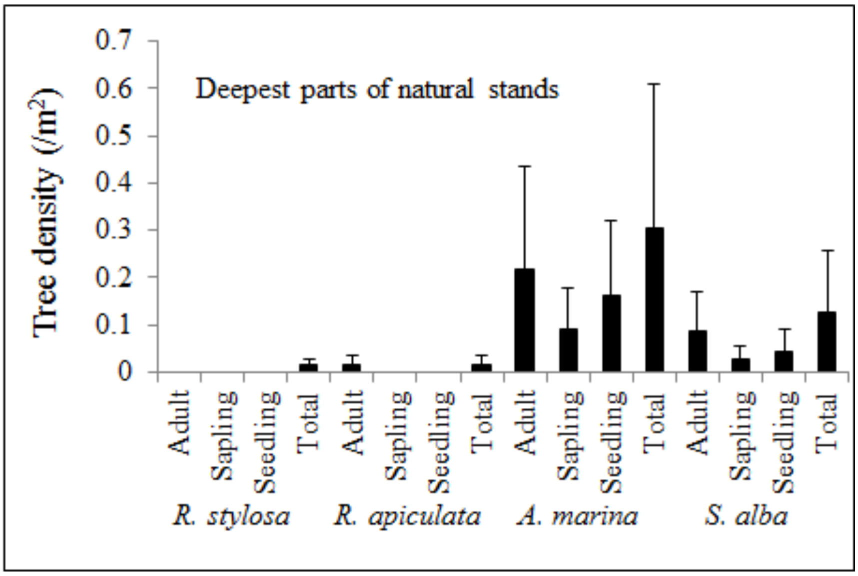


Fig. 28. Mangrove species composition in natural stands

species in this area. The composition of *Rhizophora* spp. was less than 2%. Species composition in the relatively dry zone of this area is shown in Fig. 29.

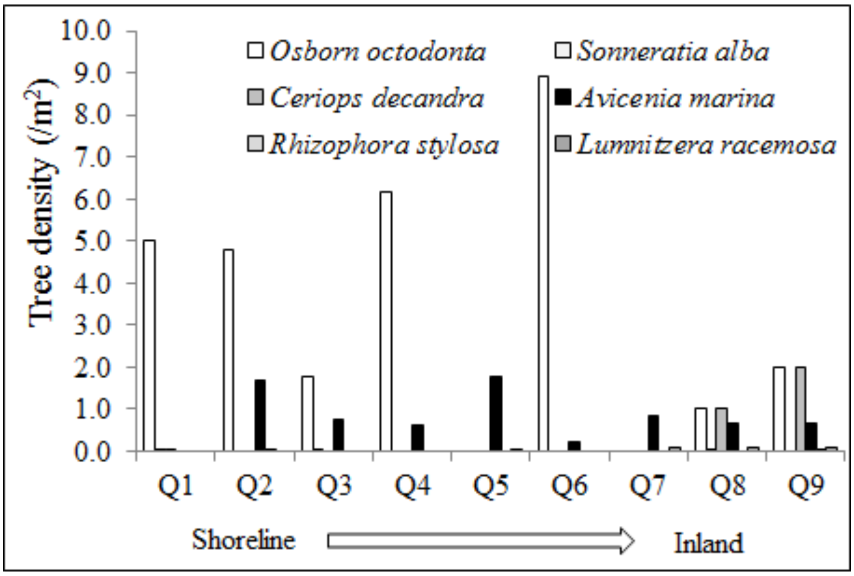


Fig. 29. Mangrove species composition in relatively drier lands

Osbornia octodonta is most dominant species in this area, followed by *Avicennia marina*. In dry area, *Ceriops decandra* was also dominant.

R. stylosa with tangling prop roots among individuals occupies all free space between trees and leaves no room for other species. Grown *R. stylosa* interrupts the use solar radiation by other species and alters the pattern of current and sedimentation. Structural data on the planted mangrove areas surveyed also showed high plant densities, slender stems, and narrower canopy cover and strikingly composed of monospecific *R. stylosa* species Besides, seeds of planted *R. stylosa* spread by the current of relatively deep water, invade into the natural stands of other species. The individual *R. stylosa* was taller and thinner at dense population. It seems, therefore, that the mono-specific plantation of *R. stylosa* extremely deteriorates species richness, variety of age distribution and likely the achievement of aims of the plantation except for fuel supply.

Interestingly, related mangrove studies undertaken in Bolinao show significant parallel results (Fig. 30). The average growth rate (daily-monthly) of the three *Rhizophora* spp was highest in site with fine-medium sand to muddy (TM) sediment composition followed by

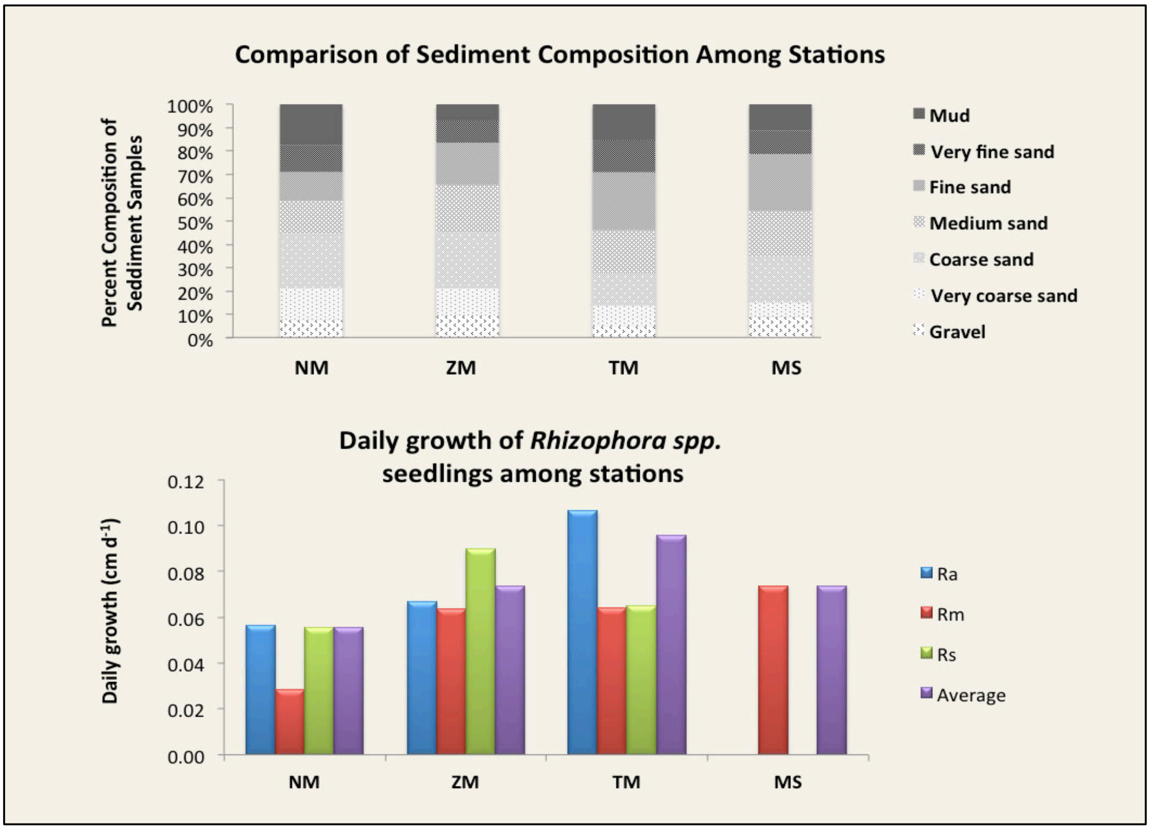


Fig. 30. Sediment composition at the stations described above matched with the daily growth rates at the stations. Ra, *Rhizophora apiculata*, Rm, *R. mucronata*, Rs, *R. stylosa*

almost fine to medium-coarse sand sediments (MS). Unexpectedly, *R. stylosa* and *R. apiculata* grew faster than *R. mucronata,* although *R. stylosa* grew well in coarse-medium to fine sand (ZM). It is also unusual that the growth rate of *R. mucronata* was higher in coarse-medium to fine sand (ZM) than in deep muddy-silt site (NM). *R. mucronata* grew well in deep soft mud, *R. stylosa* thrived best in sandy beaches and coralline substrate, while *R. apiculata* grew fast in intermediate sediment type which is composed of medium sand to very fine sand (Ding Hou,1958; McMillan,1971 and Cabahug et al.,1987). Noteworthy is the fact that identification of *Rhizophora* spp as Rm, Ra and Rs was very confusing and sometimes interchangeably used because of their similar morphologies particularly during the seedling stage.

Overall, an indication of success in the mangrove community may be reflected in the mortality and recruitment rates of the seedlings at the stations (Table 3). As expected, mortality was highest at the no-mangrove (ZM) station, and lowest at the transplant station (TM). On the other hand, recruitment was highest at the natural mangrove NM station and none at the seagrass station.

Table 3. Mortality (%) and recruitment (count) rates of the mangrove seedlings along the stations.

Mortality (%) and Recruitment (count) of Mangrove Seedlings		
SITES	MORTALITY	RECRUITS
Zero Mangrove	61	0
Natural Mangrove	27	23
Mangrove-Seagrass	8	0
Transplanted Mangrove	2	7

At the Indonesian site, values for some environmental (abiotic) parameters were gathered. These are shown in Appendix 8. Air temperature ranged from maximum 34^o C to minimum 29^{o}C and water temperature ranged from maximum 33^{o}C to minimum 28^{o}C. Depth was measured mostly during the low tide and varied from 40 – 80 cm. Current of the water ranged from 0.03 m.s^{-1} to 0.17 m.s^{-1}. Type of substrate can be classified to sandy muddy in the station A, C, natural and transplant sites and muddy-sandy in station B. Total organic matter in te substrate varied from 4.16 – 5.30 %. Light coefficient varied from 0.62 – 1.59. Salinity varied from 30.35 to 31.95$^o/_{oo}$. Nutrients in the water column for ammonium (NH4-N) varied 0.076 – 0.233 mg.l^{-1}, nitrite (NO_2-N) is <0.002 – 0.006 mg.l^{-1}, nitrate (NO_3-N) is 0.003 – 0.081 mg.l^{-1}, and phosphates <0.005 – 0.027 mg.l^{-1}. Nutrients in the interstitial water for ammonium (NH4-N) varied 0.083 – 0.557 mg.l^{-1}, nitrite (NO_2-N) is <0.002 – 0.019 mg.l^{-1}, nitrate (NO_3-N) is 0.004 – 0.092 mg.l^{-1}, and phosphates <0.005 – 0.061 mg.l^{-1} .

Biodiversity assessment

Biodiversity at the seagrass project sites is high. In addition to the dominant seagrasses, the commonly encountered associated taxa are seaweeds and animals. In the Philippines, 19 seagrass species have been found (Fortes 2013). Eight among these species are shown in Fig. 31 (Fortes et al. 2016). In general, the three species that dominate most seagrass beds in the seagrass sites are *Enhalus acoroides, Thalassia hemprichii, and Cymodocea rotundata*. *Cymodocea serrulata* is currently locally dominant, having disappeared from sites, which have been disturbed especially by pollution. In the case of *Ruppia maritima*, it is found only in highly disturbed areas (e.g. in polluted coastal waters and where coastal development is intense) and where salinity is very high (e.g. salt pans). On the other hand, *Halodule pinifolia, H. uninervis*, and *C. rotundata* are very quick to colonize areas, which have previously been disturbed. They are called, pioneering seagrasses.

Fig. 31. Species of seagrasses commonly found in the Philippines

At the SMPB seagrass sites, the most common macrobenthic plants besides the seagrasses are the seaweeds. Fig. 32 shows some of the commonly encountered seaweeds in seagrass beds in the Philippines (Fortes et al. 2016). Depending on the season and substrate types, seaweed species may vary even in the same locality.

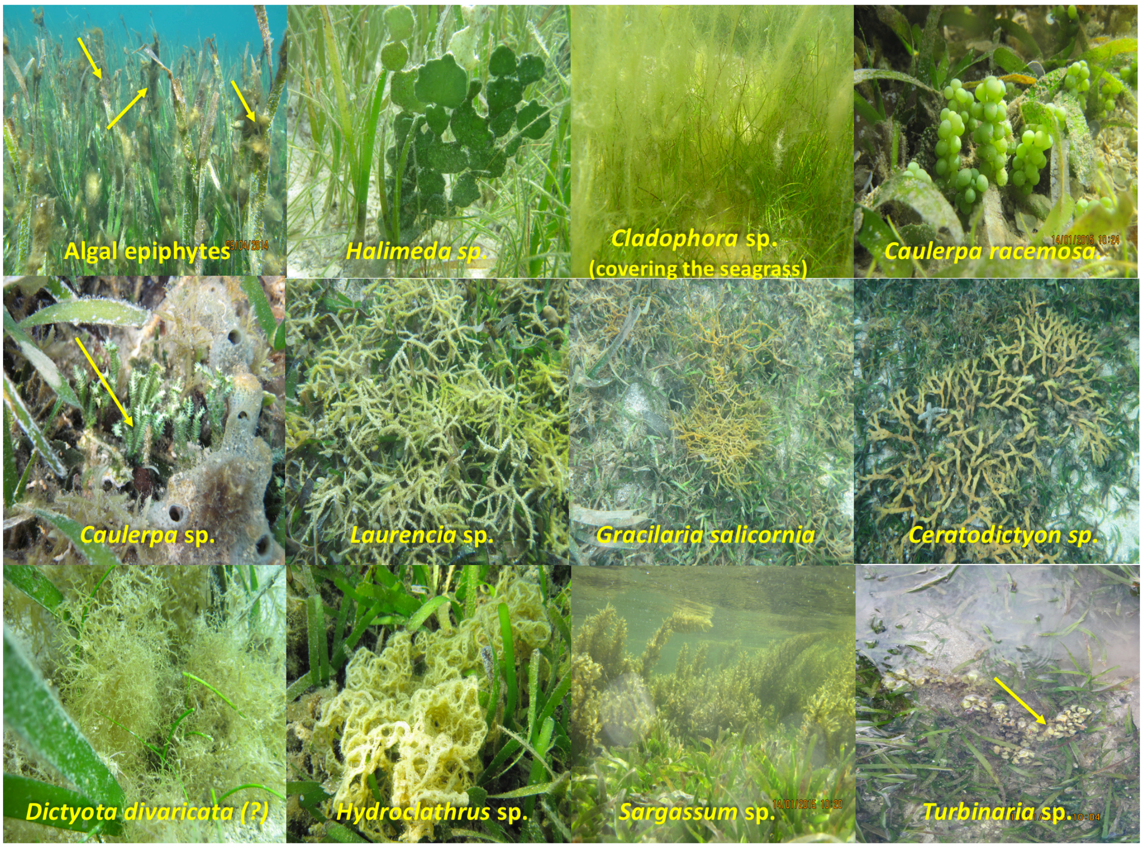


Fig. 32. Some seaweeds commonly found in seagrass beds in the Philippines

Interestingly, some seaweed farms are located on seagrass beds, because some physical (e.g. moderate water movement, shallow depth) and nutritional requirements for growth of farmed seaweeds are often found in seagrass beds. Unfortunately, seaweed farmers remove the seagrasses to prevent sea urchins from climbing up to reach and graze the 'planted' seaweeds, which are tied to the farm lines above. In Guimaras, the seagrasses are considered a hindrance in the harvest of the seaweeds. Fishes (e.g. siganids), common grazers of seagrass beds, also graze on the farmed seaweeds.

The animals that are found in seagrass beds are also highly diverse –from the minute protozoans, to the epizoans, i.e., tunicates; also gastropods, bivalves, sea urchins, star fishes, sea cucumbers, synaptids, polychaetes, shrimps, sea anemones, sponges, other invertebrates, fishes, to reptiles and mammals. Many of them are herbivores, grazing on the plants (e.g. sea turtles, dugong). Since the beds are nurseries for the juvenile stages of many organisms, they visit the beds as carnivores, preying on the smaller fishes and invertebrates. Some species are omnivores, subsisting on both plants and animals for their food. Some of the animals commonly encountered in seagrass beds in the Philippines are shown in Fig. 33 (Fortes et al. 2016).

Fig. 33. Animals commonly found in seagrass beds in the Philippines. *Dugong* is locally common in Mati and Malita

In Pari Island in Indonesia, the total number of species and total number of individual fishes in the natural seagrass beds of *E. acoroides* is higher than that in transplant *E. acoroides* unit 9 and 25 shoots.m^{-2}. Total number of individuals of fishes in the natural seagrass beds of *E. acoroides* , in the transplant unit *E. acoroides* 9 and 25 shoots.m^{-1} during high tide is higher than that during low tide (Appendix 9).

Total number species and total individual of crustaceans in the natural seagrass bed of *E. acoroides* and in the transplant *E. acoroides* unit 9 and 25 shoots.m^{-2} during low tide is higher than that during low tide (Appendix 10).

In India, among its major coastal ecosystems, seagrass meadows exist along the southeast coast (Gulf of Mannar and Palk Bay) and in the lagoons of islands from Lakshadweep (Arabian Sea) and Andaman and Nicobar (Bay of Bengal). The flora comprises 15 species and is dominated by *Cymodocea rotundata; C. serrulata, Thalassia hemprichii, Halodule uninervis, H. pinifolia, Halophila beccarii, H. ovata* and *H. ovalis*. Its distribution occurs from the intertidal zone to a maximum depth of approximately 15 m. Maximum growth and biomass are restricted from the lower littoral zone to the depth of 2 to 2.5 m. Greatest species richness and biomass of seagrass occur mainly in open marine sandy habitats. Although seagrass habitats are categorized as 'ecologically sensitive' coastal areas, they are largely ignored from both scientific and management point of view (Jagtap 1996).

The seagrass species diversity is high in the Gulf of Mannar and Palk Bay, while it is low in the Bay of Bengal (Parthasarathy et al. 1991). The seagrasses are one of the important producers in the marine environment, forming extensive meadows and supporting high biodiversity and they serve as feeding and nursery habitats. Hence, it is essential to monitor the status of the seagrass in the marine environment so the present study was aim to study the status of seagrass biodiversity, shoot density, seagrass biomass, epiphytic biomass and associated flora and fauna.

Overall assessment of seagrasses in the Gulf of Mannar region indicated that the total area of seagrass was 63%, among this 42% is distributed towards the shore and 21% on the seaward side. There are a total 13 species of seagrass found around the islands, of which 11 species are prevalent on the seaward side and all the 13 species of seagrass are present on shoreward side. Among the seagrass species, *Cymodocea serrulata* constituted 37% and is the dominant species on both the shoreward and seaward side where as *Halophila stipulacea* was least dominant species.

In India, mangroves are an important ecosystem highly adapted to saline waters. The mangrove vegetation of Tuticorin and the Gulf of Mannarregion consists mainly of the stunted mangrove species. The mangroves are situated in the Karapad creek and in close proximity to the salt pans. These mangroves are located and are thriving about 800m+ distance from the coast. *Suaeda maritima* and *S.monica* are the most abundant of the mangrove associates. The list of mangrove species in the intertidal and supratidal zones of Tuticorin in the periphery of Karapad creek at about a distance of 500 to 2000m are shown in the Table 4.

Table 4. Intertidal and supratidal mangroves of Tuticorin

Mangroves of intertidal zone	Mangroves of supratidal zone
Avicennia marina	*Suaeda monoica*
A. officinalis	*S. maritima*
Atriplex repens	*Salichornia brachiata*
Ceriops tagal	*S. herbacea*

Mangroves are present in Punnakayal, south of Tuticorin in the Gulf of Mannar region. The mangroves are predominantly composed of *Avicennia* sps. Due to high saline conditions and lack of freshwater inflow except during the monsoon, the *Avicennia* sp. appears as a bushy plant.

Trophic dynamics

The study of trophic dynamics in the context of the project has been a major thrust in its second year. The major aim of trophic ecology has been to explain the complex structures and interaction of food webs using simple models and generalities. This aim has important implications for the management of seagrass-based marine ecosystems with anthropogenic disturbance rapidly altering bottom-up (e.g. nutrient enrichment) and top-down (e.g. fisheries exploitation) processes. This study observed (underwater photography) a prominent four level food chain (epiphytic algae, mesograzers, juvenile fish, and piscivorous fish) in seagrass habitats in Pujada Bay (Mati) and Green Island (Roxas). Interestingly, dugongs open up the substrate in the process of feeding, exposing worms and other organisms which are food for macroinvertebrates like starfishes (ex. *Protoreaster nodosus*) (Fig. 34). In general, epiphyte and grazer densities were greater in developed catchments (Pujada Bay) with higher nutrient loads than in less developed catchments with much less nutrients (Green Island). However, a decoupling from the epiphyte trophic pathway was evident in higher trophic levels. The density of carnivorous juvenile fish and large piscivores displayed no significant change across the nutrient gradient of this study. This pattern indicates that a ratio-dependent functional response would be most appropriate for modeling the lower trophic levels and their responses to nutrient enrichment. In particular, the observations showed strong evidence for top-down control sometimes resulting in lower or similar levels of epiphytes in enriched areas compared to ambient 'control' areas. Hence, it can only be surmised that the structure of fish assemblages was influenced by the nutrient status of the waters they inhabited. Assemblages from developed and undeveloped catchments separated into distinct communities with higher abundances of fish in low nutrient waters. The species that contributed most to these differing assemblages were small pelagic carnivores (*Ambassis* spp.). These species appeared to be sensitive to poor water quality making them candidates for bio-indicators of anthropogenic disturbance in catchments.

Fig. 34. Dugongs open up the substrate in the process of feeding, exposing worms and other organisms, which are food for macroinvertebrates like starfishes (ex. *Protoreaster* sp.)

Overall, nutrient enrichment of coastal waters in Pujada Bay due to cutting of mangroves for fishponds promoted epiphyte growth that may compete with seagrasses for light, causing stress and possible declines in seagrass health and distribution. The observations, however, found greater seagrass biomass (*Enhalus, Thalassia, Cymodocea rotundata*) at sites with nutrient enrichment suggesting moderate increases to nitrogen-limited systems may be beneficial to these seagrasses. It also appears that the increase in primary productivity associated with nutrient loading did not translate into an increase in density of juvenile fish or piscivores in the seagrass habitats, which may not provide benefits to local fisheries production. Since nutrient enrichment alters trophic structure in coastal waters (as in

Bolinao, Fortes et al. 2012) and to have negative impacts on seagrass (Tanaka et al. 2014), it is recommended that an integrated approach to seagrass and coastal of management be developed and implemented. It was unfortunate that due to limitations and non-availability of expertise and necessary laboratory equipment and materials, the trophic dynamics part of the project was only lightly pursued. Hence, the results of the local activity, although significant, are only cursory.

Water quality

Water quality in Malita and Mati, Davao, Philippines

The results of our initial seawater monitoring with the sensors are shown in Table 5 while the results of the sensors and the pack tests for freshwater are shown in Table 6. Table 7 lists the results of the water analysis via standard laboratory protocols.

Table 5. Water quality of the sea surface (25cm beneath the surface) determined *in situ* with sensors (TOA DDK).

Station	SS1	SS2	SS3	SS4	SS5	SS6
Remarks	Malita. Most far from the river mouth	Malita. Middle of SS1 and SS3	Malita. Closest to the river mouth	Mati. Balete Bay (Pujada Bay inner most)	Mati. Guanguan along the mangrove forest	Mati. Dahican, directly facing Pacific
Date	10-Dec-11	10-Dec-11	10-Dec-11	12-Dec-11	12-Dec-11	13-Dec-11
Local time	10:24	11:17	11:55	10:39	15:14	9:49
Weather	Fine	Fine	Fine	Fine	Fine	Cloudy
North	06.22.114	06.22.801	06.23.587	06.53.432	06.54.113	06.55.455
East	125.38.075	125.37.572	125.37.218	126.09.851	126.16.129	126.16.998
Depth (m)	4.0	3.1	3.8	2.3	0.9	12.5
Conductivity (mS/m)	4610	4600	4470	4450	4490	4490
Salinity	30.7	30.6	30.1	29.6	29.9	29.8
Temperature	29.7	30.3	30	30.7	30.2	29.5
pH	8.34	8.35	8.30	8.24	8.41	8.34
Visibility at bottom	5m	<2m	<1m	2m	5m	7m

As can be seen from the data, the salinity at the seagrass beds at Mati was always lower than those at Malita even at SS6, which was facing directly to the Pacific Ocean and is without an inflowing river (Table 5). This may indicate that other sources of fresh water, such as ground water, maybe responsible for the observed difference in salinity levels between Mati and Malita.

Turbidity was much higher at the river stations compared to the stagnant ditch water. One reason for this difference is due to the inflow of turbid floodwater, and not because of the organic pollutants; the COD of the river stations were lower than the ditch water. Though the nutrient concentrations were mostly the same within the freshwater samples, COD was remarkably higher at the ditches rather than in the rivers.

Table 6. Water quality of the freshwater determined *in situ* with sensors (TOA DDK) and pack tests.

Staion	LS1	LS2	LS3	LS4
Remarks	Upper site of the river	Lower site of the river	Fish pond	Banana plantation
North	06.23.283	06.24.360	06.23.822	06.24.455
East	125.35.432	125.36.261	125.37.146	125.36.934
Depth (m)	0.5	0.5	0	0
Conductivity (mS/m)	40.2	37.4	48.3	55.3
Salinity	0	0	0	0.1
Temperature	30	31.2	31.3	31.2
Turb (NTU)	181.1	169.3	18.5	15.6
pH	8.72	8.41	8.32	8.28
COD(mg/L,ppm)	5	5	10	20
NH_4^+(mg/L,ppm)	0.2	0.2	0.2	0.2
NO_3^-(mg/L,ppm)	<1	1	1	1
PO_4^{3-}(mg/L,ppm)	0.5	0.5	0.2	0.2~0.5

Hence, based on the preliminary results of our research, we could consider that further water quality assessment is necessary in plantation areas with direct effluent discharge to rivers. Further tests may yield a better understanding of effluent quality from nearby plantations and its overall effect on seagrass health. In addition, we would also like to investigate further, possible sources of freshwater particularly in the Mati area. If the suspected freshwater source is indeed groundwater, this would pose additional complications in terms of water quality analysis, and therefore a more comprehensive water cycle assessment will be necessary.

Table 7. Results of water quality analysis of carbon and nitrogen via standard laboratory protocols. DON, ammonium, nitrite and nitrate are in µg l^{-1} and DOC is in mg l^{-1}.

	DON	Ammonium	Nitrite	Nitrate	DOC
LS1	8	5.2	10	271	0.8
LS2	18	6.7	15	289	1.2
LS3	514	14	12	60	3.1
LS4	319	31	14	609	2.0
SS4	93	4.8	0.8	13	1.2
SS5	73	0.0	0.8	16	1.2
SS6	83	2.0	0.7	27	1.4

As can be seen from the results presented in Table 7, the highest concentration of nitrogen can be found at LS3 and LS4. Furthermore, it can be seen that as one moves closer to areas of higher anthropogenic activity, the concentration of nitrogen increases; probably due to the application of fertilizers and feeds. With respect to the results obtained via pack test kits, it can be seen that despite the low concentrations detected in the laboratory, pack test kits were still able to give rough estimates of total analyte concentration.

Fig. 35 shows the water quality, indicated by the amount of turbidity at the study site in New Argao, Malita. Twenty sampling stations (yellow dots along the rivers, green dots along the coast) were made, five to represent potential impacts from Culaman River in the north, 11 stations were selected to represent the coastal waters of New Argao, and five stations assigned to represent the impacts from Lais River. It is clear that turbidity was highest where there were rivers draining the plantations and terrestrial vegetation and into the sea. On the

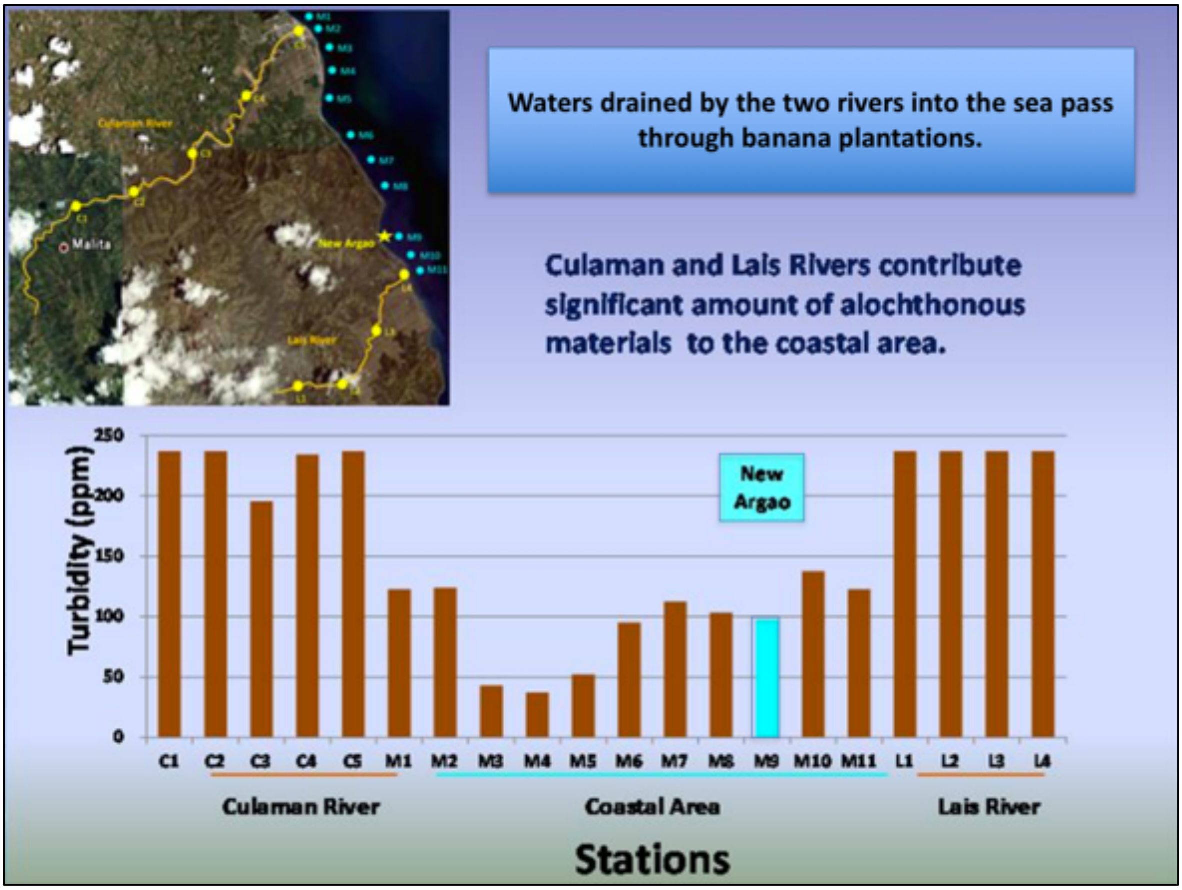


Fig. 35. Turbidity profiles at the 20 sampling stations in Malita, Davao del Sur

other hand, the parameter exhibited lowest values at the coastal stations located above and below New Argao and farthest from the river discharges. It should be emphasized that the coal-fired power plant, only 1.3 km directly north and along the shore of New Argao, was yet at the initial stages of its construction when the study was undertaken. At present, the power plant is almost completed. It is expected that its earth movements and the coal dust as well as additional sediments associated with the operation will be discharged into the environment, aggravating the unhealthy condition especially at the northern coastal portion. Hence, data are useful in providing a baseline for future studies of water quality in relation to the presence of a coal-fired power plant 1.3 km North of New Argao.

Water quality in the Gulf of Mannar, India

In the Gulf of Mannar, India, the status of water quality was determined. Along its coasts, marine water is subjected to several types of uses. Depending on the types of uses and activities, water quality standards have been specified to determine its suitability for a particular purpose. Among the various types of uses there is one use that demands highest level of water quality/purity and that is termed a "designated best use" (Table 8) in that stretch of the coastal segment. Based on this, primary water quality (Table 9) has been specified for five designated best uses as follows. (As per amendment to Schedule-1, serial no. 86 of Environment Protection Rules, 1986 dated 22nd December 1998).

Table 8. Sea Water Use Classification

SW-I	Saltpans, shell fishing, mariculture and Ecologically Sensitive Areas
SW-II	Bathing, contact water sports and commercial fishing
SW-III	Industrial cooling, recreation (non-contact) and aesthetics
SW-IV	Harbour
SW-V	Navigational and controlled waste disposal

Table 9. Primary seawater quality (SW-III)

No.	Parameters	Standards
1.	pH	6.5-8.5
2.	DO	3.0 mg/l
3.	Color & Odor	None
4.	Floating matters	No visible, obnoxious floating debris, oil slick, scum
5.	Fecal Coliform	500/100ml MPN
6.	Turbidity	30 NTU
7.	Temperature	Shall not exceed more than 5°C than the receiving water temperature

Physico-Chemical Parameters

Physico-chemical parameters such as surface water temperature, dissolved oxygen, pH, Total Dissolved Solids (TDS) and salinity observed during the present investigation are generally within the accepted range for marine organisms.

There was minimum variation in the overall surface water temperature during the sampling period which ranged from 29.2°C to 30.0°C with an average value of 29.8 °C. The maximum value was recorded in stations 10, 14 & 17. The temperature of the bottom water samples range from 29.1 to 30.0°C with an average of 29.7°C. pH of surface water samples varied from 7.8 to 8.5 with a mean value of 8.2. This value was more or less equal to the bottom water samples (7.9-8.5). The values of conductivity (4.9-5.9) and total dissolved solids (52.9-55.9) of surface water are shown and the ranges are in agreement with the values reported from the other areas in Bay of Bengal. The mean values of conductivity and total dissolved solids of bottom waters are 5.1 $S.m^{-1}$ and 54.6 $g.l^{-1}$

Salinity is used as an indicator of conservative mixing, and there can be a significant change in the behavior of trace metals due to changes in salinity. Salinity values of the surface waters varied between 32 and 33.4 psu with an average value of 33.0 psu. Salinity values of bottom waters were similar - ranging between 32 and 33.5 psu, suggesting no salinity gradient due to the shallowness of the study area. The alkalinity values of the surface waters showed a range of 125 to 170 mg $CaCO_3$. l^{-1} with mean value of 140.8 mg $CaCO_3$. l^{-1} The mean alkalinity value of the bottom water was 157mg $CaCO_3$. l^{-1}, slightly higher than the value of the surface water. Dissolved oxygen is a measure of the ability of a system to support aquatic life. Depletion of DO leads to anoxic environment, which is detrimental to fish and crustaceans. Though the response of different marine fauna to reduction in DO level varies, DO levels of less than 2 mg. l^{-1} are highly injurious and levels between 2 to 4 mg. l^{-1} will impart considerable stress. The concentration of dissolved oxygen in coastal surface waters of Tuticorin and the Gulf of Mannar region ranged between 6.8 and 7.2 mg. l^{-1} with an average of 6.97 mg. l^{-1}, whereas the concentration of dissolved oxygen in bottom waters of Tuticorin ranged between 5.5 and 6.7mg. l^{-1} with an average of 6.24mg. l^{-1} (Fig. 36). The concentration of DO is above the permissible standards for SW III class of the Central Pollution Control Board (CPCB), Government of India.

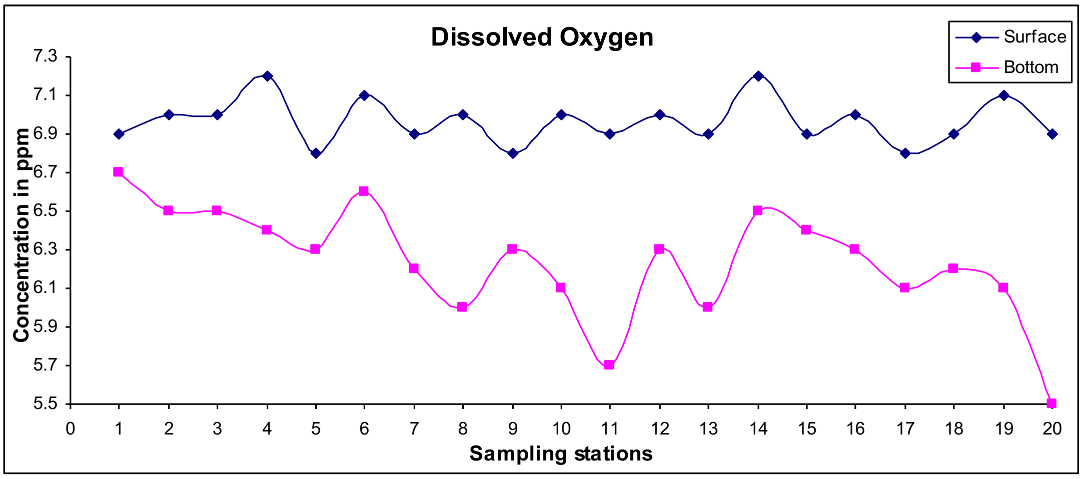


Fig. 36: Dissolved oxygen in the surface and bottom waters of Tuticorin coast

The physico-chemical characteristics of bottom waters in the Gulf of Mannar are given in Table 10. With slight variations, they are similar to normal seawater under similar conditions.

Table 10. The physico-chemical characteristics of bottom waters in the Gulf of Mannar

S.No	pH	DO (mg/L)	Cond. (S/m)	TDS (g/L)	Alkalinity (mg$CaCO_3$/L)	Temp. (°C)	Salinity	BOD (mg l^{-1})
1	7.92	6.7	4.94	52.8	145	29.1	32	2.07
2	7.95	6.5	5.08	54.7	150	29.6	32.9	2.68
3	8.06	6.5	5.06	54.3	120	29.7	32.9	4.39
4	8.19	6.4	5.05	54.1	130	29.5	32.8	2.38
5	8.24	6.3	5.04	54.2	150	29.6	32.7	2.98
6	8.25	6.6	5.05	54.5	250	29.7	32.8	4.80
7	8.27	6.2	5.09	54.8	115	29.4	33.2	2.38

8	8.46	6	5.07	54.9	140	29.6	33	3.59
9	8.26	6.3	5.08	54.5	145	29.6	33.2	2.17
10	8.26	6.1	5.09	54.7	130	29.9	33	2.88
11	8.27	5.7	5.11	55.9	145	29.6	33.3	3.59
12	8.33	6.3	5.18	55.6	140	29.6	33.3	4.89
13	8.28	6	5.14	55.6	155	29.6	33.4	2.68
14	8.28	6.5	5.14	55.6	160	30	33.5	4.79
15	8.30	6.4	5.91	54.8	185	29.7	33.2	2.07
16	8.27	6.3	5.11	55.1	165	29.8	33.3	4.90
17	8.36	6.1	5.11	55.1	170	29.9	33.3	4.99
18	8.34	6.2	4.98	53.5	180	29.7	33.4	4.89
19	8.34	6.1	5.07	55.0	180	29.7	33.3	2.08
20	8.3	5.5	5.06	55.0	190	29.9	32.8	3.19

Biochemical Oxygen Demand (BOD) is a chemical procedure for determining how rapid biological organisms use up oxygen in a body of water. It is used as a measure of the level of organic matter in a water body. The water quality status of the bottom waters in the study site varied between 2 and 5m depth. Higher BOD is indicative of low levels of oxygen available for other biota such as fish living in the water. The BOD values measured in the present survey ranged between 2.98 to 5.29 mg/l with an average of 3.92 mg l^{-1}, in the surface waters and 2.07 to 4.99 mg. l^{-1} with an average of 3.42 mg l^{-1}, in the bottom waters indicating moderately clean waters.

Nutrients

Nitrate, nitrite, ammonium, phosphate and silicate are classified as nutrients (Table 11) as they are utilized by phytoplankton for food production and growth. The phytoplankton form the food for higher order biota. Nitrogen enrichment of some coastal waters may increase algal production and can result in algal blooms; over-enrichment generally degrades the marine food web that supports commercially valuable fish. Excessive nutrients can lead to eutrophication.

Table 11. Concentration of Nutrients in surface waters of the Gulf of Mannar

S. No	**Nutrients (µmol/l)**									
	NO_2^- (S)	NO_2^- (B)	NO_3^- (S)	NO_3^- (B)	NH_4^+ (S)	NH_4^+ (B)	PO_4^{2-} (S)	PO_4^{2-} (B)	Si (S)	Si (B)
1	0.19	0.22	5.61	5.18	0.95	3.40	0.03	0.28	4.49	3.67
2	0.16	0.33	4.77	4.26	2.54	4.43	0.01	0.82	3.64	2.69
3	0.19	0.31	4.76	4.20	2.49	3.68	0.02	1.09	3.51	2.97
4	0.21	0.29	3.66	2.77	4.81	2.10	0.11	0.45	4.16	3.04

S. No	Nutrients (µmol/l)									
	NO_2^- (S)	NO_2^- (B)	NO_3^- (S)	NO_3^- (B)	NH_4^+ (S)	NH_4^+ (B)	PO_4^{2-} (S)	PO_4^{2-} (B)	Si (S)	Si (B)
5	0.23	0.22	4.39	4.20	2.13	4.96	0.04	1.03	4.25	4.47
6	0.21	0.33	3.98	3.74	4.99	2.19	3.59	1.42	4.07	4.23
7	0.27	0.31	4.40	3.38	2.71	3.11	0.10	0.78	3.36	3.35
8	0.23	0.29	4.44	3.60	2.58	8.13	0.18	0.77	3.44	2.66
9	0.25	0.23	4.21	3.54	2.56	4.03	0.72	0.49	3.95	3.23
10	0.23	0.21	3.72	3.66	5.84	1.86	1.63	2.14	3.89	2.71
11	0.22	0.21	4.84	3.92	2.00	1.64	1.35	1.24	2.98	2.68
12	0.17	0.22	3.49	3.12	3.44	1.67	0.04	2.04	3.12	3.06
13	0.17	0.19	3.25	2.77	2.57	5.19	0.92	1.58	2.94	2.50
14	0.24	0.33	3.70	3.04	4.11	3.04	1.01	3.22	4.00	2.56
15	0.20	0.25	4.59	3.80	3.51	6.82	0.03	3.29	3.67	3.39
16	0.20	0.22	6.06	5.24	2.95	6.95	1.55	1.42	4.05	2.94
17	0.22	0.31	3.63	2.61	6.65	4.03	1.03	1.46	2.85	2.37
18	0.21	0.15	4.20	3.61	3.40	1.24	0.18	4.58	3.31	2.28
19	0.24	0.24	4.80	4.20	3.48	3.36	0.53	3.78	3.34	2.18
20	0.23	0.15	4.82	4.02	5.75	4.04	0.59	2.62	3.47	1.95

Nitrate concentration in the surface water of the Gulf of Mannar varied from 3.25 to 6.06 µmol. l^{-1} with a mean value of 4.37µmol. l^{-1}, whereas nitrite concentration ranged between 0.16 to 0.27µmol. l^{-1} (mean 0.21µmol. l^{-1}). Wide variation in concentration of NH_4^+ was obvious ranging from 0.95 to 6.65µmol. l^{-1} with a mean concentration of 3.47µmol. l^{-1}. The nitrate concentration in the bottom water in the present study ranged from 2.61 to 5.24 µmol. l^{-1} with a mean value of 3.74µmol. l^{-1} whereas nitrite concentration ranged between 0.15 to 0.33µmol. l^{-1} (mean 0.25µmol. l-1). Ammonia concentration of the bottom waters was in the range between 1.24 and 8.13 µmol. l^{-1} with a mean concentration of 3.79 µmol. l^{-1} (Fig. 37). In the present investigation all the nitrogen parameters measured are within permissible limits for Seawater quality.

Concentration of Phosphate ranged from 0.01 to 3.59 µmol. l^{-1} with a mean of 0.68 µmol. l^{-1} in the surface samples. On the other hand, the bottom waters showed maximum of 4.58 µg. l^{-1} with mean value of 1.73 µg. l^{-1}. It could be due to the degradation of organic matter towards depth or the desorption of phosphate from the bottom sediments. The silicate values ranged from 2.85 to 4.49 µmol. l^{-1} with an average of 3.62µmol. l^{-1}. Whereas for bottom waters the silicate values ranged from 1.95 to 4.47 µmol. l^{-1} with an average of 2.95 µmol. l^{-1} (Fig. 38). Low levels of silicate in water samples may be due to the biological removal of this nutrient. All the nutrients are in normal range and are in agreement with the earlier reported data for southeast coastal waters (http://www.icmam.gov.in).

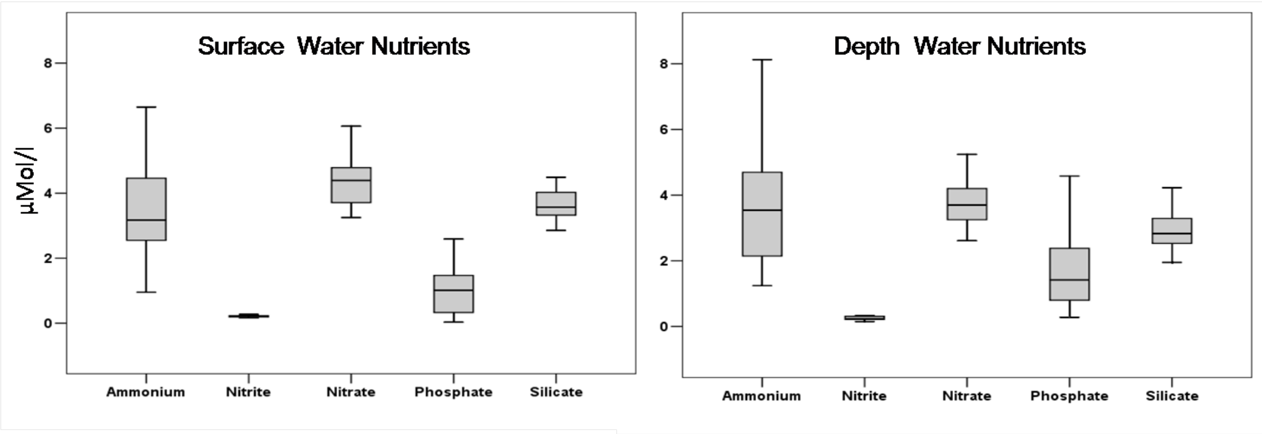


Fig. 37. Ammonium concentration of the waters in Chilika Lagoon

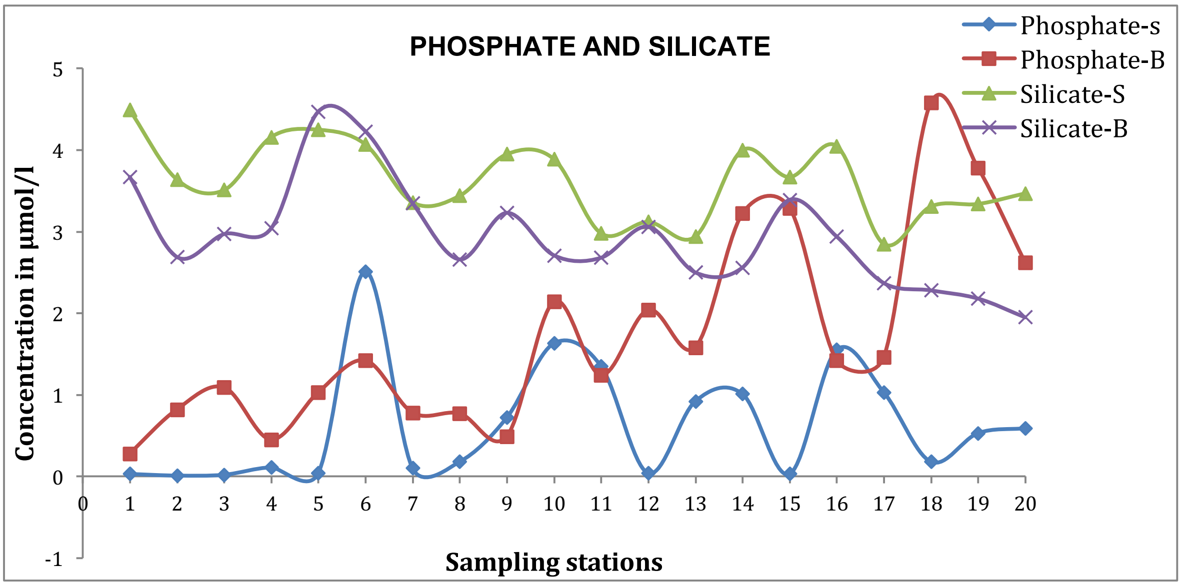


Fig. 38. Nutrients in surface and bottom waters of the Gulf of Mannar

In order to obtain an overall impression of the distribution of nutrients and other physico-chemical parameters in the Gulf of Mannar, mapping of the water quality has been made using Ocean Data View (ODV). The maps have been merged with current land use pattern in highlight the influence of human activities on the coast and offshore areas. Maps are presented for both surface and bottom waters to draw comparisons of the prevalent water quality in the coral reef/seagrass areas of the Gulf (Figs. 39-43). Appendix 12 gives details of the physico-chemical characteristic of surface waters in the Gulf of Mannar Region.

Fig. 39. Alkalinity in Bottom water

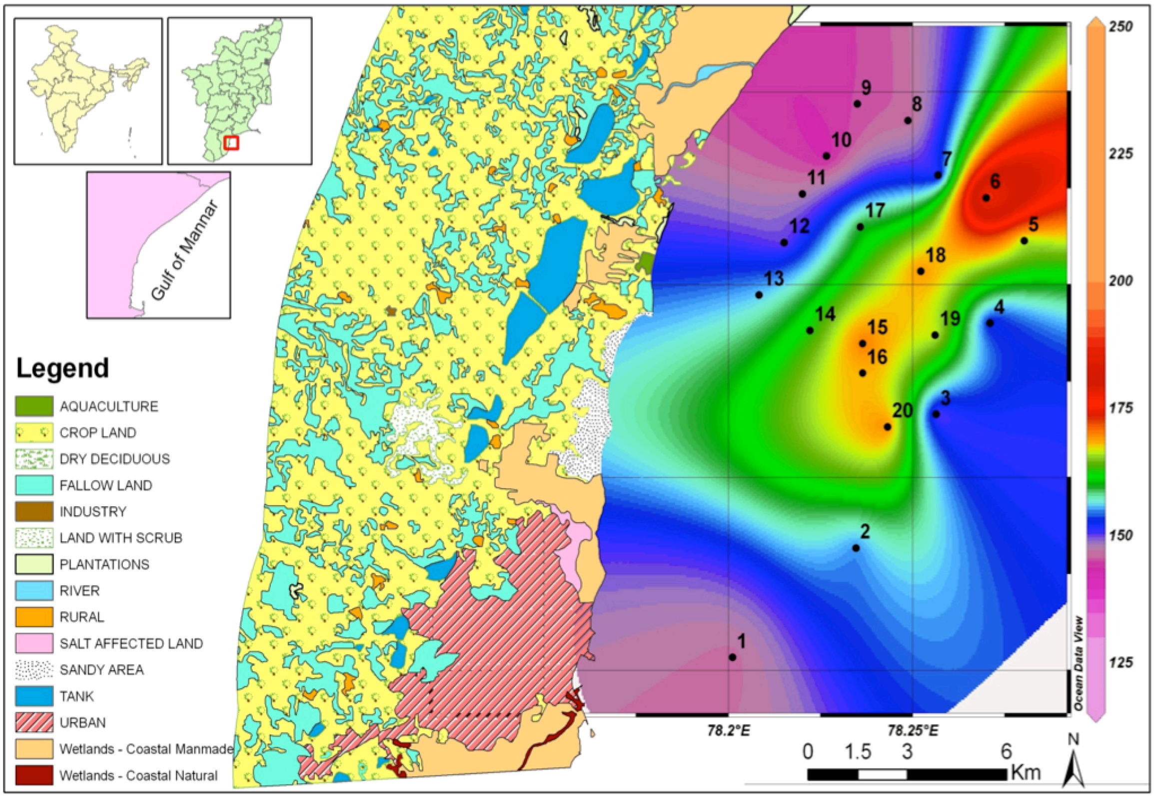


Fig. 40. BOD in Surface water

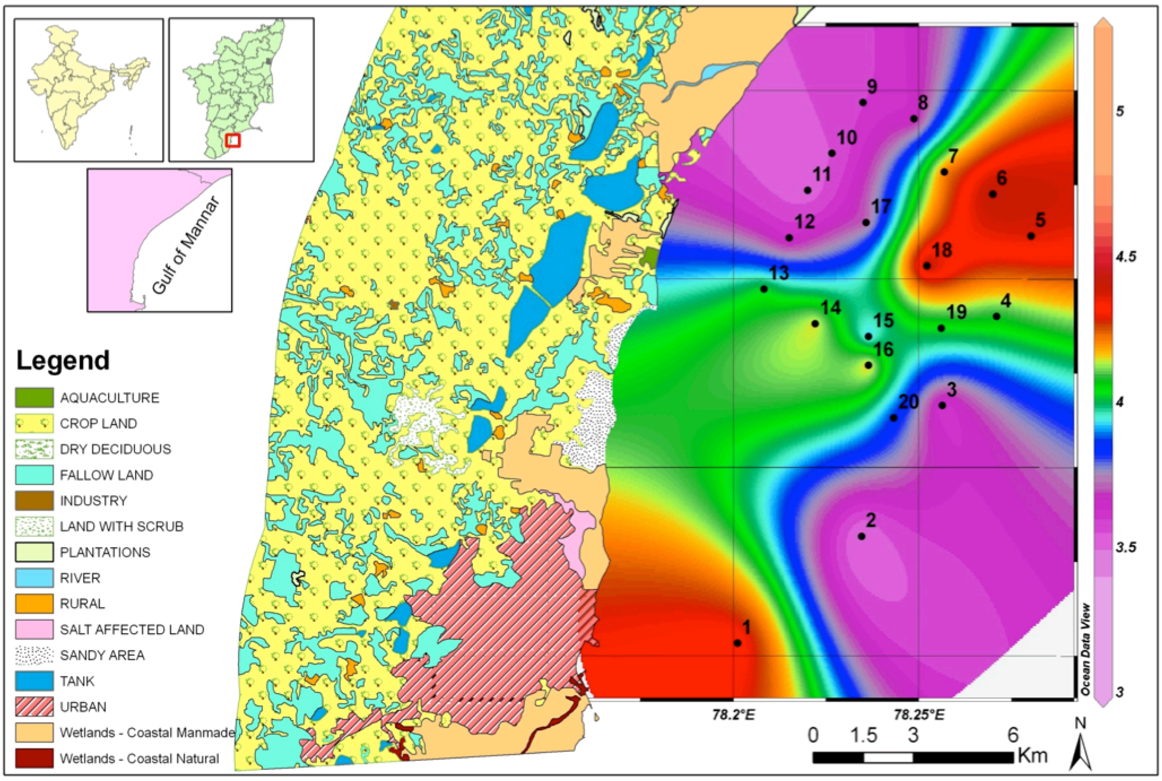


Fig. 41. BOD in Bottom water

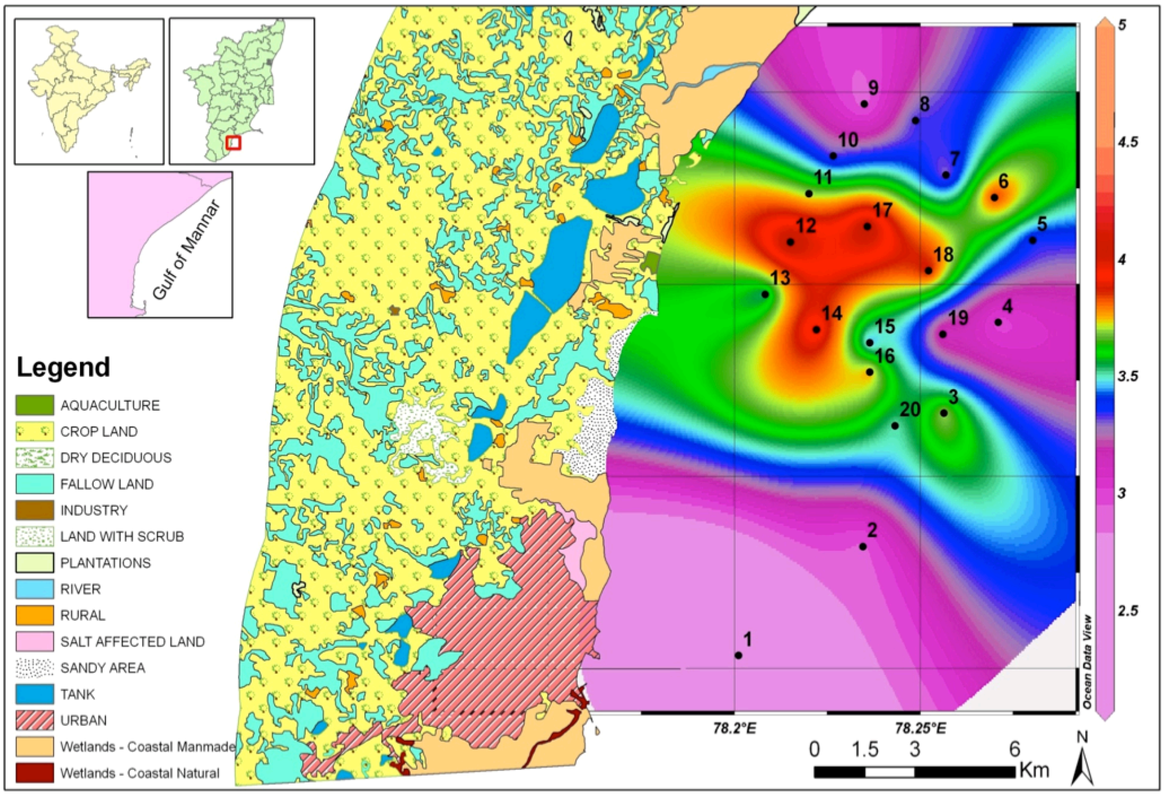


Fig. 42. Temperature in Surface water

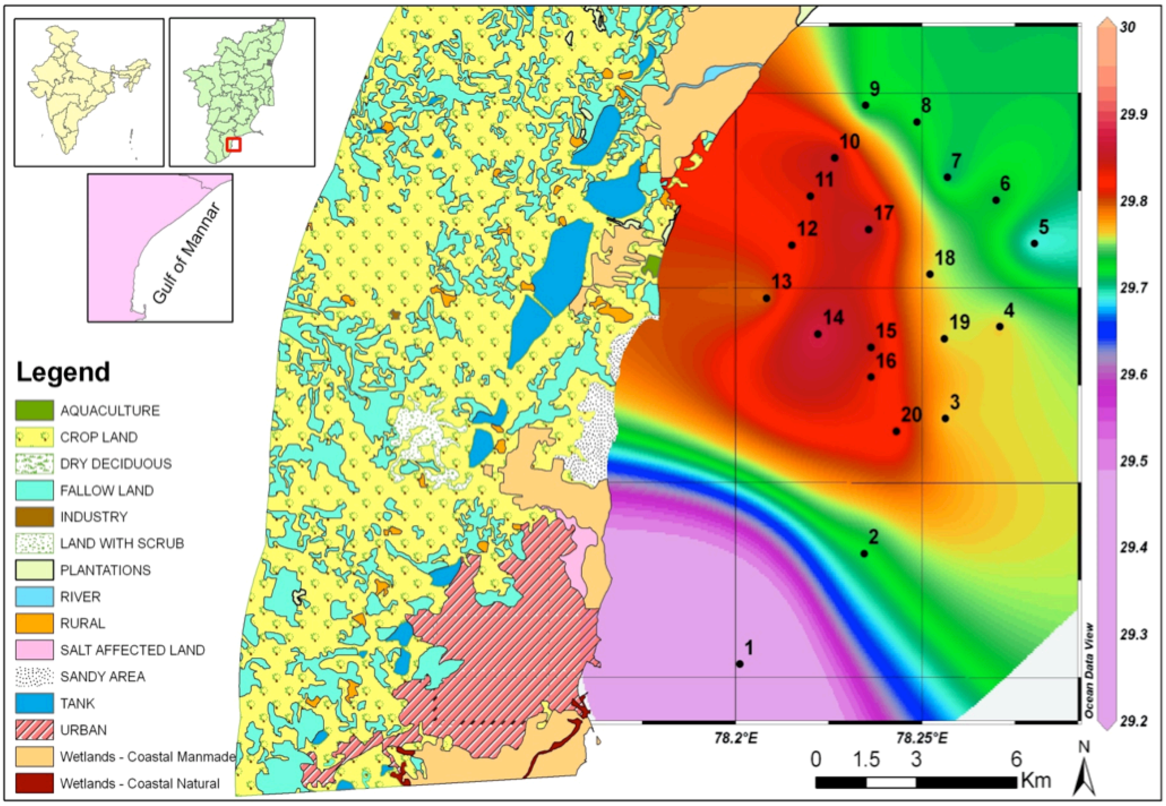
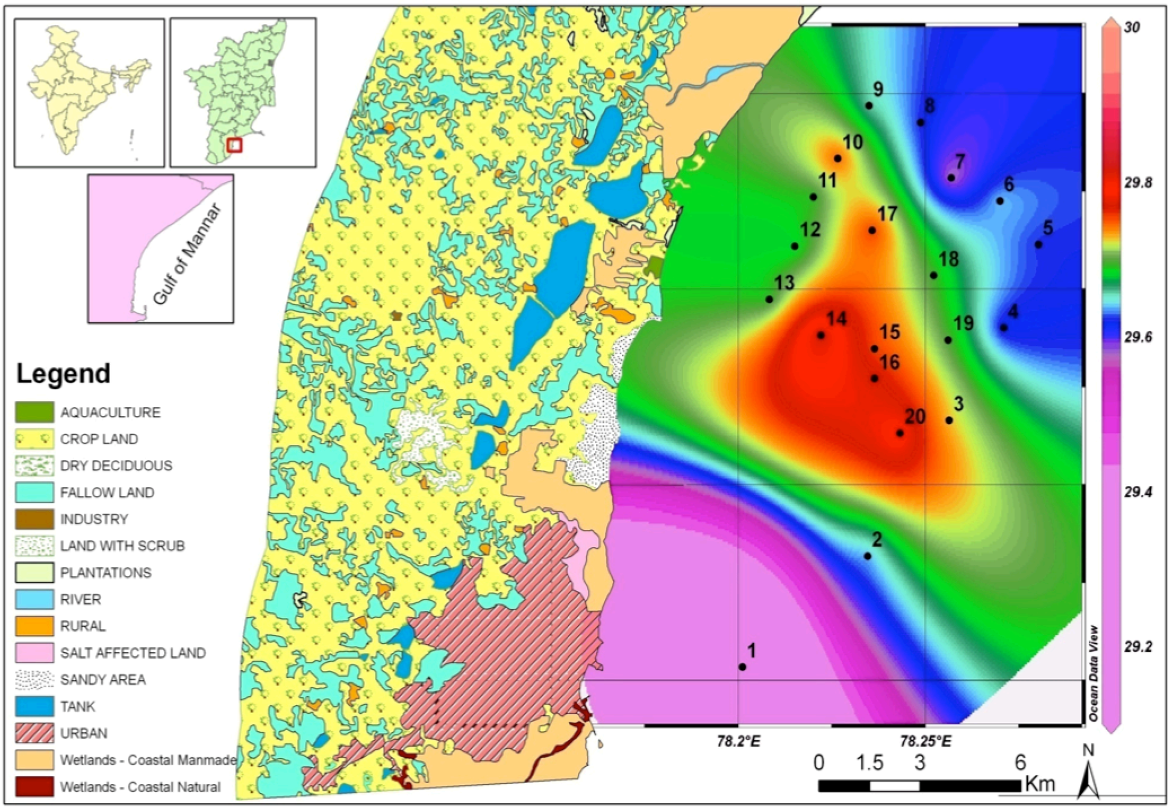


Fig. 43. Temperature in Bottom water



Stable isotope study

We have initiated the stable isotope study using seagrass samples from Malita and Mati. As can be seen from the data, the $\delta^{15}N$ values are more or less constant regardless of the species involved. Moreover, majority of the samples did not show any drastic deviations from the overall trend and hence it can be concluded that there is little effect on seagrass health in terms of nutrient load. However, based on the recovered seagrass samples, some specimens appeared to be healthier than others and hence we suspect there maybe other factors at work which maybe disrupting the natural environment, namely turbidity, herbicides and pesticide use, to name a few. The effects of such factors remain to be examined by further investigations of the area. Although preliminary, the results further indicate that differences are detectable, differentiating plants growing nearest and farthest from the area where waste water from crop plantations are discharged (Table 12). Hence, a potential is demonstrated that stable isotopes could be used as ecological indicators or environmental tracers in seagrass studies. However, there is a need to understand the basic reasons for the variations in the N and C stable isotopes in seagrasses.

Table 12. Results of Stable Isotope Ratio Analysis

	Carbon (%)		Nitrogen (%)		C/N(atom)		$\delta^{15}N$(‰)		$\delta^{13}C$ (‰)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SS1 *Halophila ovalis*	34.90	0.02	3.05	0.02	13.34	0.11	-0.88	0.06	-10.79	0.12
SS2 *Halophila ovalis*	33.38	0.19	2.97	0.04	13.10	0.10	-0.52	0.19	-11.23	0.33
SS3 *Halophila ovalis*	33.73	0.52	2.53	0.03	15.55	0.07	0.23	0.06	-12.30	0.20
SS4 *Halophila ovalis*	34.81	0.20	2.57	0.05	15.80	0.23	0.03	0.02	-7.93	0.15
SS4 *Thalassia hemprichii*	35.48	0.13	2.09	0.00	19.85	0.08	3.01	0.28	-9.31	0.04
SS4 *Enhalus accoroides*	33.09	0.06	2.35	0.05	16.45	0.35	3.01	0.09	-6.31	0.18
SS5 *Halophila ovalis*	37.84	0.19	2.68	0.02	16.50	0.23	1.62	0.09	-10.62	0.24
SS5 *Cymodocea rotundata*	36.34	0.28	2.49	0.01	17.01	0.19	1.63	0.08	-10.18	0.22
SS5 *Thalassia hemprichii*	36.67	0.18	3.03	0.00	14.10	0.05	1.76	0.09	-10.78	0.15
SS5 *Enhalus accoroides*	33.99	0.15	2.11	0.01	18.79	0.20	1.58	0.18	-9.04	0.10
SS6 *Halophila ovalis*	32.99	0.75	2.47	0.01	15.58	0.39	-1.91	0.03	-11.14	0.11
SS6 *Cymodocea rotundata*	37.95	0.63	2.94	0.04	15.04	0.03	0.94	0.06	-12.14	0.42

Carbon fluxes in the Chilika Lagoon, India

The Chilika Lagoon is a very complex, coastal, aquatic ecosystem; that behaves as an extended riverine-estuarine continuum with the estuarine characteristics (Fig. 44). The Chilika Lagoon is the largest brackish water Lagoon in tropical Asia, present on the east coast of India. The size of Chilika Lagoon fluctuates substantially within the course of a year, with a maximum area of 1,165 km^2 (depth 1.8 to 3.7 m) during monsoon and a minimum of 906 km^2 (0.9 to 2.6 m) during non-monsoon seasons (Ghosh and Pattnaik 2005). In 1981, Chilika Lagoon was designated as the first Indian wetland of international importance under the Ramsar Convention (Site No. 229) due to its rich biodiversity.

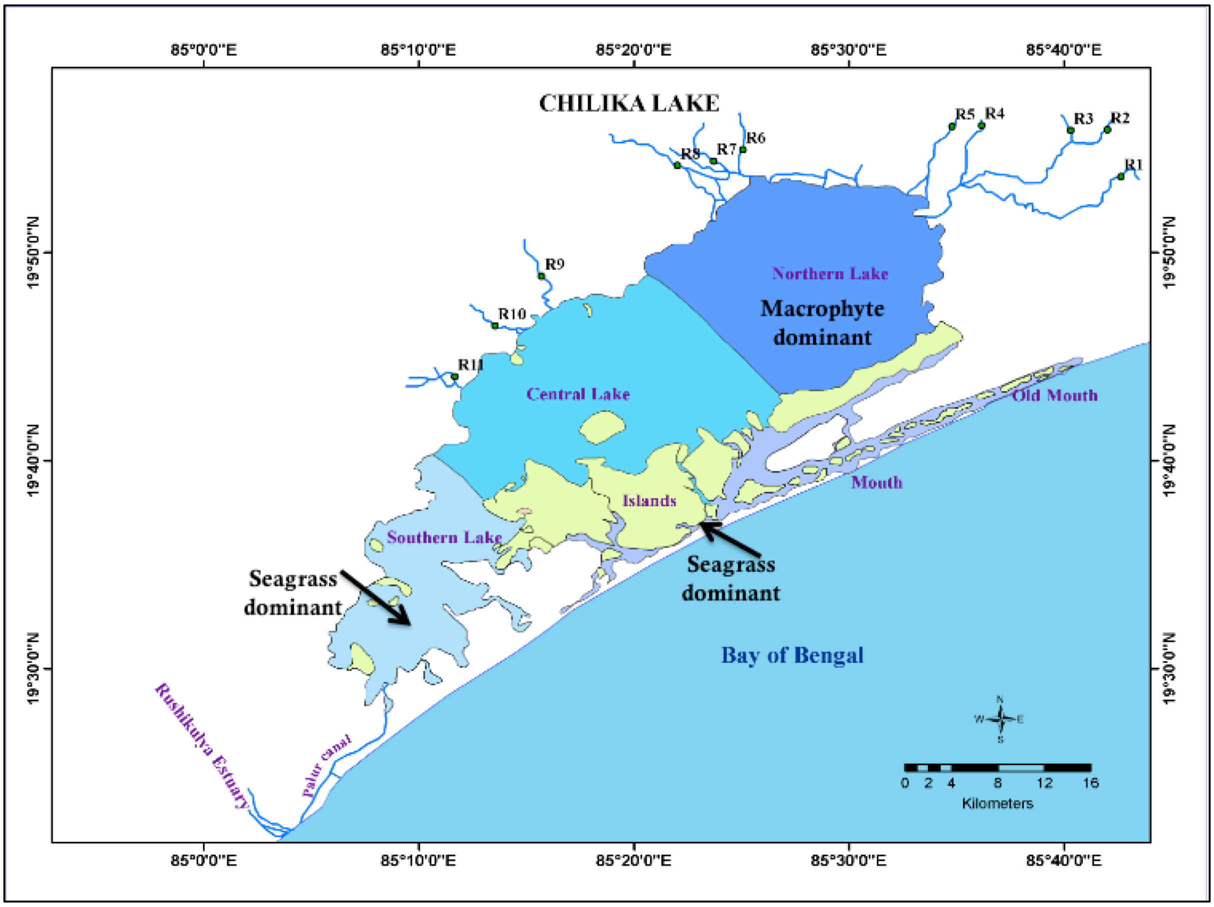


Fig. 44. Map of the Chilika Lagoon with different sectors separated by the imaginary boundary based on the salinity gradient

The local weather condition is mostly controlled by the southwest (SW) and northeast (NE) monsoons and the Lagoon experiences the SW monsoon between July and September and the NE monsoon between November and December. The period from June to September is the monsoon season while October to February months are the post-monsoon transition period and March to May months comes under pre-monsoon period. In order to survey the Chilika Lagoon, sampling has been conducted during monsoon (September 2012). The sampling has been carried out on 35 selected locations of the lagoon (Fig. 45).

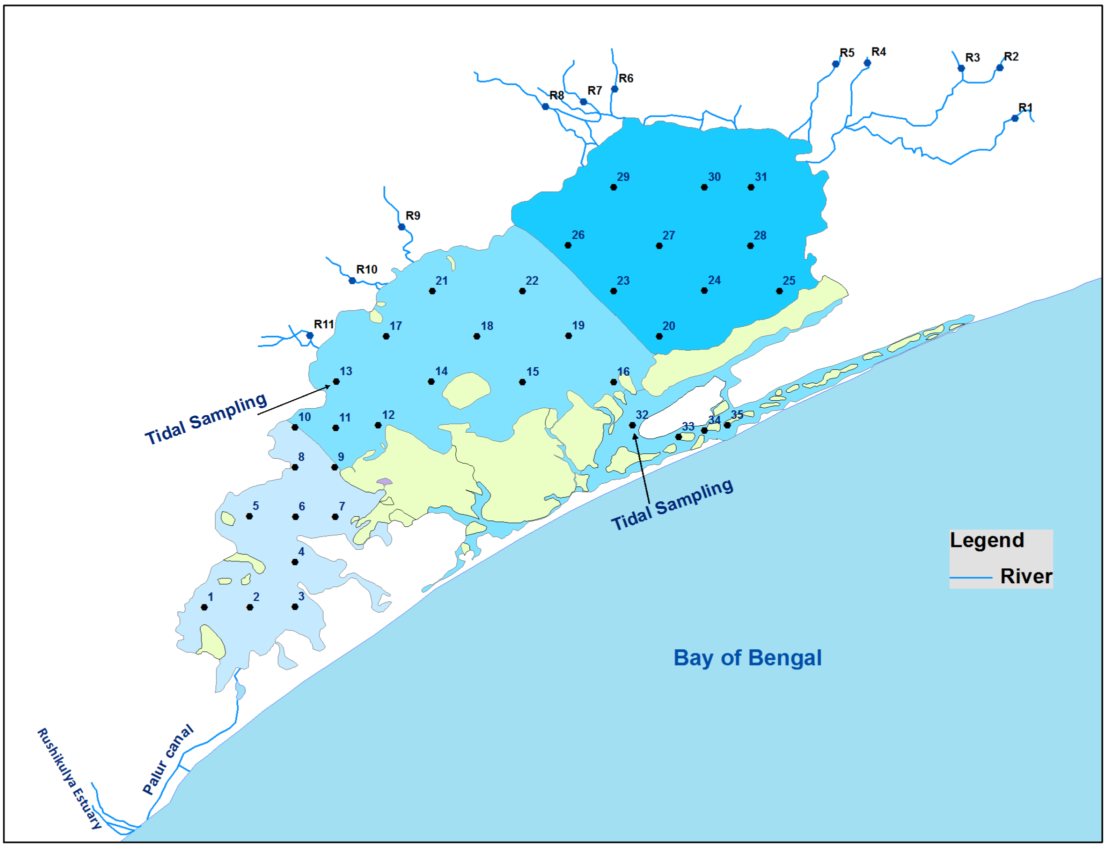


Fig. 45. Map of the sampling stations in the Chilika Lagoon

Air-sea gas exchange (fluxes) of CO_2 from the Chilika Lagoon

The CO_2 flux corroborate with the spatial variation of surface water pCO_2 and also its hydrodynamic properties of the lagoon system. The pCO_2 data reveals a significant variation in its saturation level in spatial scale. During monsoon, the pCO_2 levels are supersaturated and shows a pronounced gradient from very high level in river water (14025 ± 3051 µatm), northern lagoon (3448 ± 3357 µatm) and decreases further to several fold lower in the central (1157 ± 223 µatm), southern lagoon (1126 ± 193 µatm) and outer channel (836 ± 127 µatm). The spatial distribution of pCO_2 in the Lagoon is shown in the Fig. 46.

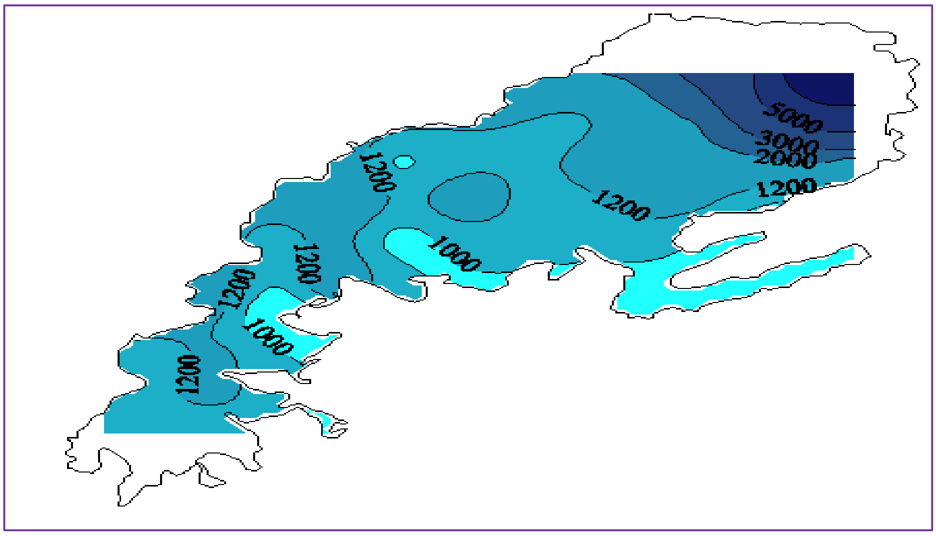


Fig. 46. Spatial distribution of pCO_2 in the Chilika Lagoon during the monsoon

The air-sea exchange (flux) of pCO_2 from different sectors of the Chilika Lagoon is shown in Fig. 47. The northern sector of the lake had the highest, while the outer channel had the lowest value.

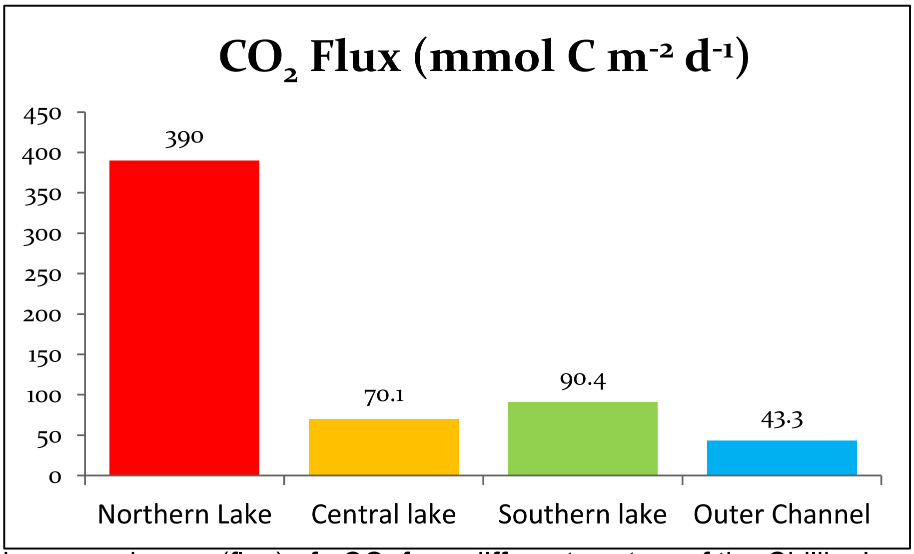


Fig. 47. Air-sea exchange (flux) of pCO_2 from different sectors of the Chilika Lagoon

The north-south gradient of pCO_2 is concomitant to the variation of salinity in the Lagoon. The high pCO_2 levels in the river water and parts of northern Lagoon are associated with the fresh water characteristics (Gupta et al. 2008) and elsewhere (Borges et al. 2006; Paquay et al. 2007). The overall spatial distribution of surface water partial pressure of carbon dioxide (pCO_2) and its fluxes (FCO_2) are given in Table 13.

Table 13. Spatial variation of pCO_2 and CO_2 flux in the Chilika Lagoon during monsoon

Lagoon Sectors	pCO_2 (µatm)		CO_2 flux (mmol m^{-2} d^{-1})	
	Range	Mean (±SD)	Range	Mean (±SD)
Monsoon				
Rivers	10068-18127	14025±3051	1135-2039	1574±334
Northern	1072-11797	3448±3357	128-1021	390±312
Central	853-1538	1157±223	34.1-199	70.1±45.6
Southern	702-1428	1126±193	56.7-201	94.0±49.0
Outer Channel	668-943	836±127	27.3-72.4	43.3±20.3
Lagoon total		1766±2045		166±219

The CO_2 fluxes vary mostly in the similar manner to the pCO_2 levels in different Lagoon sectors. During monsoon, the CO_2 flux is observed to be highest in the river system (1574 ± 334 mmol m^{-2} d^{-1}) and decreases significantly at northern Lagoon (390 ± 312 mmol m^{-2} d^{-1}) and further decreases several folds in the central (70.1 ± 45.6 mmol m^{-2} d^{-1}) and southern Lagoon sectors (94.0 ± 49.0 mmol m^{-2} d^{-1}). However, the southern Lagoon fluxes are remarkably higher than the central Lagoon, which could be due to combined effect of wind forcing and water current though pCO_2 level remains same. The lowest CO_2 flux is observed in the outer channel among all Lagoon sectors. Positive flux indicates its net flux to the atmosphere from Lagoon Surface during monsoon.

During monsoon, the pCO_2 levels remained mostly supersaturated compared to the atmospheric level in the Chilika Lagoon. The supersaturation level significantly varies along a north-south gradient from nearly twice at most saline waters to 30 times in the fresh waters. Following high influx of freshwater the northern Lagoon witnesses a drop in pH (6.78 - 7.85) resulting in high pCO_2 (1072-11797 µatm) and are highly supersaturated. However, with the limitation in freshwater flow the pCO_2 level decreases exponentially further in the central (853-1538 µatm), southern (702-1428 µatm) Lagoon and at outer channel (668-943 µatm) and so also its saturation level. These variations could be due to increase in salinity, which controls the CO_2 emissions from the Lagoon (Borges et al 2005 or 6?). The O_2 is also found undersaturated (average: 69 ± 25%) during monsoon and spatial variation of O_2 is following the opposite trend with pCO_2 concentrations suggests the significant CO_2 supersaturation in the lagoon.

Air-Sea Gas Exchange (Fluxes) of CH_4 from Chilika Lagoon

Emission of CH_4 from coastal waters varies significantly with seasonal and spatial scale due to several complex processes involved in methane production, transport, oxidation and also on numerous natural and anthropogenic sources (Abril and Borges 2004). During monsoon, wide variation of dissolved CH_4 concentration along the salinity gradient is observed. The highest concentration is found in the river water (273 ± 74.3 nmol l^{-1}) followed by the northern Lagoon (70.0 ± 77.0 nmol l^{-1}), with high concentration in the low saline water to lower level towards high salinity regions (16.4 nmol l^{-1} to 245 nmol l^{-1}) (Table 14). Similarly, at central (44.7 ± 9.88 nmol l^{-1}) and southern Lagoon (34.6 ± 10.0 nmol l^{-1}) the concentrations are several times lower as compared to the fresh water conditions of the Lagoon. The concentration in the outer channel is observed to be lowest (28.4 ± 8.10 nmol l^{-1}), which varies from 21.3 nmol l^{-1} to 33.4 nmol l^{-1}. During monsoon, the high CH_4 flux (FCH_4) is observed in the river water (25.4 ± 6.62 mmol m^{-2} d^{-1}) and nearly fourfold lower in northern Lagoon (6.82 ± 5.98 mmol m^{-2} d^{-1}), which further decreases exponentially in other Lagoon sectors (Table 14).

Table 14. Spatial variation of dissolved CH_4 and FCH_4 flux in the Chilika Lagoon during monsoon

Lagoon Sectors	CH_4 (nmol l^{-1})		CH_4 Sat. (%)	CH_4 flux (mmol m^{-2} d^{-1})	
	Range	Mean±SD	Range	Range	Mean ± SD
Monsoon					
Rivers	177-408	273±74.3	7656 -15578	16.2-37.8	25.4±6.62
Northern	16.4-245	70.0±77.0	646 - 10278	1.77-16.5	6.82±5.98
Central	32.3-60.3	44.7±9.88	1567 - 2960	1.71-9.20	3.37±2.07
Southern	20.2-52.3	34.6±10.0	959 - 2536	1.54-8.80	3.68±2.20
Outer Channel	21.3-35.4	28.4±7.10	1057 - 1846	1.30-4.37	2.70±1.48
Lagoon total		47.2±43.4			4.37±3.84

The higher river water concentration and its fluxes, suggests the Lagoon CH_4 dynamics are significantly influenced by the riverine CH_4 sources, where Lagoon plays a significant role in transferring riverine CH_4 sources to atmospheric carbon sink (Fig. 48). The observed CH_4 fluxes from Chilika Lagoon, however, are lower in comparison to other Indian Lagoons (Verma et al. 2002) and mangrove systems (Krithika et al. 2008). Though, the high fluxes are mostly reported during the monsoon could have been resulted from the anthropogenic inputs from the seasonal rivers (Purvaja et al. 2004; Krithika et al. 2008).

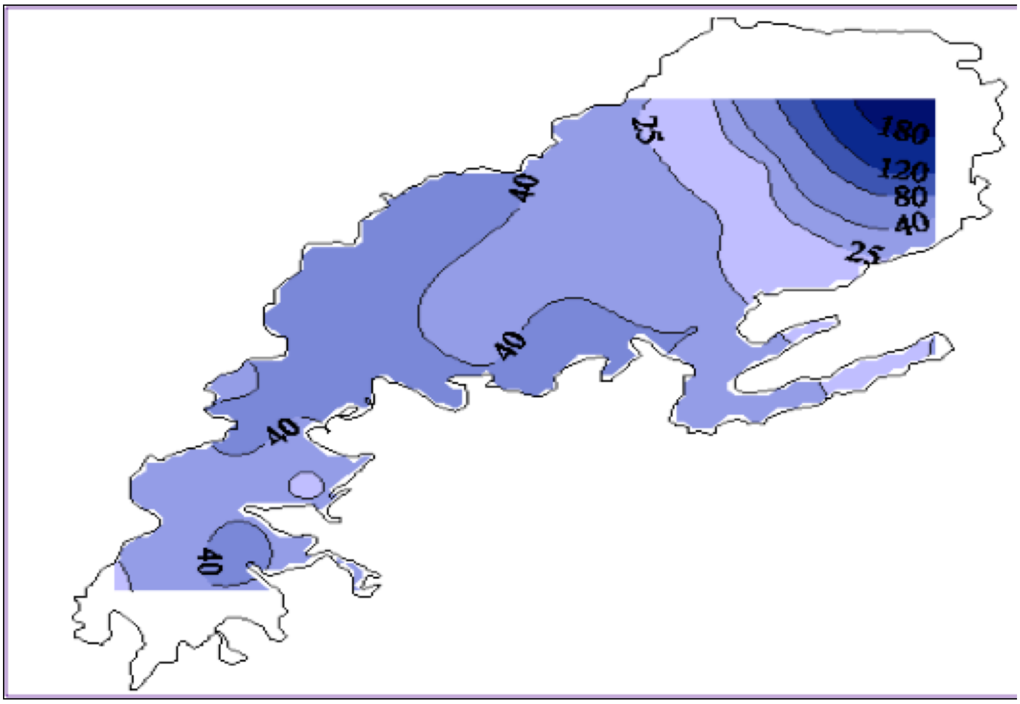


Fig. 48. Spatial distribution of CH_4 in the Chilika Lagoon during monsoon

Air-sea exchange (flux) of CO_2 from different sectors of the Chilika Lagoon during monsoon is shown in Fig. 49.

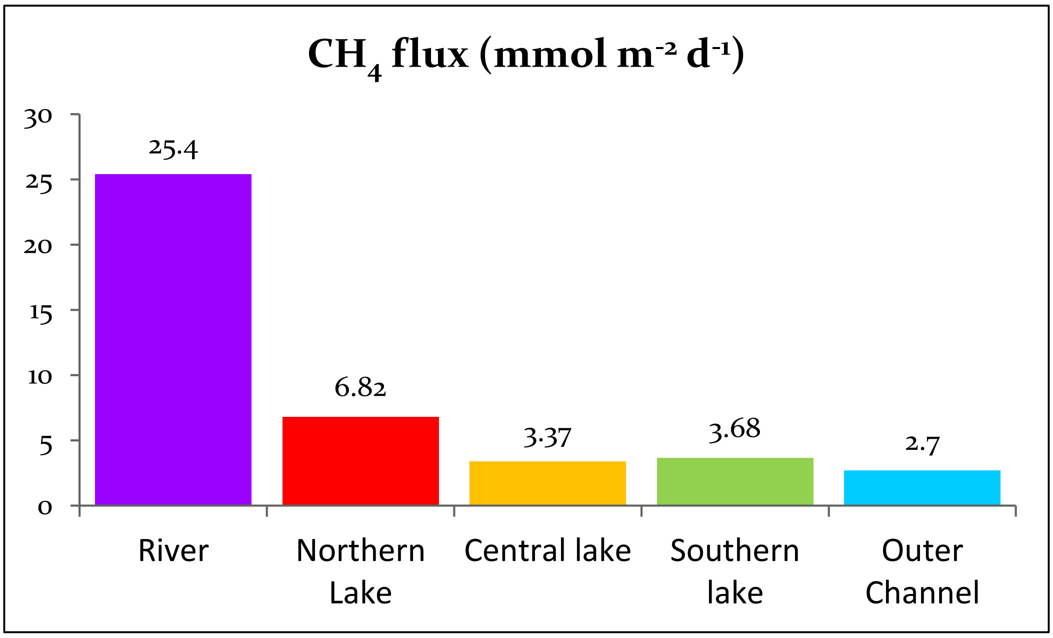


Fig. 49. Air-sea exchange (flux) of CO_2 from different sectors of the Chilika Lagoon during monsoon

During monsoon, the loss of CH_4 and gain in pCO_2, in the Lagoon water may be due to the CH_4 oxidation in presence of O_2. The methane oxidation contributes to CO_2 production. The presence of high SPM during monsoon is evident in the occurrence of CH_4 oxidation in the Lagoon. Considering a net carbon mass balance in the river and Lagoon system (and assuming a constant Lagoon-sea exchange), the higher Lagoon CO_2 concentration (18%) than the CH_4 concentration in monsoon may be influenced by the river CH_4 dynamics.

The above results are of direct significance to the thrusts of SMBP. This is in terms of the following facts:

- Highest concentration of trace gases such as pCO2 and CH4 have been observed in the Northern Sector of the lagoon, which is dominated by freshwater macrophytes such as *Phragmites* during the wet season (monsoon)
- Concentration of both pCO2 and CH4 were at least 4 times lower in the southern sector of the lagoon, which is dominated by seagrass
- Further studies during the dry season (March to May) is necessary to determine the contribution of seagrasses to the trace gas emissions from the lagoon

Ecohydrological modelling and simulation

Bolinao coastal waters may have been a tropical marine ecosystem paradise thirty years ago but at present they are little more than a polluted feedlot where sheltered waters are grossly eutrophicated, where seagrass and coral reefs struggle to survive in polluted coastal waters and where the mangroves have been virtually eradicated from sheltered waters while mangrove seedlings are planted in exposed waters where they struggle to survive.

Scattered throughout the sheltered waters there are numerous fish cages and fish pens (Fig. 50). Fish are farmed at high density (Fig. 51) with apparently excessive amounts of food thrown at them several times a day. There appears to be no control of the amount of food pellets that can be used in order to avoid eutrophication of the waters. The cages are shallow and the underlying waters would receive large amounts of excess fish food, food scraps from messy eaters, as well as fecal pellets.

Fig. 50. Floating fish cages in Bolinao

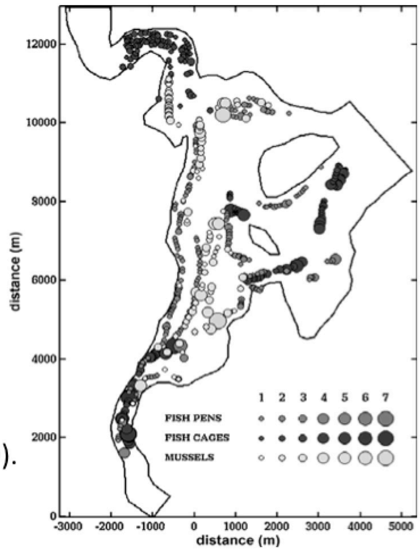


Fig. 51. …and their locations and quantity (= 1,170 units) (black-and-white picture). (Reproduced from Gecek and Legovic 2010).

There seems to be no water quality data at depth. Surface waters were sampled. Sheltered waters are highly enriched in dissolved nutrients and chlorophyll; these waters are eutrophic. The coastal waters by comparison have much smaller concentrations of dissolved nutrients and chlorophyll and the spatial gradients in these concentrations are very strong between sheltered and coastal waters.

There are large diurnal changes in the dissolved oxygen concentration in surface waters. Over the seagrass, night-time values as low as 2 ppm are observed, indicating hypoxic conditions harmful to aquatic life (Fig. 52; Wolanski, 2007).

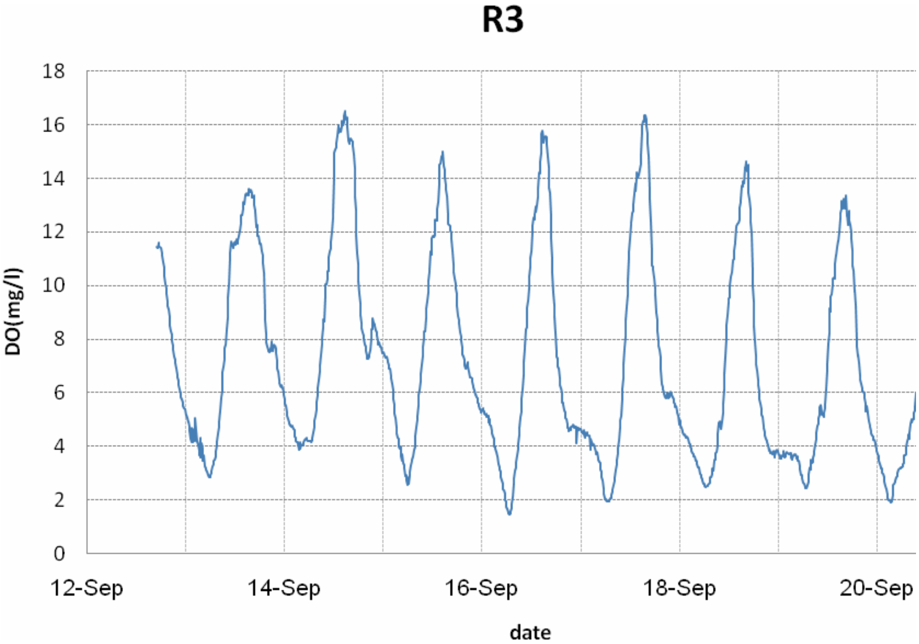


Fig. 52. Time-series plot of dissolved oxygen concentration over the seagrass beds.

There are no data available on dissolved oxygen concentration in the sheltered waters nor anywhere else deeper in the water column. We suspect that in the sheltered waters amongst the fish farms, the waters may be occasionally anoxic as evidenced by occasional fish kills and by occasional whiffs of H_sS at night in sheltered waters near the University of the Philippines Bolinao Marine Laboratory.

As a probable result of these water quality properties, at present seagrass and corals do not occur in sheltered waters and are restricted to coastal waters, although in the past they were present in sheltered waters.

Mangroves used to thrive in embayments in the sheltered waters. They have been eradicated to make room for aquaculture. Attempts are now made to plant mangroves over seagrass beds in coastal waters, i.e. in areas where they did not exist naturally (Fig.53). These planted mangroves are severely stunted even at 5 years; a number of seedlings are overtopped by floatsam; the soils are too shallow (often < 0.2 m before the rock base is reached) to support healthy mangrove root developments; these attempts to plant mangroves where they did not exist before are clearly unsuccessful.

Fig. 53. (Left) an aquaculture pond built over a former mangrove swamp and protected by a rock wall in sheltered waters, and (right) mangroves planted over seagrass in coastal waters

– in the foreground are seedlings, in the background are 5-year old, stunted mangroves. Note the seagrass on the bottom. Note the small rock wall built to protect the mangroves from waves and to trap the mud.

The waters are shallow; the mean depth in sheltered waters is 4.8 m. Bathymetric data for sheltered waters are available from Gecek and Legovic (2010). The team is gathering data for the bathymetry of the coastal waters. Past the 10 m depth, bathymetric surveys are available from nautical charts.

There is an available oceanographic model for this area (Gecek and Legovic 2010) but it is restricted to the sheltered waters shown in Fig. 54 and as such it is not useful for quantifying how the fish farms are affecting the seagrass (and the coral reefs). However we extracted bathymetric and oceanographic data from that study and added then to those collected by the project team and the nautical charts. Based on that, we developed and verified a 2D model of the oceanography of Bolinao; the model follows that of Oliver et al. (1992) and Wolanski et al. (1993). The model domain is shown in Fig. 46. The model has 110 X 120 cells because it needs to extend far enough from Bolinao itself in order to be forced by the correct open boundary conditions in open waters. The model forcings are the tides, the wind, river inflow, waves breaking on coral reefs, and the mean oceanographic currents in open waters. The model was verified against the field data in Bolinao sheltered waters, there are no oceanographic data in coastal waters.

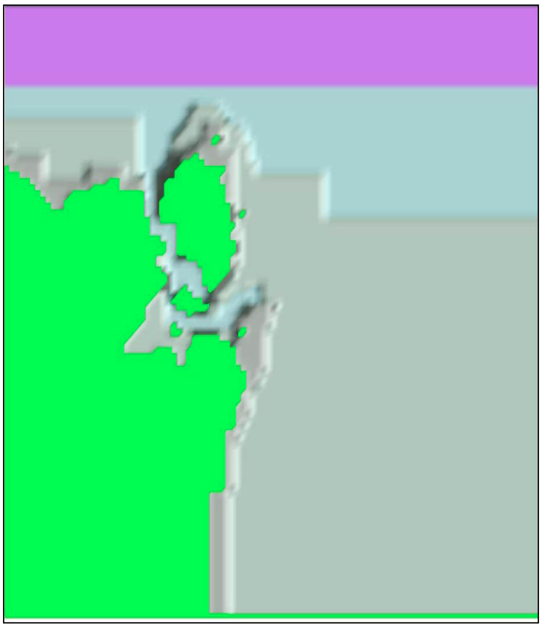


Fig. 54. The model domain

Typical model predictions for tidal currents are shown in Fig. 55. Peak tidal currents seldom exceed 0.3 m/s anywhere in the area. There are some minor asymmetries in currents even the absence of winds and/or of a prevailing oceanic current offshore. These asymmetries are more pronounced (not shown) under the influence of a wind and of a prevailing oceanic current offshore.

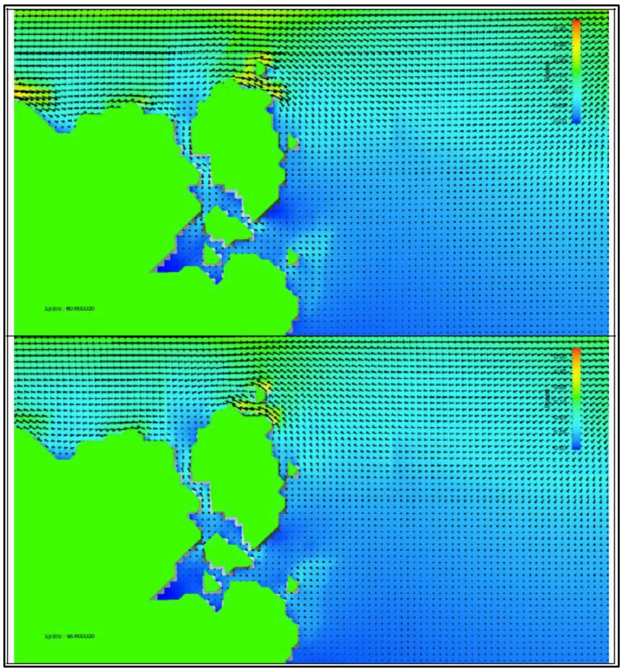


Fig. 55. Tidal velocity distribution in the study area during spring tides showing reversing ebb and flood tides.

To illustrate the fate of water-born contaminants in the system we released tracers at point A (sheltered waters; Figs. 56 and 57), point B (coastal waters over the seagrass; Fig. 58), and at point C (offshore; Fig. 59) over 1 diurnal tide cycle. We then predicted the fate of the contaminants over several days after release of these tracers. The predicted plumes are shown in Figs. 56-61 below:

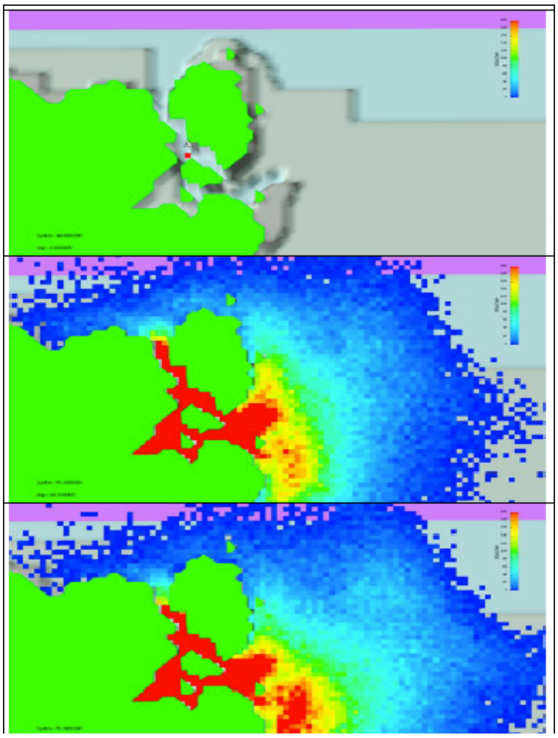


Fig. 56. Predicted contaminant plumes: spring tides, release at Pt. A, at time = 0 (top), 48 hr (middle) and 72 hr (bottom)

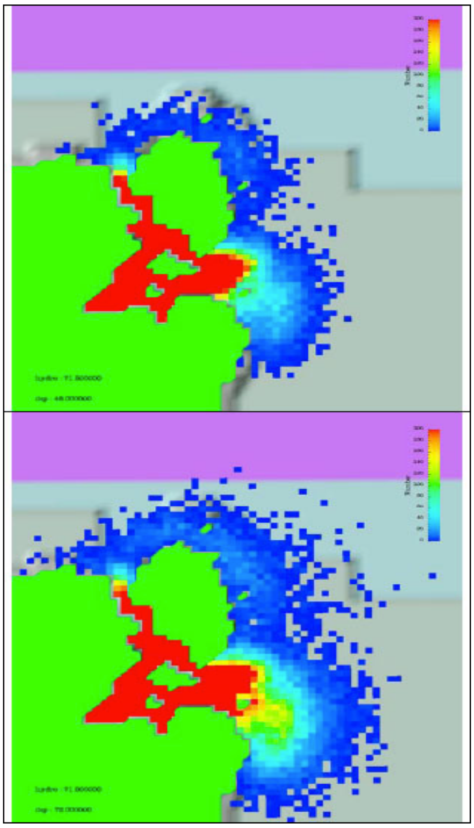


Fig. 57. Predicted contaminant plumes during neap tides for a release at point A, at time = 48 hr (top) and 72 hr (bottom).

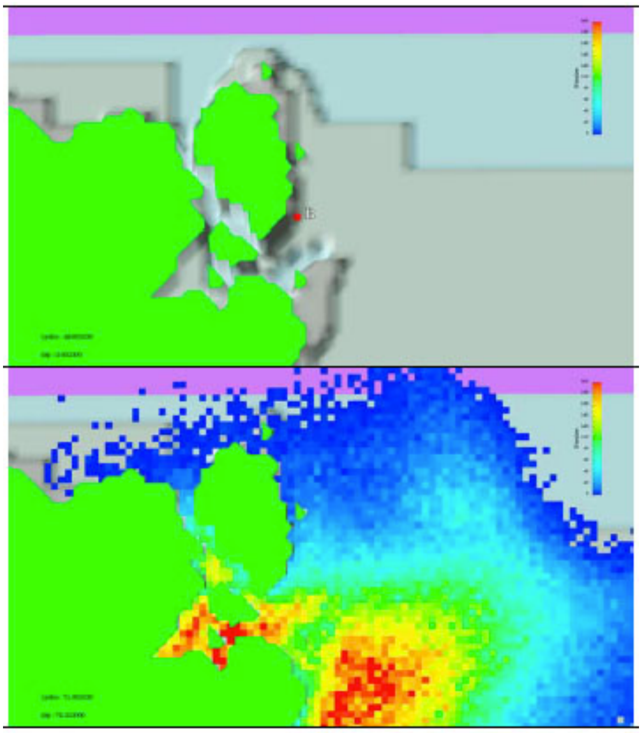


Fig. 58. Predicted contaminant plumes during spring tides for a release at point B, at time = 0 (top) and 72 hr (bottom).

It is apparent from these figures that the contaminants disperse faster at spring tides than at neap tides. Also the contaminants disperse the fastest from site C (open waters), and this is dispersal rate is faster than that from site B (coastal waters), and this is faster again than that from site A (sheltered waters). Faster dispersion results in a larger plume and higher dilution.

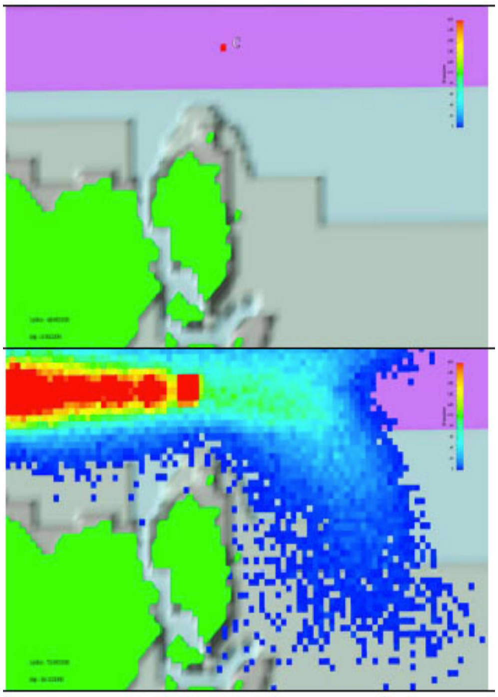


Fig. 59. Predicted contaminant plumes during spring tides for a release at point C, at time = 0 (top), and 72 hr (bottom).

The contaminants released in sheltered waters disperse first throughout the sheltered waters – implying that all sheltered waters are connected. Later these contaminants exit the sheltered waters to disperse in coastal waters; this dispersion in coastal waters takes the form of a coastal plume that tags the coastline both of the mainland and of the island, both to the east and west of the main channel. There is an order of magnitude difference however between the contaminant concentration in sheltered waters and over the seagrass in coastal waters, and there is a further order of magnitude difference between that concentration and the concentration of contaminants over the coral reefs. This model prediction explains the field observations of a rapid transition of ecotones, from eutrophicated waters in sheltered waters with no seagrass and corals, to first seagrass and then to coral reefs. Essentially the hydrodynamics enable a sharp transition of ecotones.

However the eutrophicated waters from the sheltered zone do affect the seagrass and the corals (as evidenced for instance by the high nutrients and chlorophyll-a concentration; the seagrass and corals are seriously stressed by excess nutrients and low dissolved oxygen concentration as result of the eutrophication from fish farms.

The local residence time of waters is very different in sheltered waters, in coastal waters, and offshore, and it varies also between spring tides and neap tides. This was calculated from the model by tracking the contaminants issued from sites A, B and C and remaining within 300 of the release point in any direction. For site A, the local residence times for these 600 m X 600 m boxes for a 10% retention are about 4 and 9 days during spring and neap tides, respectively (Fig. 60).

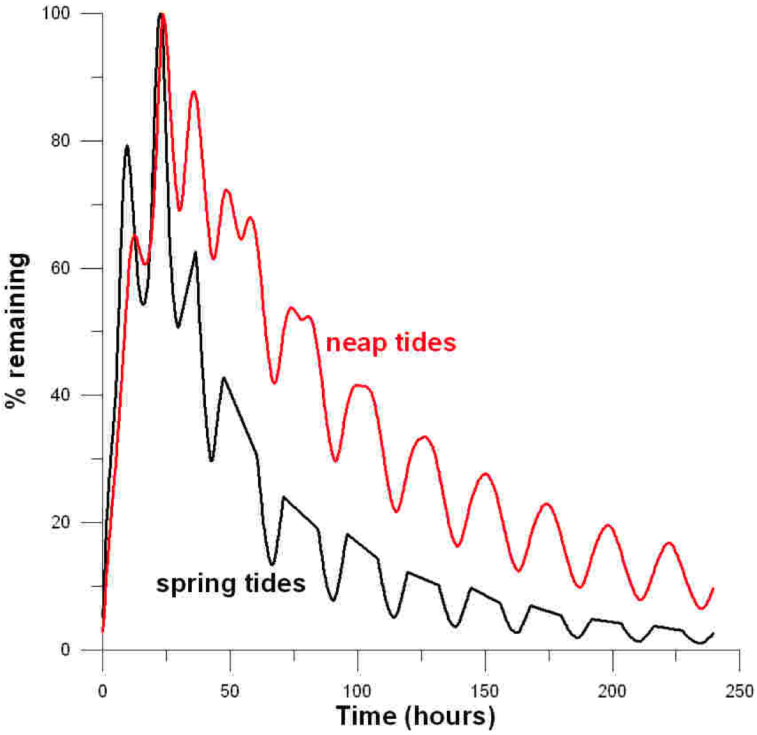


Fig. 60. Percentage of water-borne contaminants released at point A over a 24 h period and remaining within 300 m in any direction from that point, during both spring and neap tides

For sites A, B, and C, the values of these residence times during spring tides are about 4, 3 and 1 days (Fig. 61).

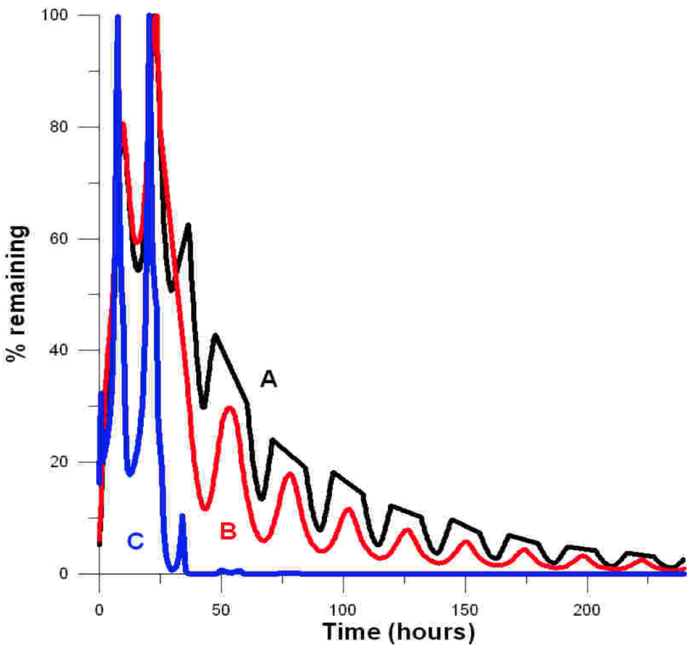


Fig. 61. Percentage of water-borne contaminants released at points A, B and C over a 24 h period and remaining within 300 m in any direction from these points, during spring tides.

These time scales should be compared with the time scales for degradation of the food scraps and fecal pellets; data on these times scales as well as the nutrient loading rates and the rate of transformation to food scraps, are urgently needed. Where the flushing time scales are much smaller than the degradation time scales, fish farms do not significantly degrade the environment if the loading rates are small. Where the flushing time scales are of the same order of magnitude as the degradation time scales, fish farms have the potential to degrade the environment.

For site B this implies that the contaminants (excess nutrients) from the fish pens over the seagrass are potentially less harmful to the environment than those in sheltered waters. Nevertheless these residence times are high enough for some of the excess nutrients from the fish pens to be processed by primary consumers, leading to locally-produced high values of chlorophyll-a (as opposed to the effect of the nutrients originating from sheltered waters). In turn, this leads to low values of the dissolved oxygen concentration at night because of respiration.

These findings suggest that if the management of Bolinao waters would change to get away from its present neglect of the environment to a new focus on conservation of seagrass and mangroves (and coral reefs) while using the sheltered waters for fish farming, then the fish pens over the seagrass should be removed.

The next key question for environmental management is what are the maximum allowable number of fish cages and fish pens in sheltered waters, and the allowable daily use of fish feed. The model of Legovic (2008) suggests that the maximum carrying capacity in sheltered waters is already reached in the sense that the depth-averaged and spatially-averaged dissolved oxygen concentration may reach hypoxic, and possibly anoxic, conditions at night. This prediction is probably optimistic (i.e. the system is actually over-exploited) because the assumptions behind that model are unrealistic and conservative: the model assumes that all food is consumed and that there are no messy feeders (i.e. no food scraps). Worldwide experience however is that much of the fish feed in floating fish farms is not used and becomes food scarps. This fish food and the fecal pellets from the fish settle to the bottom where they generate a biological oxygen demand, which depletes the near-bottom dissolved oxygen and can create anoxic waters at the bottom. This kills the benthos, including seagrass and corals, and creates a ‘dead zone’.

In view of the field data and the modelling, we suspect that this dead zone occurs occasionally in sheltered waters of Bolinao and deserves detailed investigations. If the management of Bolinao waters was serious about preserving a healthy environment, then stricter limits on fish farms and their use of fish feed are needed, as has to be determined by detailed studies.

Finally there is a need to pursue the study initiated and examine the effectiveness of planting mangroves over seagrass in coastal waters (e.g. near site B). Primavera et al. (2012) have reviewed such practices at a number of sites in the Philippines and observed that generally they have a negative impact. In Bolinao our visual observations of the stunted growth of the mangroves and the trapping of mud behind the rock walls that are built to protect the mangroves (Fig. 53) – thereby further degrading the seagrass - suggest that the planting of mangroves over seagrass in coastal waters may actually be degrading the environment. This is also suggested by the estuarine ecosystem model of Wolanski et al. (2009) that considers mangroves, seagrass and coral reefs as well as estuarine waters; the model suggests that there is no gain for the ecosystem health in degrading the healthy seagrass in order to produce unhealthy mangroves over the same area, because the value per unit area of ecosystem services provided by mangroves and seagrass are of similar magnitude (Granek et al., 2009).

In the Gulf of Mannar, a Hydrodynamic Model (HD) was carried out in four Islands for the month of November 2011 using MIKE 21. Input parameters include i) tide levels and/or ii) wave climate. Based on these criteria, the current direction and velocity were modeled and the flow fields are given in Figs. 54 through Fig. 56. In addition, littoral drift pattern for the study site was also obtained from secondary sources.

Climate and Meteorological Conditions

Temperature ranges from maximum of 35°C to a minimum of 20°C. The average annual rainfall is 601mm, with most of the rainfall during October- December.

Tide Levels

The tide levels from Chart Datum at Tuticorin are given below:

Mean Lower Low Water Springs	: + 0.25 m
Mean Low Water Springs	: + 0.29 m
Mean Low Water Neaps	: + 0.55 m
Mean Sea Level	: + 0.64 m
Mean High Water Neaps	: + 0.71 m
Mean High Water Springs	: + 0.99 m

Wave Climate (Observed Data-Secondary data source)

Table 15 and Table 16 provide the typical wave climate for the area, based on data collected from ship based observations from 1950 to 1959.

Table 15: Distribution of Wave Heights (Indian Ports Association)

Wave Height (m)	No. of Days of occurrence in a year	% of time of occurrence in year
0.00 – 0.61	94	25.40
0.62 – 1.22	112	30.70
1.23 – 1.83	89	24.40
1.84 – 2.44	54	14.80
2.45 – 3.05	9	2.47
3.06 – 3.66	3	0.83
3.67 – 4.27	3	0.83
4.27 & above	1	0.27

Table 16: Distribution of wave periods around Tuticorin region of the Gulf of Mannar

Period (s)	No. of Days of occurrence in a year	% of time of occurrence in year
0.0 – 5.0	183	50.12
5.1 – 7.0	110	30.20
7.1 – 9.0	41	11.20
9.1 – 11.0	12	3.28
11.1 – 13.0	4	1.10
13.1 – 15.0	3	0.82
15.1 and above	12	3.30

Current (Modeled Data)

The modeled current velocity and current direction are shown in Fig. 62 below. The predominant current direction is 150 to 180°. Based on the model estimates, maximum current velocity was determined to be 0.045 m/s.

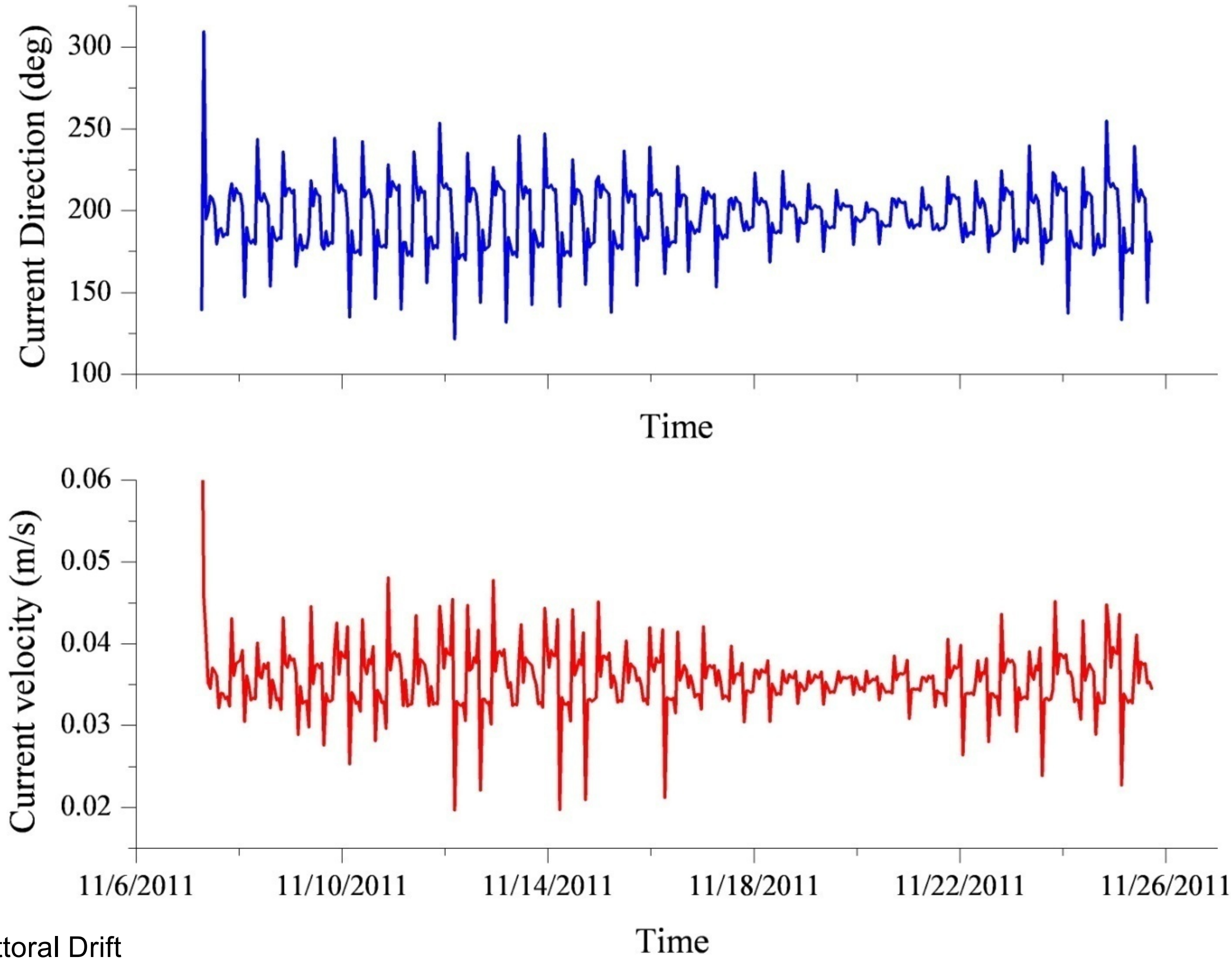


Fig. 62. Current Direction and Current Velocity (m/s)

Littoral Drift

The area in and around Tuticorin Port is almost free from Littoral Drift. The annual littoral drift is 0.1 x 10^6 m^3/year, which can be compared to the estimate of 1 Mm^3/year along the Chennai coast.

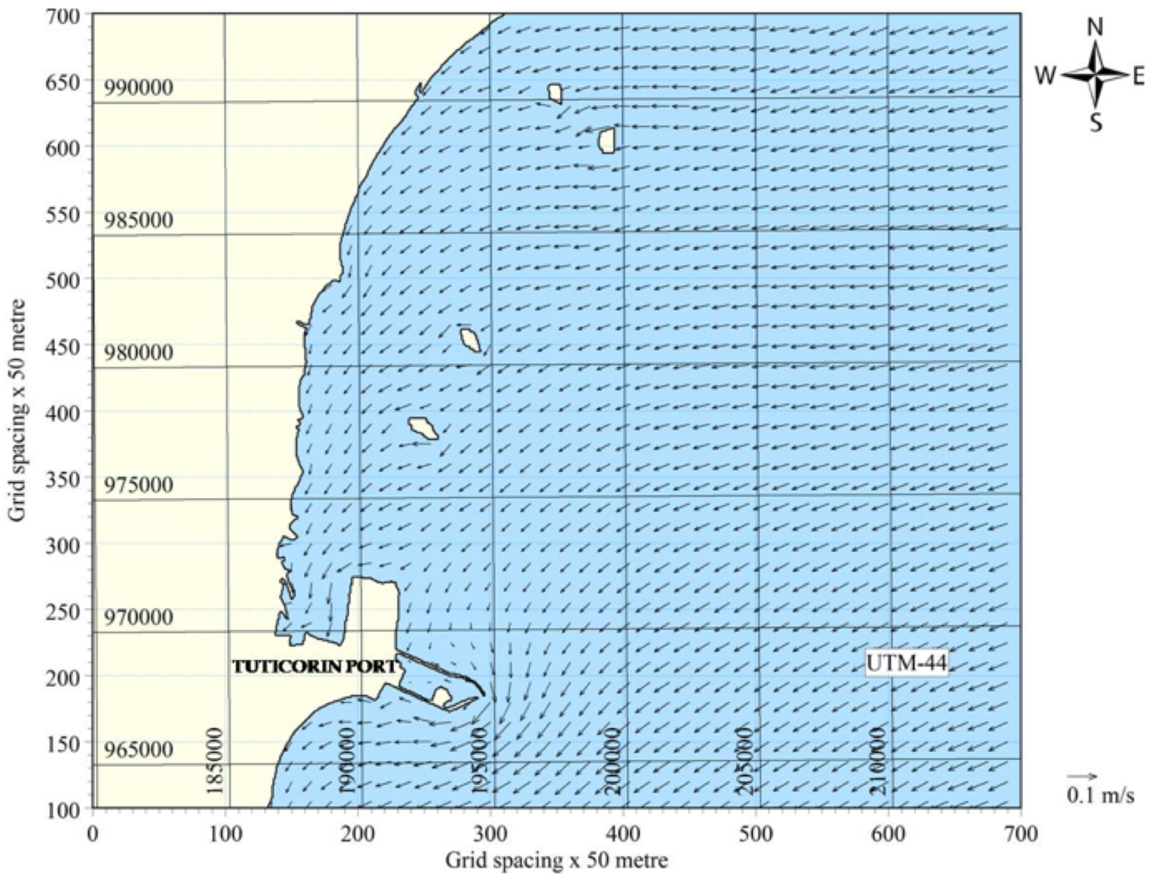


Fig. 63. Flow field - November - Spring tide - Flood phase

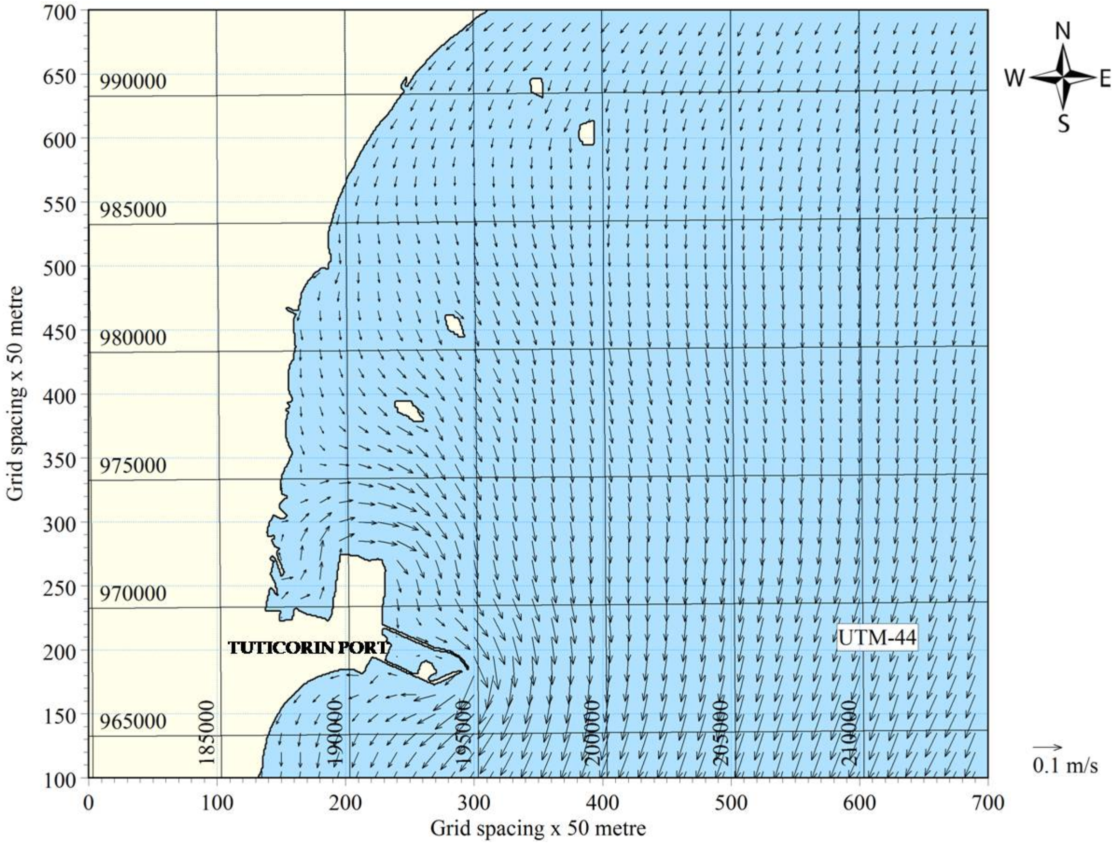


Fig. 64. Flow field - November - Spring tide - Ebb phase

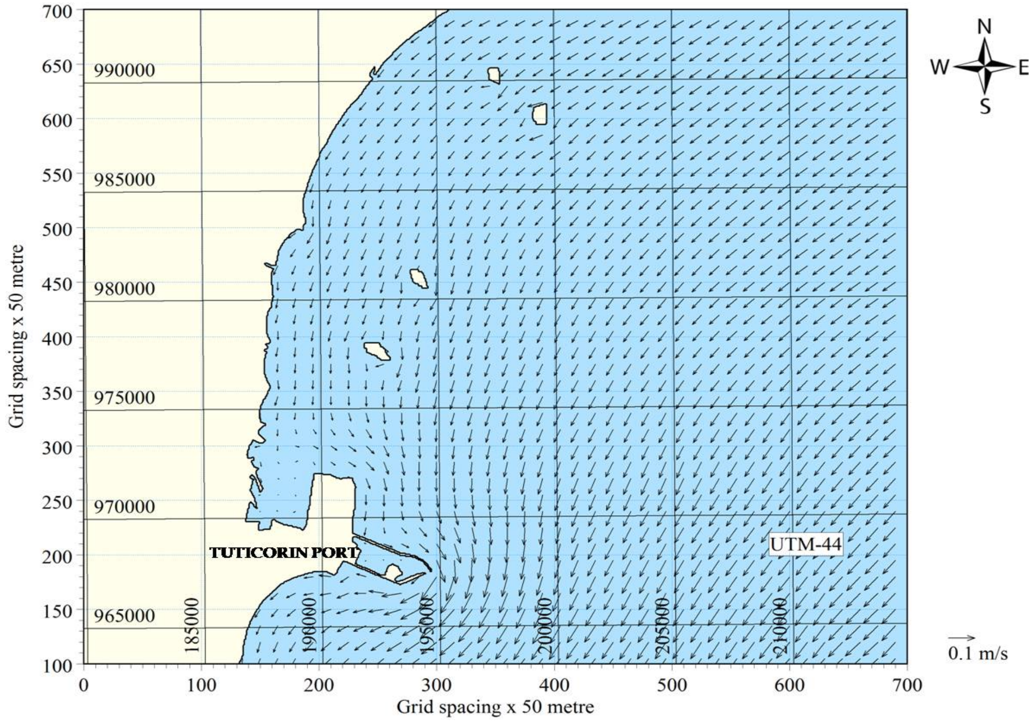


Fig. 65. Flow field - November - Neap tide - Flood phase

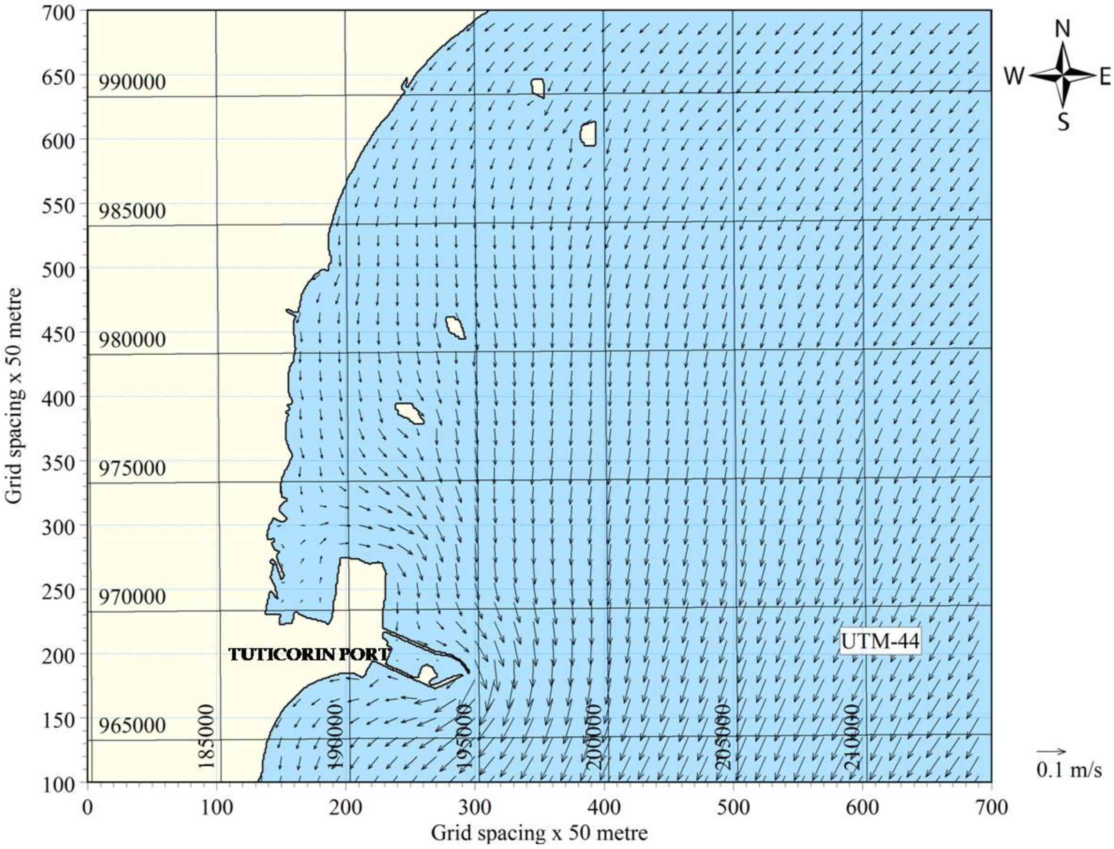


Fig. 66. Flow field - November - Neap tide - Ebb phase

Mangrove Transplantation

In order to identify and quantify the bioshield function of a broad range of mangrove habitats, it is necessary to have a good idea of the trajectory of mangrove processes along a wide range of mangrove conditions. With these, knowledge on morphometric dynamics is essential. Hence, Bolinao in the province of Pangasinan, northwest Philippines, was selected because it represents one end of the extreme condition (disturbance), while Mati in Davao represents the other (undisturbed) condition. It is necessary, however, to initially undertake studies at other sites where conditions are intermediate between the two environmental extremes. In addition, more robust data and information are already partly available at the latter sites. Hence, these studies were initially undertaken at these 'reference sites' in the southern part of the Philippines (Olango, Siquijor, and Banacon) prior to the initiation of the 'primary' project studies at the selected sites (Bolinao and Mati).

Mangrove forests provide important social and ecological functions; they reduce the magnitude of damages to inland by surges and tsunamis, trap sediment discharged from the terrestrial zone into coastal area. Therefore, artificial planting of mangroves in coastal belt has been popular practices in many tropical countries. The species and method of planting, however, depends on the ease of seed acquisition and rate of survival of juvenile trees after introduction. In the Philippines, *Rhizophora stylosa* is solely planted due to the higher rate of establishment of the species. Due to mono-specific planting and use of higher individual density, the phenological condition of planted mangrove stands is quite different from that of natural mangrove forests. We assume that the prevailing phenology of planted mangrove forest might usher some ecological issues in near future, which would hinder the achievement of ultimate objective of plantation. In this project, we have studied the ecological effects of existing planting practices of mangrove forests at the central Philippines.

Mangrove species composition and their morphology were investigated both at planted and at natural stands in Olango and Banacon islands. In mono-specific plantations at both islands, *Rhizophora stylosa* has extensively been planted for surge protection and for fuels. In Banacon islands, in particular, the plantation had been initiated at about 60 years ago. *R. stylosa* was chosen for its high survival rate after planting and year-round availability of propagules. In the plantation, propagules are planted at 50cm intervals.

In Olango island, 10m × 10m quadrats were taken from natural and planted stands, and all tress inside the quadrats were identified. In Banacon island, canopy width and diameter of breath height (DBH) of trees were measured at randomly selected natural and planted stands. Tree height and DBH were also measured for trees at the centre and the edge of a stand.

Fig. 67 show the view of a natural stands and an artificially planted stand at Olango island, respectively. At natural stands, the main species at the most outer edge was *Sonneratia alba*, followed by a *Avicenia marina* dominating stand in the behind. The density of these stands was relatively scarce, leaving an ample room for the colonization of other species. At planted areas, on the other hand, almost the entire population was composed of *R. stylosa* with same age. Species composition of the natural and the artificial stands are shown (Fig. 68). *Sonneratia alba* or *Avicenia marina* are dominant at natural stands, while at planted stands, *Rhizophora stylosa* are dominant or even in some patches, it is the only species. Species density was far higher with planted stands of *Rhizophora stylosa*, such as 20,000 tress/ha, compared with others (less than 1000trees/ha), indicating high density of trees at planted stands.

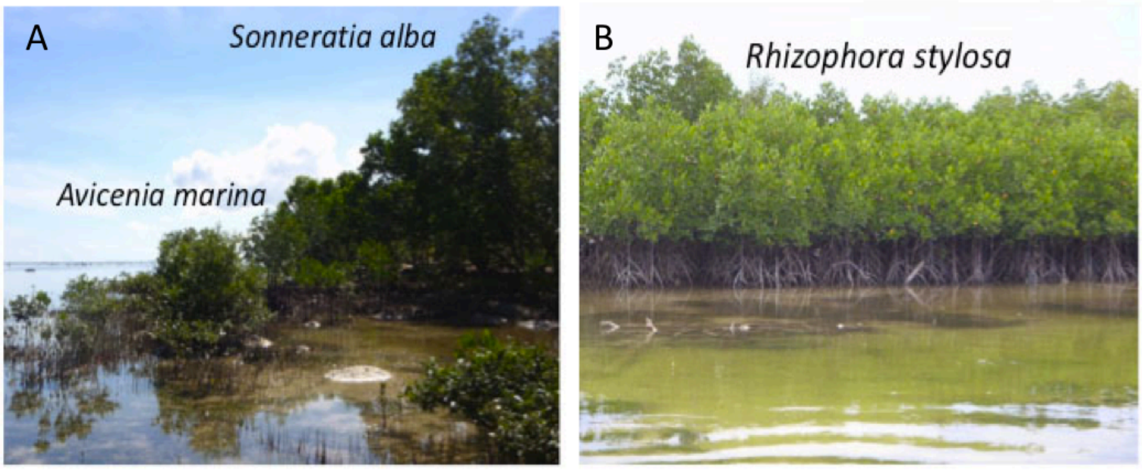


Fig. 67. Natural (A) and transplanted (B) stands of mangroves in Olango Island.

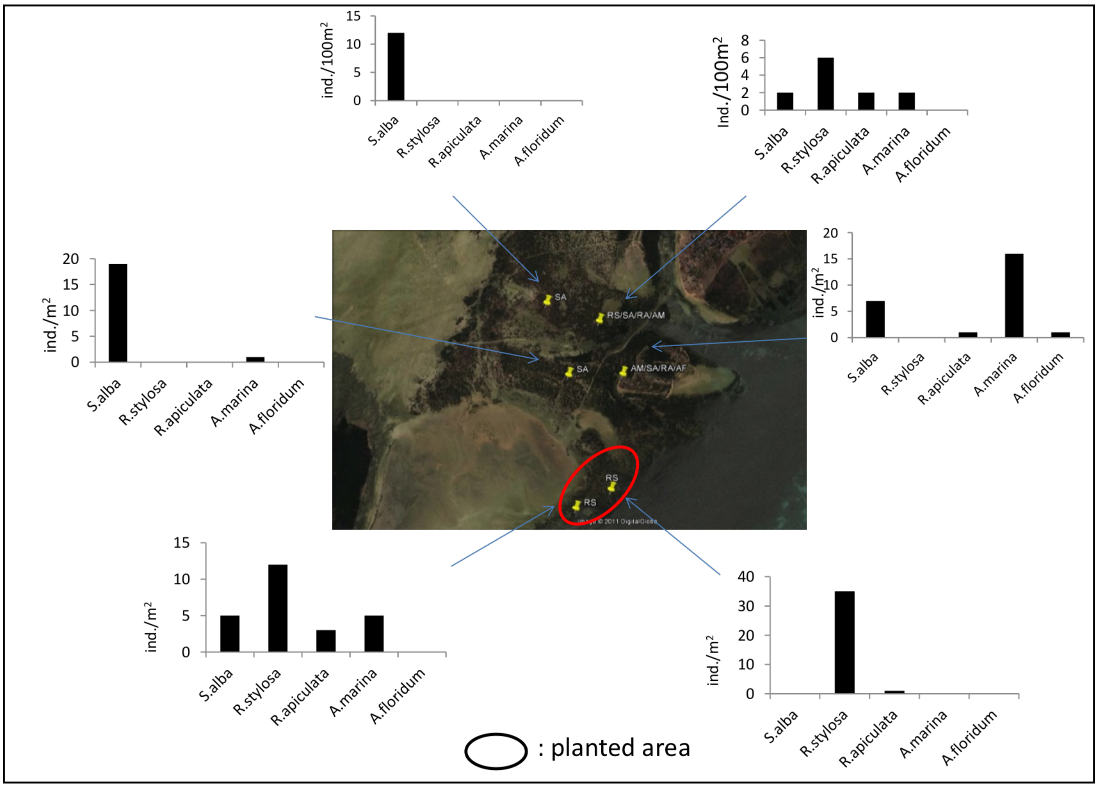


Fig. 68. Species composition at the natural and transplanted stands of mangroves In Olango Island

Mangrove parameter simulation

The growth of mangrove trees and the expansion processes of their forest are important factors to assess the effects of mangrove forests as a bioshield along the coastal zone. There are several models to describe the growth of an individual mangrove, while models describing forest processes are limited. This study is finally aimed at the development of the processes of forestation of mangroves. In this year, collection of some morphology datasets was conducted from both field works and literature reviews.

Tree height and diameter of breath height (DBH) of differently aged *Rhizophora stylosa, Avicenia marina* and *Sonneratia alba* were measured at the three reference sites. At the same time morphological datasets were obtained from the literature.

Figs. 69 to 71 show the relationships between DBH and tree height, between tree age and tree height and between tree age and DBH, respectively. All these figures include results of field observation. Fig. 69 describes the distribution of tree height with DBH. The data exhibits strong relationship (R2 =0.9343). Data from Bohol island was considered to obtain the curve. Fig. 70, on the other hand, describes the distribution of tree age with tree height. From the distribution, the relationship between two parameters are slightly less strong (R2 = 0.8769). Data includes both Bohol island and Olango island field observation data.

Fig. 71 describes the relationship between tree age and the DBH and these two parameters exhibits strong relationship with R2 = 0.9525. Bohol island field data were considered to obtain the relationship.

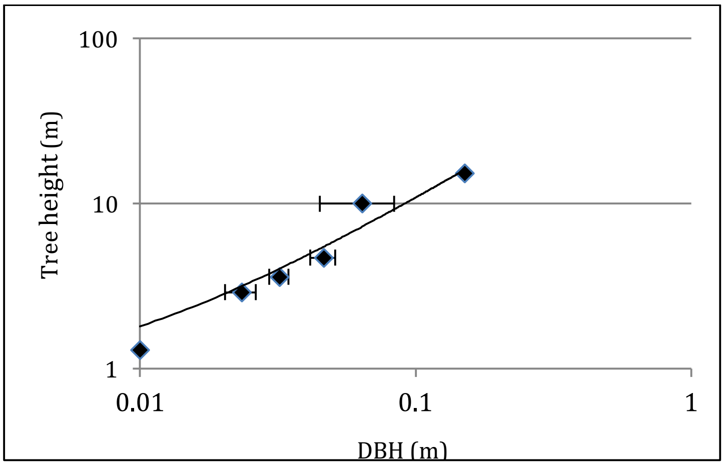


Fig. 69. *Rhizophora* sp. tree height, DBH distribution.

♦-Bohol island data; ▲-Olongo Is.

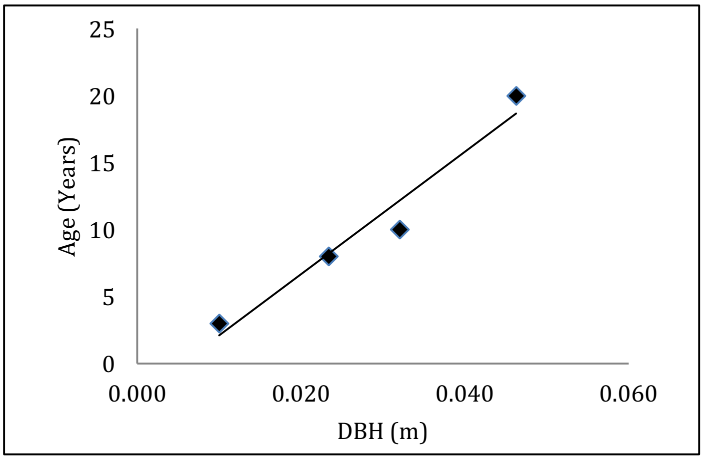


Fig. 70. *Rhizophora* sp. tree age and DBH distribution.

♦-Bohol island; ▲-Olongo Is.

These figures imply the following relationships (power functions):

For between DBH and tree height

Tree height = 101.09 (DBH) + 0.7978 (R^2 = 0.9343) (1)

For between tree age and tree height

Tree age = 3.8124 (Tree height) - 1.8454 (R^2 = 0.8769) (2)

For between tree age and DBH

Tree age = 457.6 (DBH) - 2.5151 (R^2 = 0.9525) (3)

The relationship between tree age and the AGB was obtained from Komiyama et al. (2008) and Sherman et al. (2003). The relationship between the two parameters are slightly less strong (R2 = 0.8118).

Fig. 71, on the other hand, describes the relationship between tree age and the BGB. Data obtained from Kairo et al. (2008) and some data from Komiyama et al. (2008), were interpreted using regression equation for AGB/Tree age to obtain tree age (Tree age = 0.2081 (AGB) + 10.466)

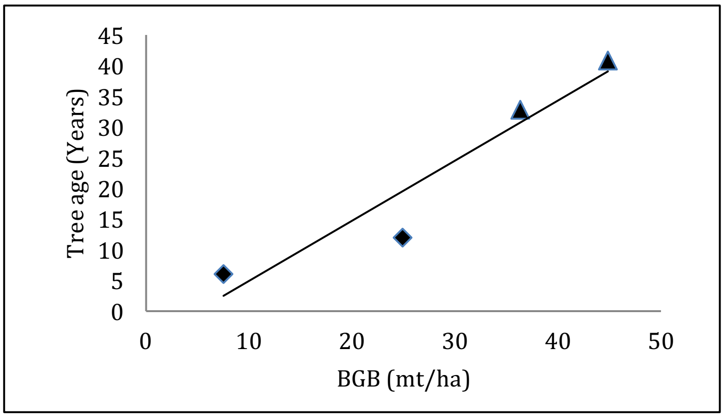


Fig. 71. *Rhizophora* sp. Age, BGB distribution.

♦- Kairo et al., (2008); ▲- Komiyama et al. (2008).

Equations (4) to (5) provide AGB, BGB and LP as a function of tree age such as,

Tree age and tree AGB

Tree age = 0.2081 (AGB) + 10.466 (R^2 = 0.8118) (4)

Tree age and tree BGB

Tree age = 0.9793 (BGB) - 4.8711 (R^2 = 0.9069) (5)

Although trunks, branches and roots are accumulated year by year, leaves are decomposed after defoliation. Decomposition coefficients are 0.0020 (*Rhizophora mucronata*) - 0.0024 (*R. apiculata*) (Wafar et al.1997), thus the leaf litter accumulates year by year such as 6.18 - 8.44 mt/ha/year for *R. apiculata* (Ong et al. 1985), 10.03 mt/ha/year for *R. mangle* (Bernini and Rezende 2010).

Hence, from the data, it is clear that there are some clear relationships between age and other factors such as AGB, BGB, DBH and tree height in *Rhizophora* sp. Further, the DBH and tree height also exhibits a strong relationship. However, slightly low R2 of tree age to tree height regression curve and tree age to AGB regression curve suggests that there is more complex relationship among those parameters. Further, studies will provide necessary data sets to find out complex relationships and other parameters such as litter production rates, tree stand density, crown diameter, etc. which are vital for the study of reforestation of mangroves. This activity is a necessary ingredient in understanding and applying the bioshield functions of mangroves.

Ecosystem services of local seagrass and mangroves

In the Indo-Pacific region, some ecosystem services provided by seagrass beds and mangroves have been categorized into four types: direct extractive, direct non-destructive, environmental services, and biodiversity services (UNEP (2007a). Both ecosystems have closely similar functions, differing largely in the degree these are emphasized and the extent they were studied for the project purpose. In the region, mangroves are relatively well studied, since they have been used for varied purposes since the early 1900's (especially as a source of alcohol), compared to seagrasses which were the object of academic interest only in the last three decades and their economic value formally documented only in the last two. UNEP (2007a) gives a recent and more detailed and thorough guidelines for the economic valuation of coastal ecosystem goods and services in the South China Sea sub-region. In addition, UNEP (2007b) gives the procedure for determining national and regional economic values for the goods and services of these two transitional habitats (ecotones). The study reports that the value of total annual production of goods and services by the two habitats demonstrates unequivocally the importance of mangroves in the region, with a total annual value of production exceeding US$ 5.1 billion, compared with a mere US$86 million for seagrass habitats.

At the three SMBP sites in the Philippines (Bolinao, Mati and Malita), and using the categories adopted by UNEP (2007a), the services provided by local seagrasses and mangroves are given in Table 17. As indicated by the results of the Gap and Training Needs Analyses, seagrass beds are lesser known, when compared to mangroves. Among the three sites, Bolinao ranks first in terms of knowledge and utilization of seagrass resources. Mati ranks second and Malita, third. This differing level of awareness on seagrass is a direct offshoot of the exposure of the population to the activities of research institutions, programs, projects and agencies dealing with coastal resources. This scenario is relatively wanting in Mati and much less in Malita. In terms of mangroves, however, the state of knowledge on the services of the ecosystems is high for all three sites, most coastal populations are knowledgeable on the resource, and variations are only very slightly. The primary reason for the variation appears to be the relative size of the mangrove areas, especially those targeted for development. Hence, Bolinao mangroves are practically gone due to removal in favor of fish cages and fish pens; Mati mangroves are originally small in area since the place is limited and not conducive to mangrove growth; and the mangroves in Malita are even more limited in size, but is known by many simply as a place to give way to fishponds.

Table 17. The four categories of uses of seagrass beds and mangroves at the SMBP sites (Modified and updated from UNEP 2007a)

	Seagrass Beds			Mangroves		
Direct (Extractive)	Bolinao	Mati	Malita	Bolinao	Mati	Malita
Timber	NA	NA	NA	L1	L1	L2
Firewood	NA	NA	NA	L1	L1	L1
Poles	NA	NA	NA	L1	L1	L1
Charcoal	NA	NA	NA	L1	L1	L1
Leaves/palm fronds	L3	L3	L3	L1	L1	L1
Fruits/propagules	L2	L3	L3	L1	L2	L2
Bark (tannin and dyes)	NA	NA	NA	L2	L2	L2
Medicine	L3	L2	L3	L2	L2	L3
Sap (sugar, alcohol, vinegar)	NA	NA	NA	L2	L2	L3
Wood tar	NA	NA	NA	L2	L3	L3
Fish, crab, prawn capture	L1	L1	L2	L1	L1	L1
Shellfish collection	L1	L1	L2	L1	L1	L1
Insect and larvae capture	NA	NA	NA	L2	L2	L2
Worms	L2	L3	L3	L1	L1	L2
Wildlife hunting	L2	L2	L3	L1	L1	L1

Zooplankton	L3	L3	L3	L2	L2	L3
Jellyfish	L1	L2	L2	L2	L2	L3
Bees, honey, wax	NA	NA	NA	L1	L2	L2
Seaweed	L2	L2	L3	L2	L2	L3
Direct (non-extractive)						
Tourism/recreation	L2	L2	L3	L2	L2	L2
Transport	L2	L2	L3	L1	L2	L2
Education	L2	L2	L3	L1	L1	L2
Research	L2	L2	L3	L1	L1	L2
Fish, crab, prawn culture	L2	L2	L2	L1	L1	L1
Other culture (pearl, oyster)	L3	L3	L3	L2	L2	L3
Environmental Services						
Shoreline protection	L2	L2	L3	L1	L1	L2
Erosion prevention	L2	L2	L3	L1	L1	L2
Flood protection	L3	L2	L3	L2	L2	L3
Wind break	L2	L2	L3	L1	L1	L1
Carbon sequestration	L3	L3	L3	L2	L3	L3
Prevents seawater intrusion	L2	L2	L3	L2	L2	L3
Primary production	L1	L2	L3	L2	L1	L2
Sediment, contaminant, nutrient removal/storage	L2	L2	L3	L2	L2	L3
Oxygen release	L1	L2	L3	L2	L1	L2
Nursery feeding areas	L1	L1	L2	L1	L1	L1
Shoreline accretion/land increase	L2	L3	L3	L2	L2	L2
Biodiversity Services						
Existence values of species, genes, communities	L2	L3	L3	L2	L2	L3
Migratory species	L2	L2	L3	L2	L1	L2
Endangered species	L2	L1	L2	L1	L1	L1
Ecosystem existence values	L2	L2	L3	L2	L2	L2
Social/Cultural significance						
Religious/spiritual	L3	L3	L3	L2	L3	L3
Historical importance	L3	L3	L3	L2	L2	L2
Presence of distinctive human activities	L3	L3	L3	L2	L2	L2
Aesthetic	L2	L2	L3	L1	L1	L2

L, Level of knowledge: L1, relatively well documented; L2, in general, less documented, but initiated, and only in very few communities; L3, least documented, study methods not yet well established and reliable; NA, not applicable (Fortes 2012)

Conclusions

SMBP aims: (1) to identify and address the gaps in knowledge and conservation of seagrass and mangroves resources; (2) to provide practical models enabling testing of scenarios of various decisions regarding human and natural impacts on the bioshield functions of the ecosystems; (3) to provide a framework support for a local marine emergency contingency policy, anchored on a Zoning Plan and Coastal Community Vulnerability Index (CCVI); and (4) to provide a framework for an Integrated Decision Support System (IDSS) to support and enhance local governance. This part of the report focuses on the most significant correlation and integrated analysis of findings that answer directly the four objectives of SMBP. It contextualizes the project in relation to the bigger picture of tropical coastal ecosystems (seagrass and mangrove) serving as, as our hypothesis, natural biological protector or bioshield of communities against the impacts of biodiversity loss and changes along Indo-Pacific coasts. Hence, in our attempt to meet our objectives, the SMBP is firstly localized and contextualized within the Driver-Pressure-State-Impact-Response (DPSIR) analysis framework, then looked at in relation to the most compelling evidences or main reasons affecting seagrass and mangroves (e.g. the demise of seagrass in Bolinao), how science is linked directly to local policies (e.g. data on dugong sightings and behaviour as an aid to local conservation and tourism policies), how all these are synthesized via a decision support system (IDSS), and finally integrate the most salient points to justify and support our bioshield hypothesis. Each of these statements are described in more detail below.

SMBP in the context of the DPSIR analysis framework

The major concerns or issues at the SMBP sites (primary and secondary) are summarized in Fig. 72. They are contextualized within the Driver-Pressure-State-Impact-Response analysis framework (DPSIR, EEA 2000). Of particular focus are the actions undertaken by the project in response to the local priority concerns. These actions relate mainly to provision of the knowledge and skills necessary, so that local stakeholders would have the capability to use them in addressing issues pertaining to seagrass and mangrove conservation by themselves. The materials provided are largely in the form of data published in scientific journals, in a guidebook, posters, brochure, video, or educational and advocacy instruments culled out and shared during local Focus Group Discussions (FGDs), workshops, training courses, and in a national conference. In a few cases, knowledge and information generated by the project were presented to bigger audiences as in a national and international meetings and symposia.

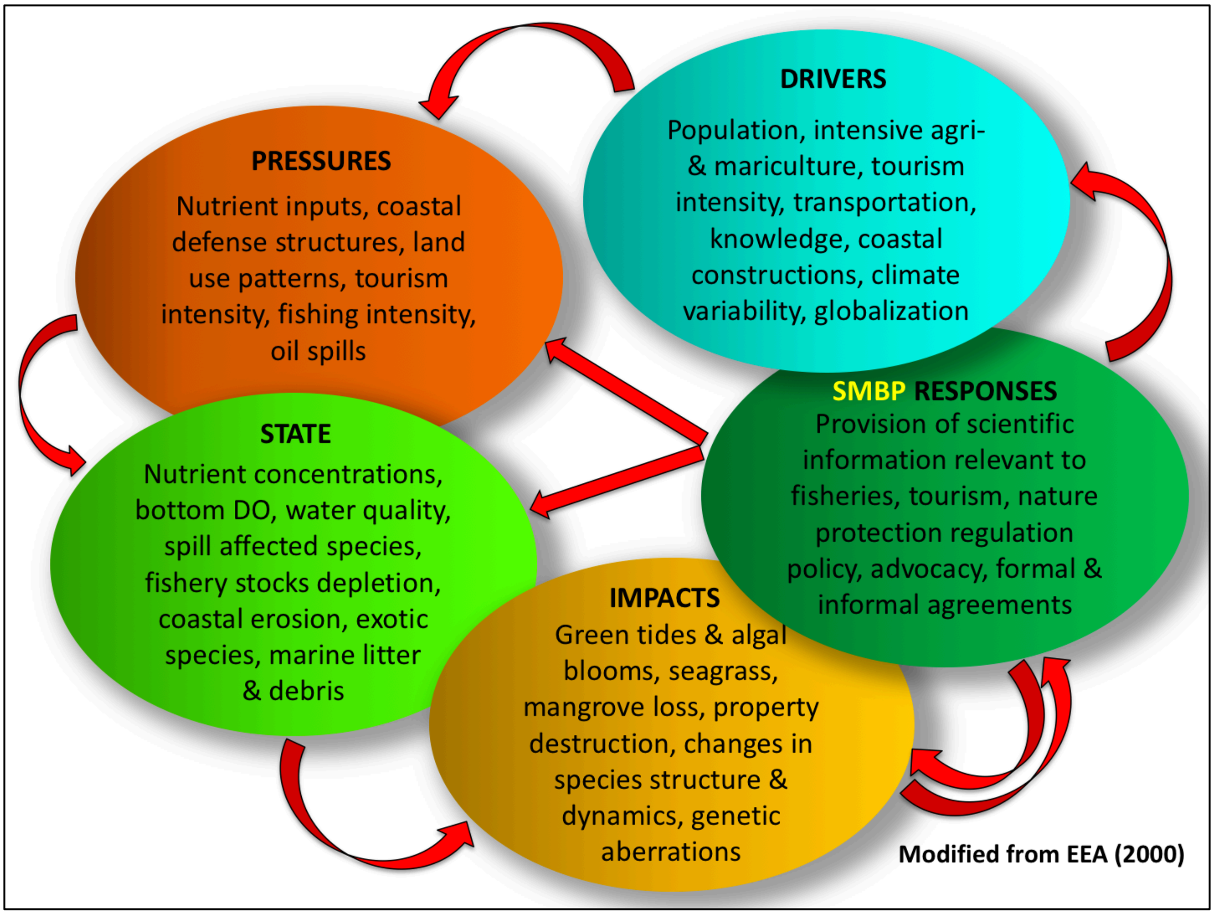


Fig. 72. The major concerns at the SMBP sites, emphasizing the project's responses to help address the issues and adapted to the DPSIR framework (Modified from EEA 2000).

Mariculture in Bolinao, a major factor in seagrass and mangrove demise

In January-March 2014, the Bolinao studies further revealed noteworthy results: change in the fractional seagrass cover in Bolinao was greatest in 2001-2004 within the 17-year period from 1989-2006 (Fig. 73). This coincided with the lowest record in seagrass density (Fig. 74). Of particular interest is that both changes are correlated directly with the peak in the number of fish structures (fish cages and fish pens) in that part of the channel (Fig. 75), implicating directly the negative impact of these structures (and increased mariculture activities) on the seagrass ecosystems, which are the primary natural biological support in the Bolinao Reef System. As Fig. 76 shows that this case of eutrophication impacts on seagrass and mangroves in Bolinao, clearly links science with policy and practice within a 'social-ecological system' or SES context.

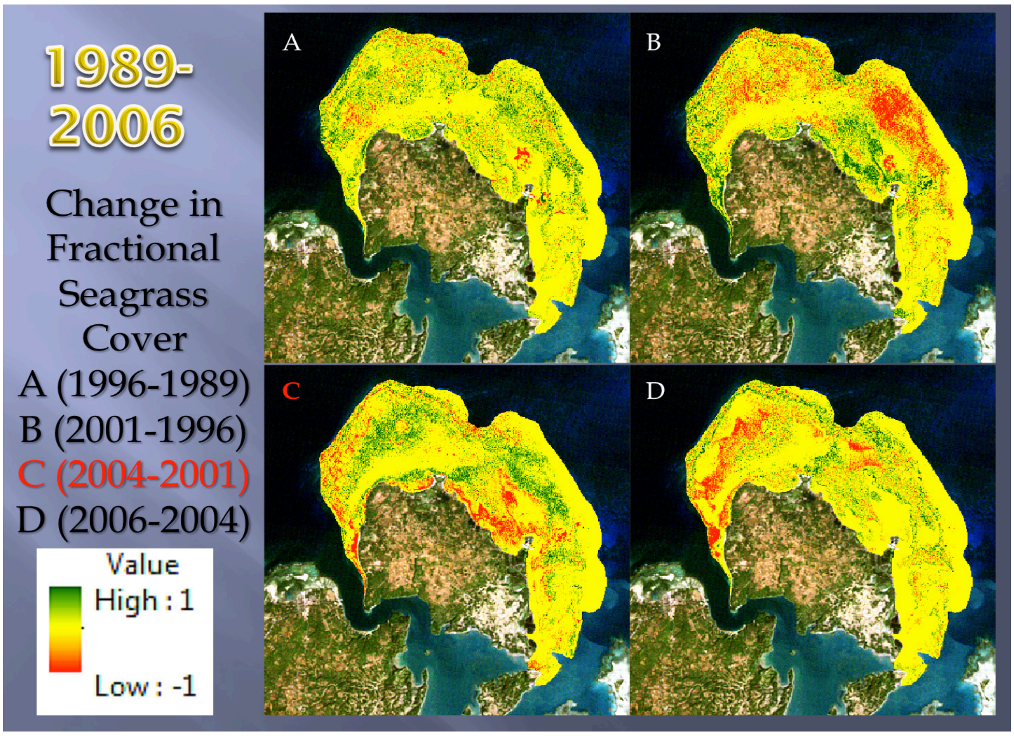


Fig. 73. Change in the fractional seagrass cover in Bolinao was greatest in 2001-2004, C, within the 17-year period from 1989-2006 (Courtesy of UPDGE)

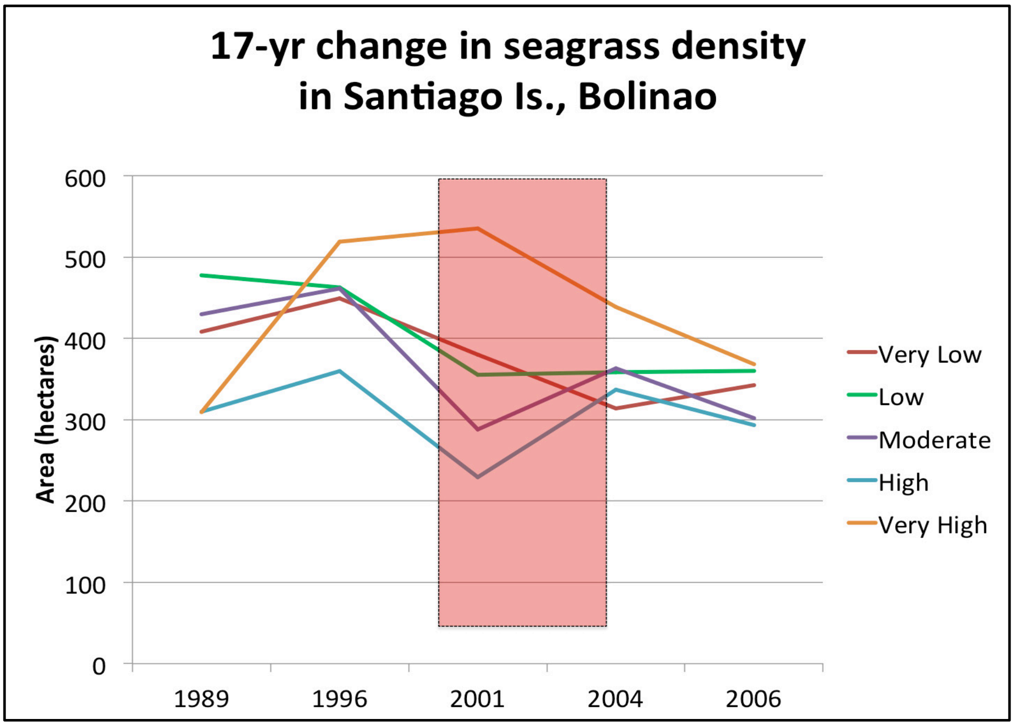


Fig. 74. The period 2001-2004 (shaded) exhibited the lowest seagrass density and fractional cover in Bolinao.

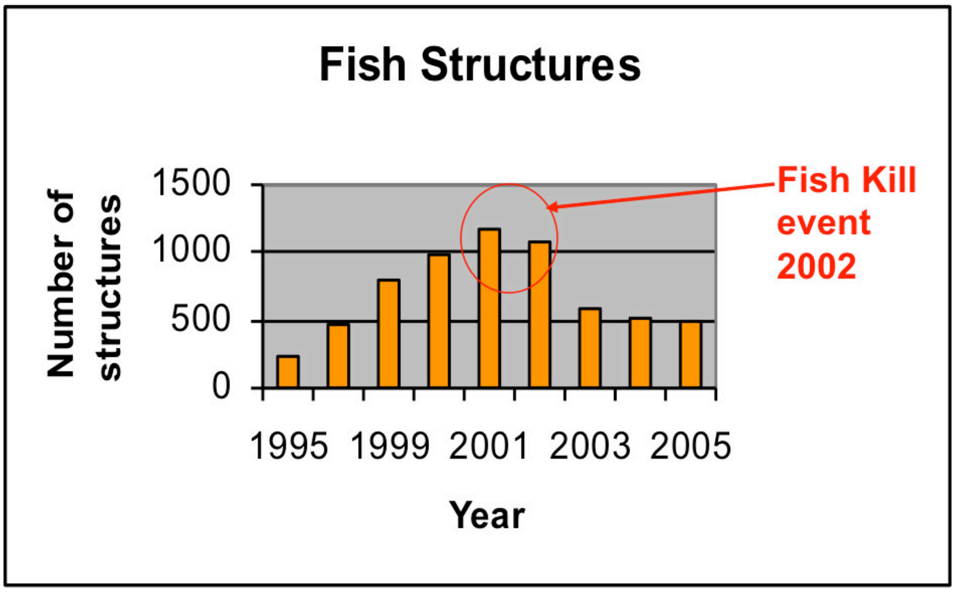


Fig. 75. Peak in the number of fish structures coincided with the occurrence of the first fish kill event in Bolinao in 2002 (encircled) and the lowest seagrass density and fractional cover shown in Fig. 73

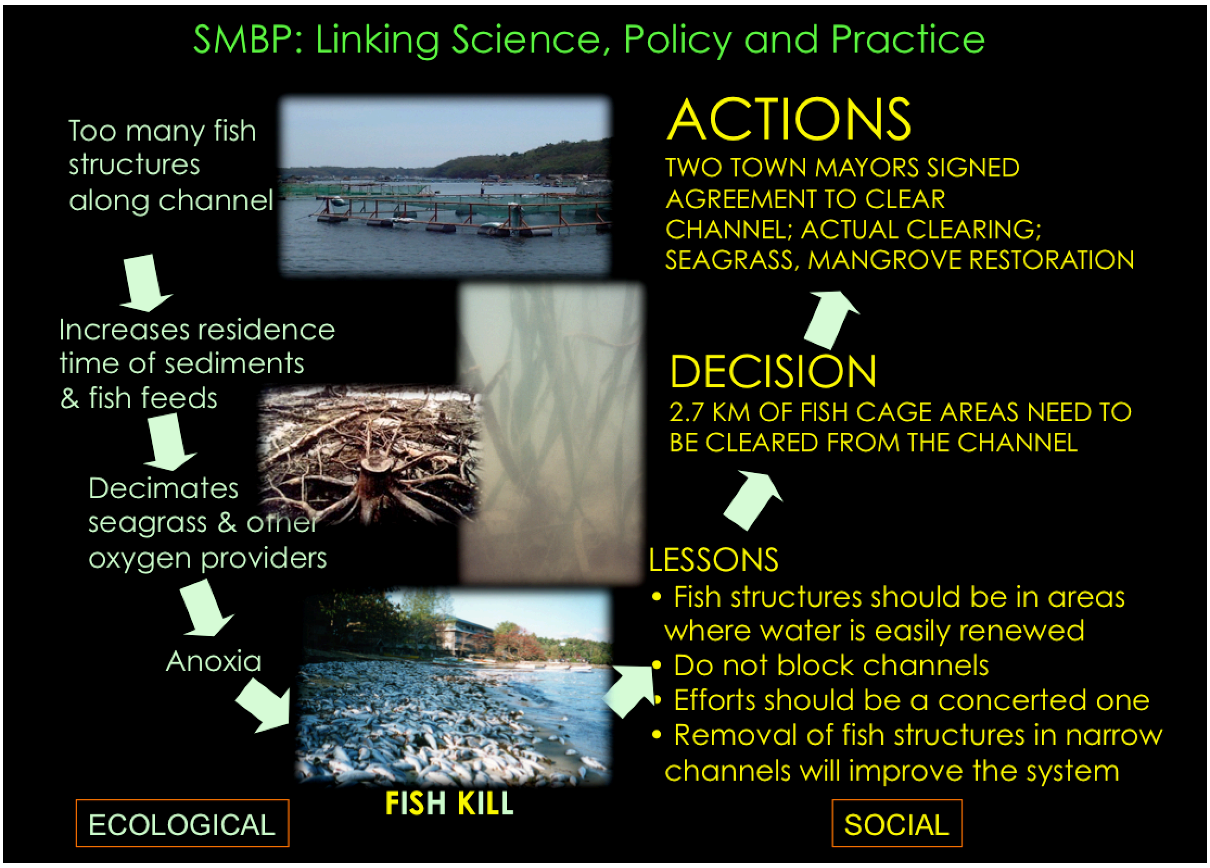


Fig. 76. The ‘fish kill’ events in Bolinao clearly show how SMBP helps link science, policy and practice within a ‘social-ecological system’ context

Scenario analysis and prediction

In Bolinao, and with data on seagrass and ecohydrology, the project took part in the development of scenarios to answer the question: *What is the fish mortality in mariculture areas with varying % reductions in fish feeds*? Tsuchiya et al. (2013) in part provides an answer. Under scenario 0 (keeping present condition) and Scenario 1 (with 25% feed cut in both areas), the latter could bring about a drastic reduction in the fish mortality (Fig. 77). However, this reduction in mortality is limited if Anda does not cooperate (Fig. 78), suggesting the vital role of mutual agreement and cooperation between the two municipalities if they want substantial improvement in their mariculture industry and protection of their common coastal environment.

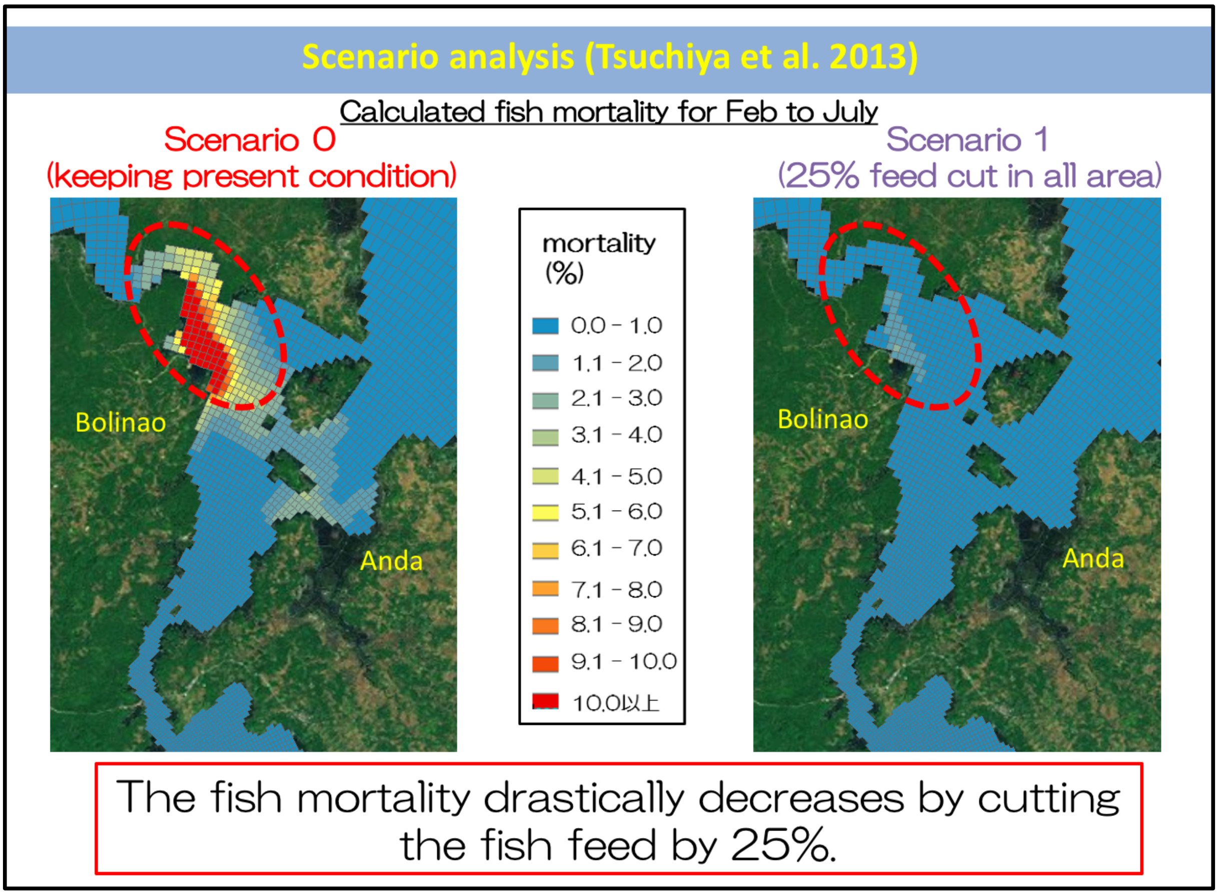


Fig. 77. Cutting the amount of fish feeds by 25% in both municipalities would drastically reduce fish mortality in the fish cages and fish pens

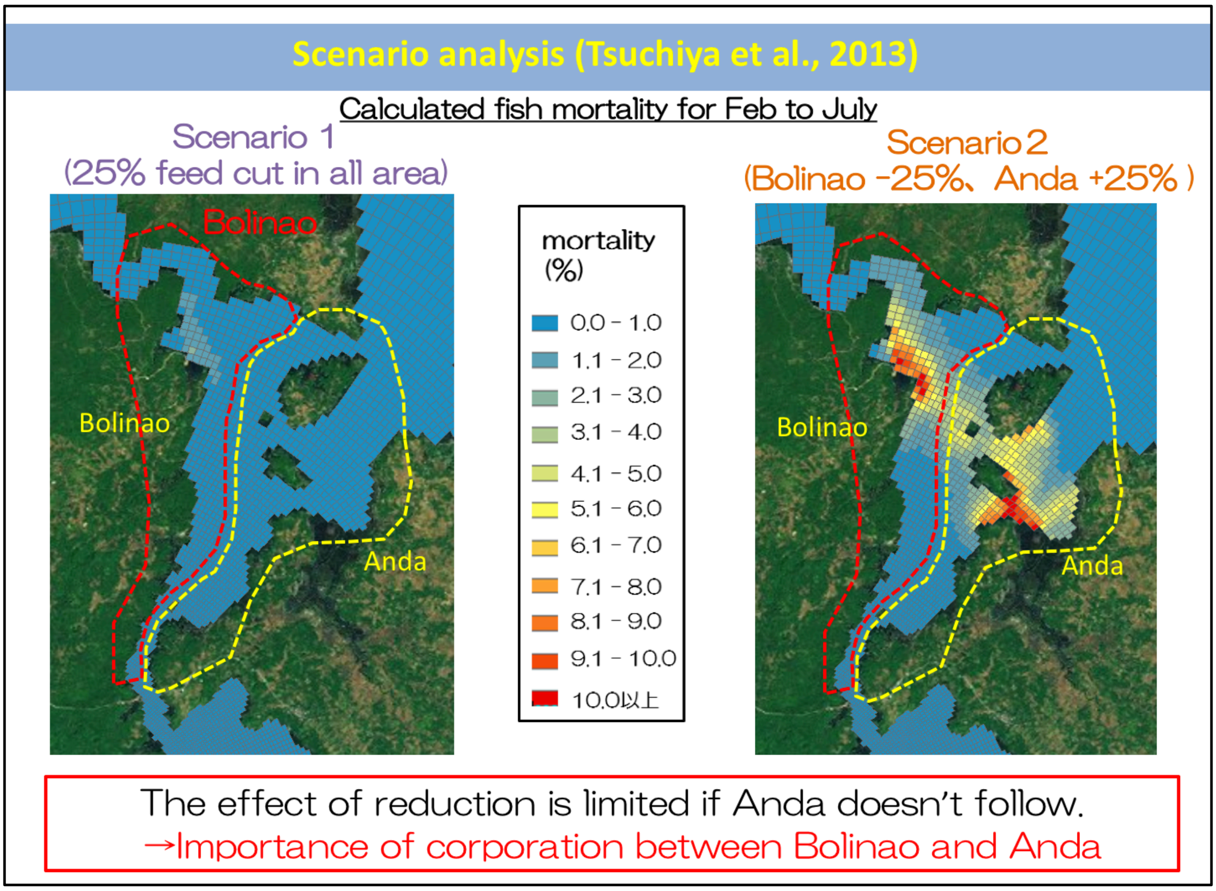


Fig. 78. Scenarios showing the outcome if one of the two municipalities does not cooperate in reducing the amount of fish feeds

Dugong sightings vs. environmental parameters

Correlation analysis was done among dugong sightings vs. time of day, temperature, correlated with the number of tourists and boats. The outcome of the monitoring of dugong sightings, time of day, sea surface temperature (SST), number of tourists and boats at the sites reveal significant implications to conservation and policy. Fig. 79 shows that cumulatively over 18 months from June 2014 to November 2015, bimodal peaks in dugong sightings occurred consistently around 9-11 AM in 2014 and 1-3 PM in 2015. Minor exceptions, however, occurred in October, November and December, which showed peaks either earlier or later but in the same period of the day. In addition, there was significantly greater number of dugong sightings recorded in 2014 than in 2015. These sightings did not show a clear pattern of highs and lows, unlike in 2015 when the bimodal distribution occurred in summer and in the wetter months. Interestingly, significantly higher SST occurred in 2014 when compared to 2015, although this may not be true during the other parts of the year in 2015. Interestingly, dugongs appear to “like” more people although they seem not to “like” the presence of boats. Hence, the implications of the results of the monitoring to policy on dugong and seagrass conservation and tourism (dugong watching) are immense.

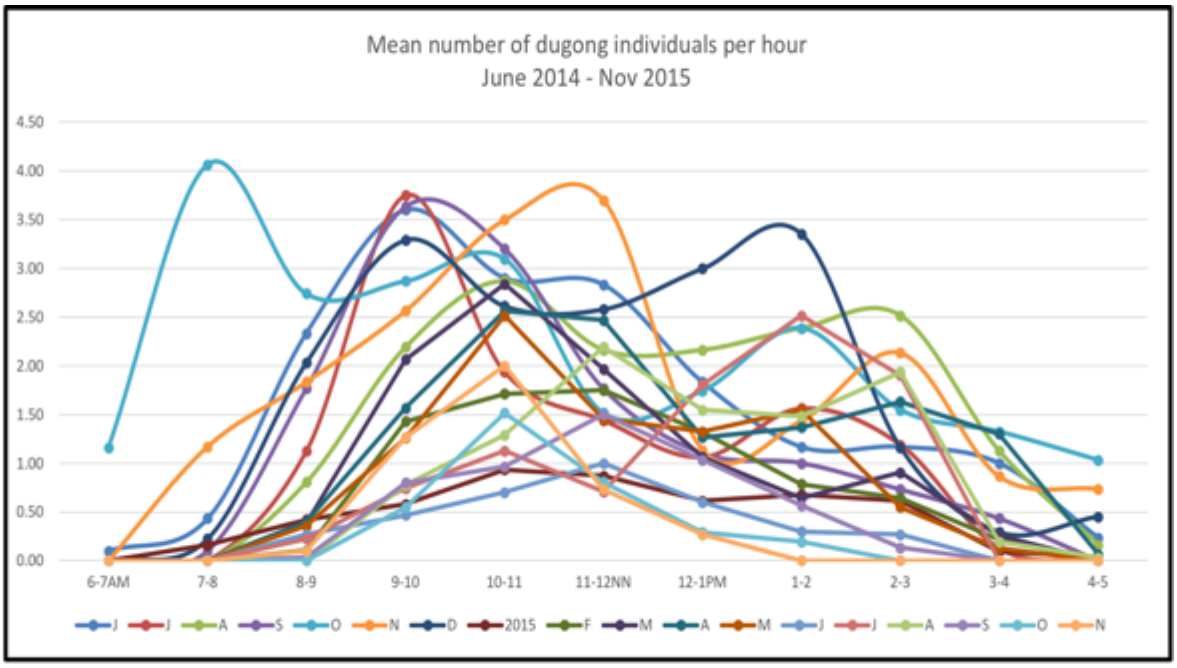


Fig. 79. Collated dugong sightings vs. time of day (June 2014 – November 2015) in Malita, Davao del Sur.

In addition, there was significantly greater number of dugong sightings recorded in 2014 than in 2015 (Fig. 80). These sightings did not show a clear pattern of highs and lows, unlike in 2015 when the bimodal distribution occurred in summer and in the

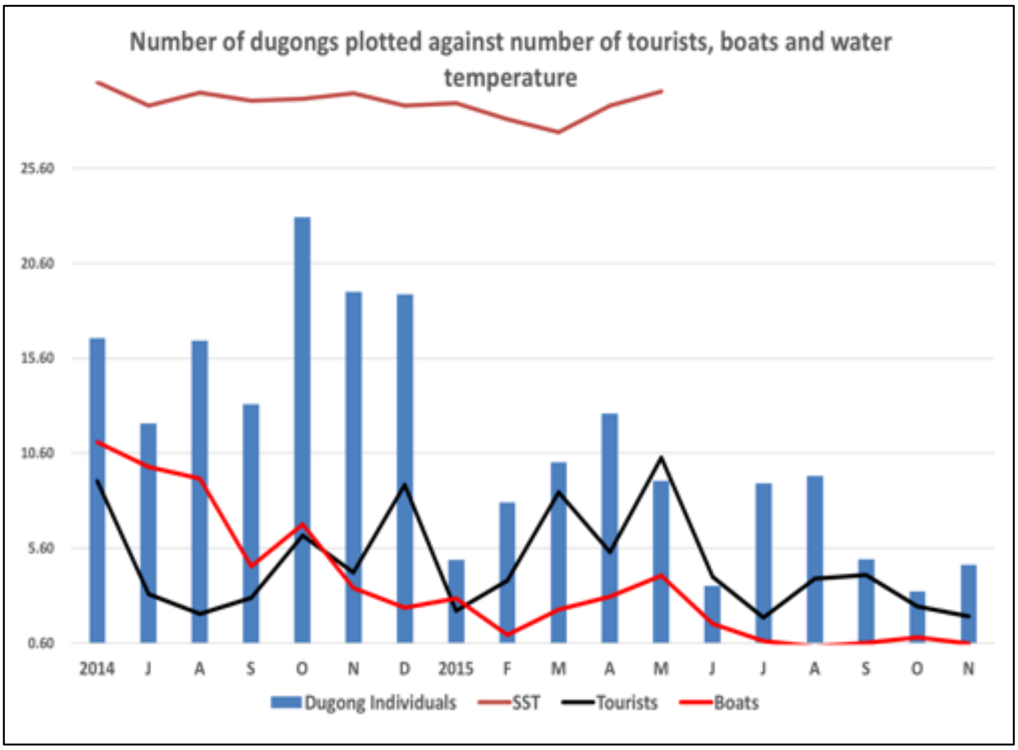


Fig. 80. Dugong sightings plotted against sea surface temperature (SST) and number of tourists and boats (Malita, June 2014-Novemebr 2015)

wetter months. Interestingly, significantly higher SST occurred in 2014 when compared to 2015, although this may not be true during the other parts of the year in 2015. Interestingly, dugongs appear to “like” more people although they seem not to “like” the presence of boats. Hence, the implications of the results of the monitoring to policy on dugong and seagrass conservation and tourism (dugong watching) are immense.

Coastal Community Vulnerability Index (CCVI)

The scientific findings of the project (Years 1 and 2), coupled with the socio-economic data obtained from the sites (Year 3) were also synthesized and analyzed in the context of a Coastal Community Vulnerability Index (CCVI) (Orencio and Fujii 2012). This topic was not explicit in the original proposal but here emphasized to compensate for the deletion of some scientific parameters (i.e., trophic dynamics) and cutting short the underwater surveys for dugong feeding trails and quantification of seagrass dynamics. The socio-economic data used in formulating the index were gathered from onsite interviews and Focus Group Discussions (FGDs). The results substantially inputted into the local disaster risk reduction and management plans as complements to aspects which the latter did not touch. Hence, shown in Fig. 81, only seven of the 21 sub-factors required for full accounting of the index were undertaken by the SMBP (with asterisks in the figure, modified from Orencio and Fujii 2012). These are: availability of seagrass and mangrove ecosystems, relative frequency of natural hazards, importance of seagrass and mangrove ecosystem services, access to these services, availability of food from seagrass beds and mangroves, participation of communities, and institutions with environmental initiatives. Unfortunately, only one meeting with the local NDRRMC and concerned LGUs to integrate the project data with theirs was held, despite this project’s insistence to pursue such important undertaking.

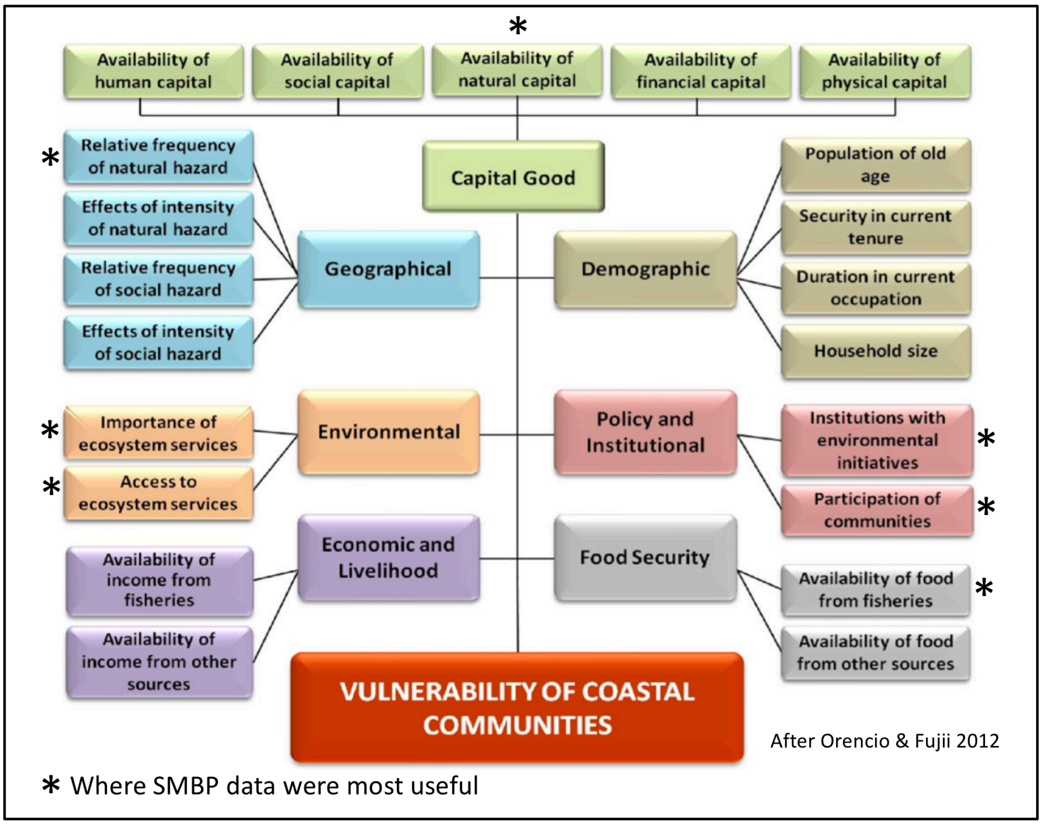


Fig. 81. Indicative framework of major factors, and their respective sub-factor Indicators that comprised the composite index used for analysis of coastal community vulnerability (Modified from Orencio and Fujii 2012)

Observations on variations in the seven sub-factors with relatively high values that directly contributed to CCVI measurements supported the idea that inherent conditions exist between municipalities. More importantly, these variations presumably contributed to their level of vulnerability to coastal hazards. Generally, at the four sites, slight variations occurred in the degree of availability of seagrass ecosystems, frequency of natural hazards, importance of seagrass services, and availability of food from the beds (Fig. 82). Significant differences, however, occurred in the values for access to seagrass resources, participation of communities, and institutions with environmental initiatives.

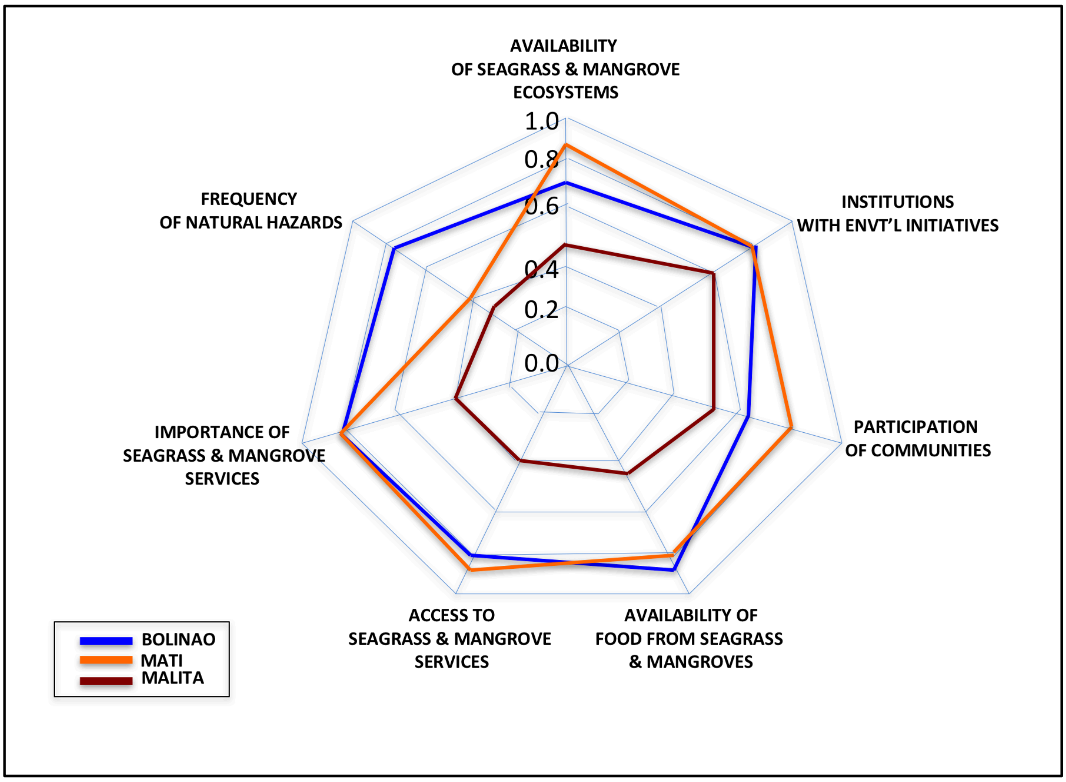


Fig. 82. Mean aggregated sub-factor values and their level of contribution to overall vulnerability scaled from 0 (least contribution) to 1 (most contribution) as indicator values for each site

Malita separates out in terms of practically all vulnerability sub-factors, when compared to Bolinao and Mati. It is also the least developed among three sites. The latter two municipalities substantially recognize the importance of seagrass and mangrove services, since a large percentage of coastal folks depend upon the resource for their fisheries needs (Bolinao) and tourism and recreation (Mati). On the other hand, seagrass beds in Malita are small, inaccessible, knowledge about it comes almost entirely from the few research initiatives of e.g. SPAMAST in line with coastal conservation. It can be assumed therefore that the vulnerability of the municipalities, with the exception of Bolinao which is along the path of typhoons entering the Philippine Area of Responsibility (PAR), is apparently highly controlled by their high level of dependency on fisheries for food and income, knowledge and information from institutions, as well as their low participation in environmental management activities of institutions.

Conservation zoning plan for Mayo Bay

One of the issues critical in the development of coastal Mati is the proliferation of many unsustainable practices associated with the booming tourism industry. These practices include conversion of huge tracts of mangroves into fish ponds, mining, construction of resorts that disregard the setback law, beach water enclosures using rocks and cement, disposal of domestic wastes into the waters, jet skis, etc. The two bays in Mati that are the subjects of these concerns –Pujada Bay and Mayo Bay- yield marine species of high conservation value, which make the beaches nesting sites, and their seagrasses, feeding and nursery grounds, or simply playgrounds: dugongs, sea turtles, whale sharks, manta rays, and dolphins. Their mere presence would dictate that the bays should be protected. With the persistent campaigns of SMBP in collaboration with the Davao Oriental State College of Science and Technology (DOSCST), the local NGO caretaker, Amihan Boys and the Local Government Units, a zoning plan of the bays was conceived and operationalized. As a science support of the plan were SMBP's activities comprising assessment of the habitats and of the associated species of conservation value, the results converted into educational and advocacy materials. The base plan is given in Fig. 83. At present, a Municipal Ordinance, which included the plan in a broader coastal management has been drafted.

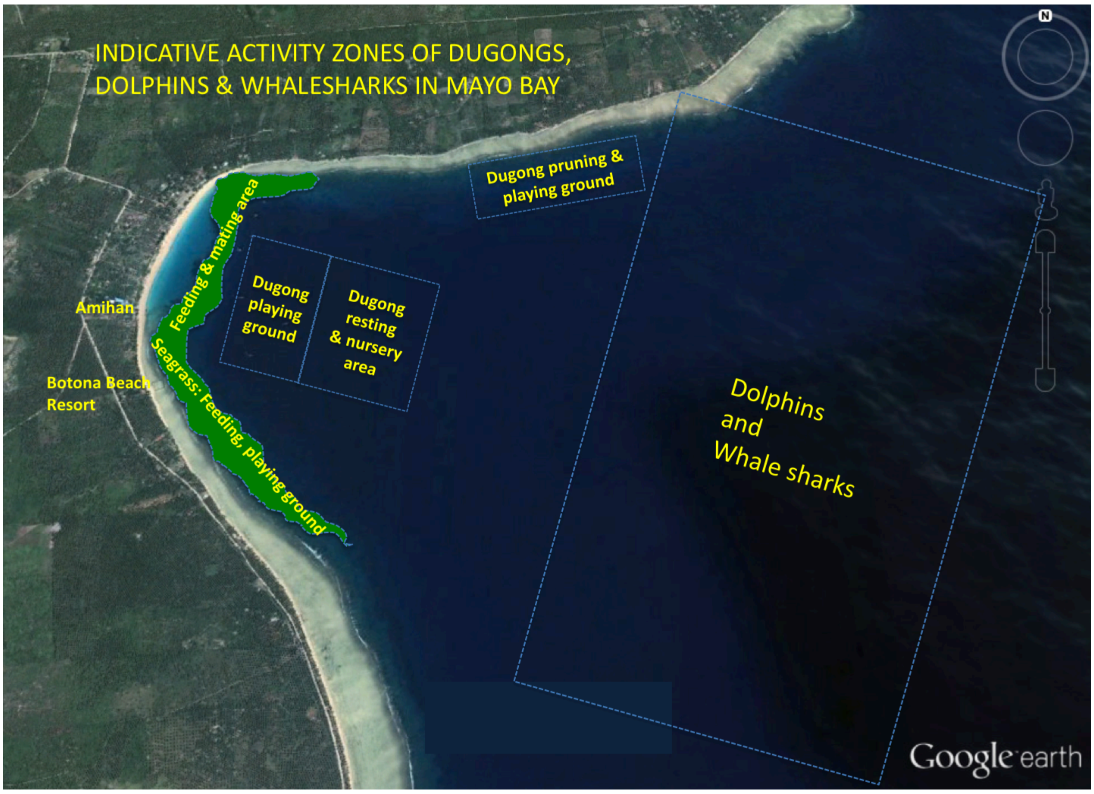


Fig. 83. Draft conservation zoning plan of Mayo Bay in Mati.

SMBP input into the land use plan of Abuyog

The focus of SMBP on seagrass and mangrove ecosystems has been a major consideration in the formulation of an enhanced Comprehensive Land Use Plan (Fig. 84) for the municipality of Abuyog, Leyte. On the part of the local government, the plan is a disaster risk mitigation and adaptation mechanism of the communities, a need, which was dictated by the devastation wrought by the Super-Typhoon Haiyan on the municipalities last 8 November 2013. SMBP was requested to inform the populace especially on the bioshield functions of the ecosystems as a 'special area study', train them on the basic methods of assessment and analysis, and advocate for their protection.

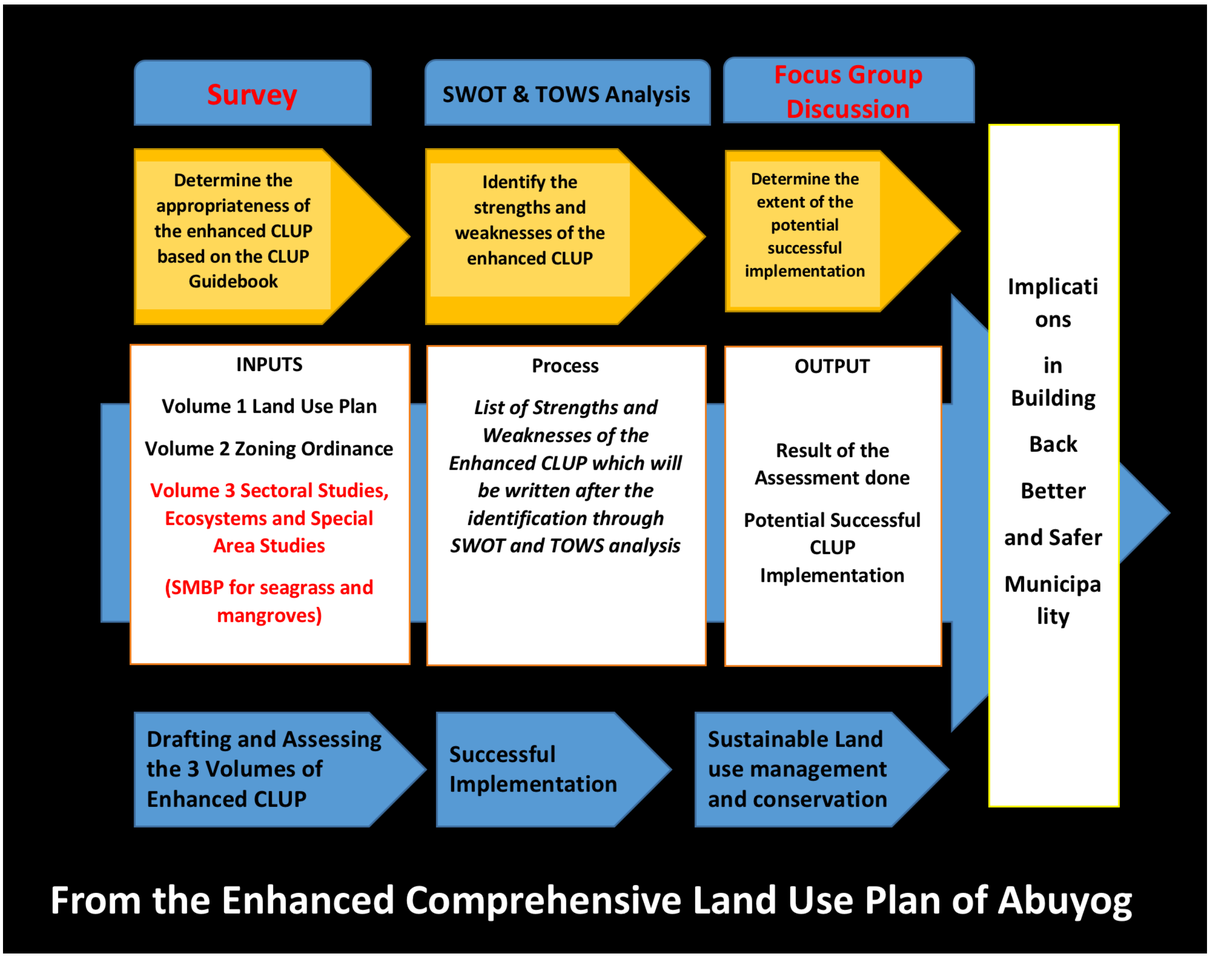


Fig. 84. The Enhanced Comprehensive Land Use Plan of Abuyog, emphasizing the role of seagrasses and mangroves as a 'special area study' (in red).

Framework of an Integrated Decision Support System (IDSS)

The project has provided a basis of a science-based tool in decision making. In order to initiate its development, the 29 on-site interactive actions with the local constituents were facilitated by the project (Appendix 1). These activities consisted of Focus Group Discussions, workshops, informal caucus, training courses, and a national conference. Indirectly or directly, they provided the stakeholders, both basic and applied insights on the importance and role of seagrasses and mangroves (and other coastal ecosystems) in the coastal zone. Backed by actual experiences gained from previous and current research projects of this writer, these knowledge and information input into a decision support system, the principal components of which, plus its salient features, and processes are depicted in Fig. 85 below. It essentially is undertaken in 9 steps, but is iterative in order to refine the outcome. It is of interest, that all stakeholders are (and should be) involved early on in its development through consultations. It was fortunate that in actuality, the IDSS as proposed was fairly completely understood and appreciated in most project sites, but was incompletely accepted in Batanes, primarily because the government decision makers at the latter site did not have the time (and the interest?) to know more about it.

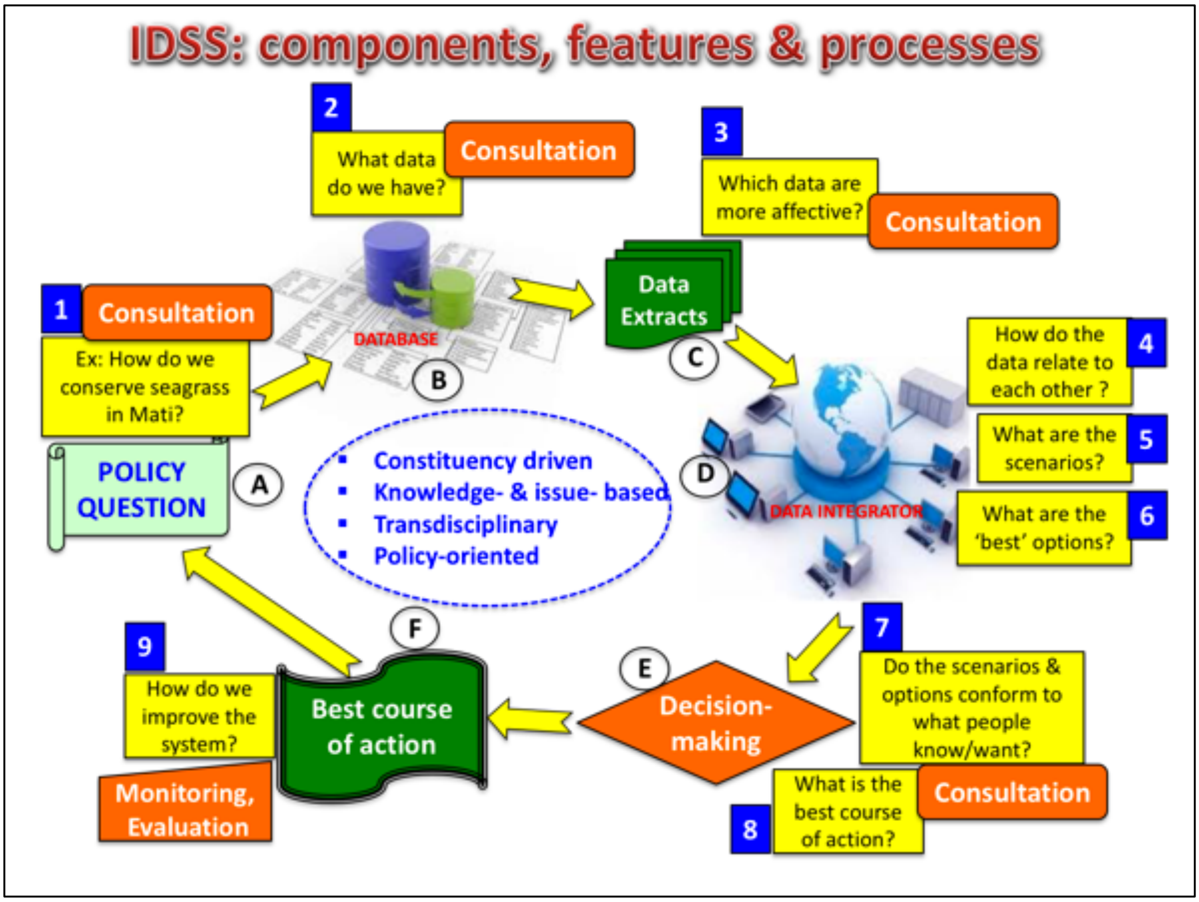


Fig. 85. The components, features and processes in an Integrated Decision Support System (IDSS). The numbers indicate the sequence to be followed.

Are seagrass and mangrove ecosystems 'bioshields'? The paragraphs that follow will strongly support the hypothesis that indeed, they are!

What is a 'bioshield'? Literally, a 'bioshield' is a biological protector. Hence, when we speak of seagrass or mangrove as a bioshield, we refer to the ecosystem's inherent functions to protect the coastal environment and its dependent populations by counteracting or mitigating the threats and negative impacts of both human-induced and natural forcing factors. This way, the seagrass and mangrove bioshield enhances the productivity of plant and animal communities, enabling them to adapt to stresses and be able to bounce back to its original or close to its original healthy state. This concept is shown in Fig. 86, emphasizing the role of projects and programs which study and assist the system in the process:

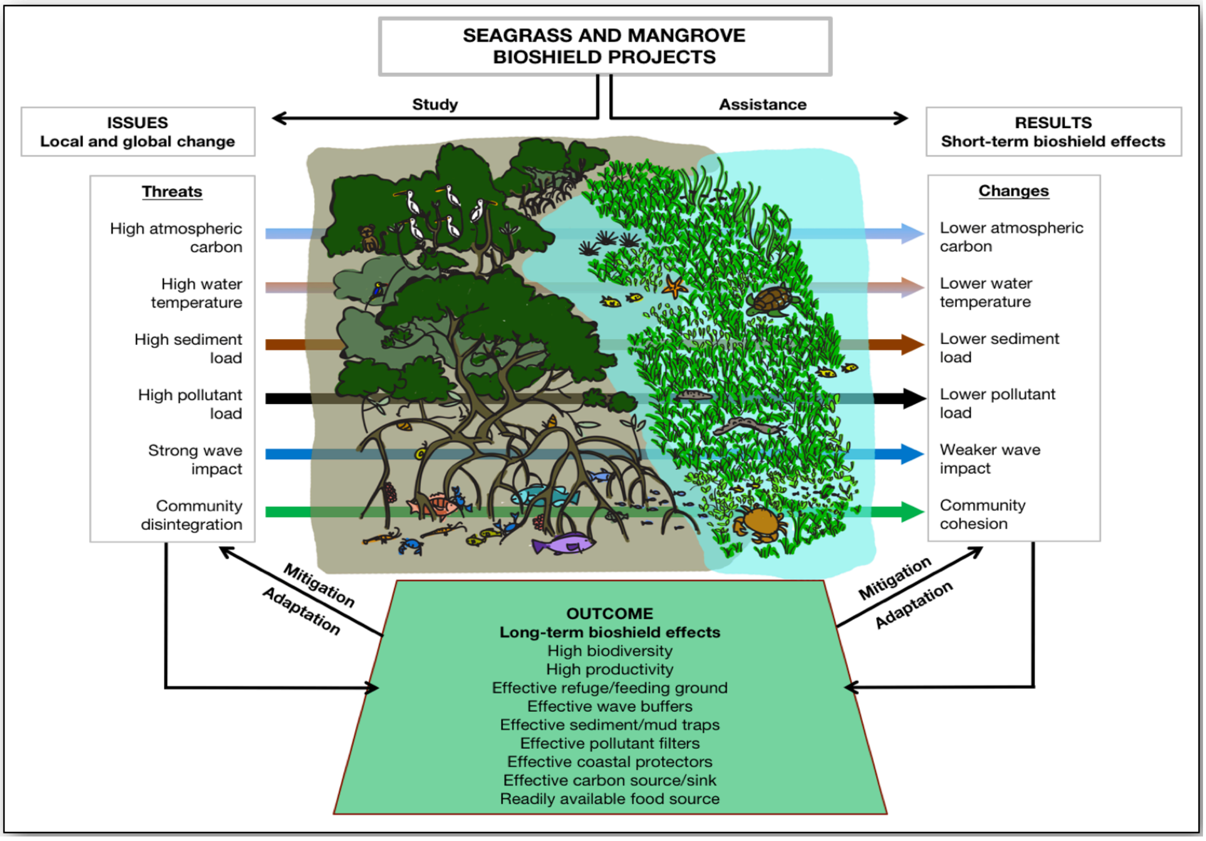


Fig. 86. The concept of seagrass and mangroves as 'bioshield' emphasizing the role of the studies and research undertaken by SMBP in the process.

At the SMBP sites, seagrass beds and mangroves were studied to ***elucidate the concept of 'bioshield' especially in relation to climate change and biodiversity conservation.***

How does a seagrass bed protect us from biodiversity loss? Seagrass and mangroves provide a three-dimensional structure wherein other smaller organisms can avoid predators, where nutrients are found in abundance especially for the juvenile stages of countless invertebrates and vertebrates, and where the structure provides additional substrates where organisms could establish and colonize. This way the ecosystems protect people from the loss of biodiversity -the ready source of food, medicine, income, hence, livelihood for most coastal populations in the Philippines and in tropical coasts.

How does it protect us from the impacts of climate change? Seagrass and mangrove ecosystems reduce the impacts of threats like high atmospheric carbon, high water temperatures, and strong wave impacts which, emanate from the current climate variability. Directly or indirectly, these threats result into the disintegration of communities. Once these threats are reduced, with the support of external initiatives like projects and programs of government, the inherent ability of the ecosystem to counteract stress and disturbances is restored. The buffering effects of intact seagrass bed and mangroves is able to prevent erosion or accretion of the sea floor and coastal fringes.

In the context of the SMBP, the strong arguments which lead to support our hypothesis that seagrass beds and mangroves are bioshields are given below:

Bioshield to associated biodiversity

In India, the seagrass meadows (e.g. Chilika and Palk Bay etc.) provide shelters and food materials to various threatened species such as dugong, manatee, sea turtles, sea horses and Irrawaddy dolphins. Increase of population of these endangered species was recorded with the increase of seagrass cover in Indian coastal waters. High calcification rates were observed in the surrounding waters of seagrass ecosystems, thus facilitating a luxurious environment for coral growth.

Seagrass response to eutrophication

We analysed 21-month data on seagrass species composition, % cover, shoot density, biomass and leaf growth rates from four 50 x 50 m quadrats established along a 5-km gradient in nutrients, chlorophyll-a, and siltation in the area. Results show that some definite biological reactions (or bioshield functions) along the gradient can be summed up in the following (Fig. 10, from Section 3, reproduced here for ease in analysis). From low levels of the 'stressors' ('less stressed' condition) to high levels ('more stressed' condition): (1) There was a marked decrease in the number of seagrass species; (2) In terms of cover and

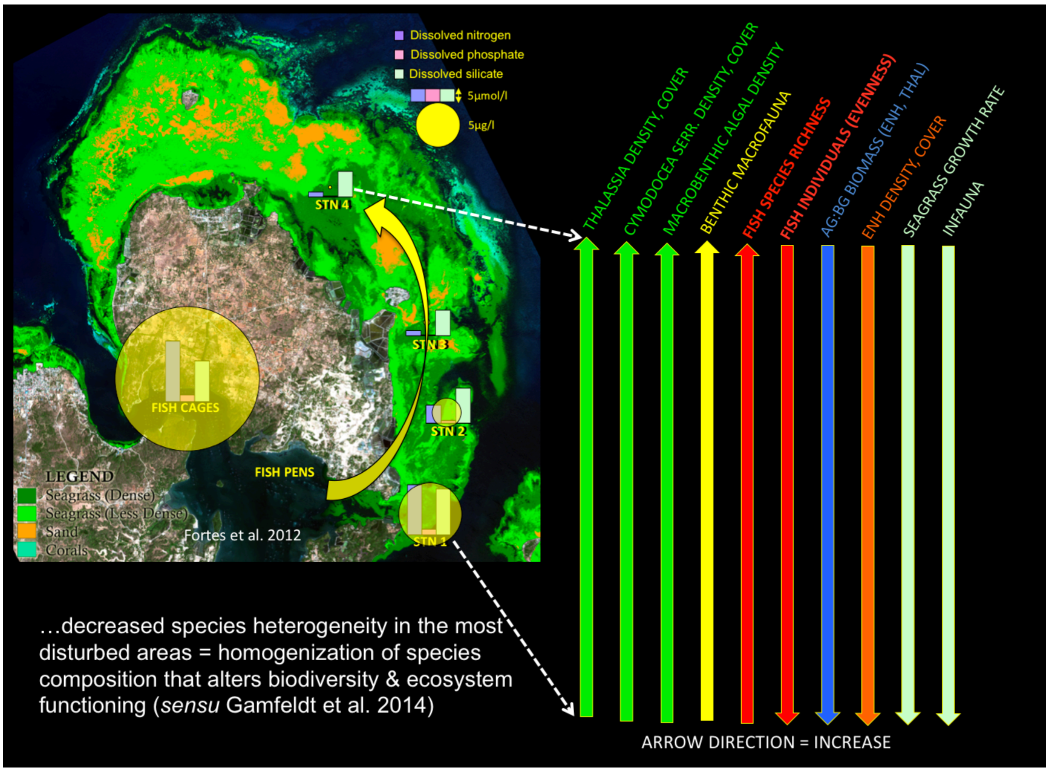


Fig. 10 (from Section 3). Collective response of seagrass bed components to gradients in dissolved N, dissolved phosphate, silicate and chlorophyll-a in Bolinao, north-western Philippines.

density, *T. hemprichii* and *E. acoroides* exhibited opposite responses, with *T. hemprichii*, showing marked decreases in both parameters, while *E. acoroides* showed increases; (3) In terms of biomass, ratios between the above- and belowground biomass in each of the two species showed general *(E. acoroides)* but a marked (*T. hemprichii*) increase; and (4) In terms of leaf growth rate (cm day^{-1}), growth of both species was faster under 'more stressed' than in 'less stressed' conditions. However, under both conditions and regardless of the period, *T. hemprichii* consistently had much slower rate of growth than *E. acoroides*. Based on increasing sensitivity (decreasing resistance) to a combined effect of nutrients, chlorophyll-a and siltation, we propose the following sequence of the species: \

Enhalus acoroides > Thalassia hemprichii >Cymodocea rotundata >

Halodule uninervis > C. serrulata > Halophila ovalis > Syringodium isoetifolium.

The results are a collective response of the seagrass ecosystem to a combined effect of eutrophication and siltation. They support earlier studies on the impact of fish farming on seagrass (Holmer et al. 2002, Marbà et al. 2006, Rountos et al. 2012) or of siltation from the rapid changes in land use patterns in the coastal zone (Fortes, 2001, Short and Burdick 1996, Terrados et al. 1999), or its induction of changes in the sediments by increasing the concentration of nutrients, organic matter and water content (Kamp-Nielsen et al. 2002, Halun et al. 2002), changing the redox condition of sediments favourable for benthos (Marba et al. 2010), or affecting indirectly the trophic structure of the community by enhancing an increase in grazer population density (Rountos et al. 2012). Hence, these results point directly to the inherent ability of the seagrass ecosystem to act as bioshield, hence, they protect nearby reefs and coastal communities dependent upon them from the undesirable impacts from fish cage and fish pen effluents (e.g. nutrients and silt). Despite the presence of the stressors, this protection can be translated into the ecosystem's ability to support high seagrass, fish and macroinvertebrate biodiversity and, in the case of *E. acoroides* and *T. hemprichii*, selectively sustain the ecosystem functions even at the most stressed part of the gradient. On the other hand, this is based on the assumption that the nutrients are taken up by the benthos, so that increase in dissolved oxygen away from the aquaculture may not necessarily be a bioshield effect; it could also be due to primary production consuming the extra nutrients as well as dilution in the water column. Differentiating between the two effects will be done with a model to predict which one effect is dominant or is minor.

Particle tracking simulation

Particle tracking simulation further supports our hypothesis that seagrass beds are an effective bioshield against eutrophicaiton and or sedimentaiton. This they do by blocking or holding back or absorption of excess nutrients discharged from nearby fish cages and fish pens especially during the wet season when the wind (and current) direction is northeasterly (Fig.87). The three –dimensional structure of the beds also facilitate adherence of sediments (silt) on the surfaces of the bed components, thereby reducing the amount that would otherwise be detrimental to offsite biodiversity.

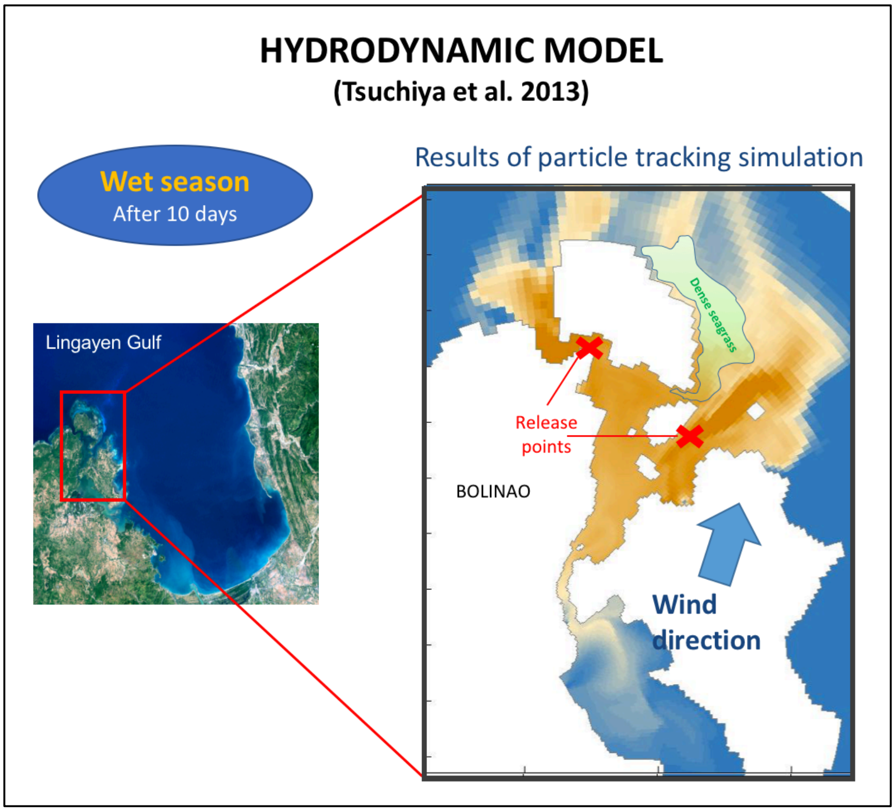


Fig. 87. Simulation showing how seagrass beds act as bioshield in Bolinao (After Tsuchiya et al. 2013)

In India, transport of nutrients to the coastal waters through diffusive and advective processes often causes nutrient enrichment of the coastal waters. Seagrass ecosystems can process these nutrients up to certain threshold concentrations and prevent bio-physical accumulation of dissolved nutrient in the water column. Additionally, fast settlement of riverine particles in the seagrass meadows, stimulate the transfer of particulate organic carbon to the bottom sediment and causes effective long term storage of it. In seagrass meadows, sedimentation rate ranged from 6.5 – 6.9 mm yr-1 and mass accumulation rates ranged from 1.06 – 1.12 g cm-2 yr-1. In non-seagrass coastal waters under similar conditions, sedimentation rate and mass accumulation rates were calculated to be 5.7 mm yr-1 and 0.93 g cm-2 yr-1, respectively. In seagrass bed, the organic carbon (OC) concentration varied from 0.79 - 0.96%, leading to the burial of OC at a rate of 6.97 – 8.99 mol C m-2 yr-1. The rate of sedimentation in seagrass meadow was almost 1.5 times higher than that observed in major Indian mangrove ecosystems. Rapid settlement of riverine particles in the seagrass meadows, results relatively slower decay and regeneration of dissolved nutrients.

Enrichment of dissolved nutrients often causes algal bloom in the coastal waters. These algal blooms are associated with eutrophication events which often lead to oxygen depletion and lowering of pH (ocean acidification) in the coastal water. Eutrophication, coastal anoxicity and ocean acidification are the three major threats to the coastal biodiversity, coastal fisheries, global economy and climate change. Eutrophication of coastal waters is largely attributed to increased loadings from land-based sources containing nitrogen and phosphorus (e.g., sewage, chemical fertilizers) as well as micro-nutrients such as silica.

Findings from recent studies showed that eutrophication can enhance ocean acidification and coastal anoxia. Excess organic matter production (e.g. algal blooms) in coastal and oceanic environments eventually undergo microbial degradation, whereby O2 is consumed and CO2 is produced in the water column through microbial respiration which can result in a drop in pH. This source of CO2, in addition to inputs from the atmosphere, exacerbates the acidification problem and has been modelled, for example, in the Gulf of Mexico and the Baltic Sea, to be more than additive in seawater at intermediate to higher temperatures resulting in decreased pH values of 0.25 - 1.1 units.

In India mangroves and salt marsh ecosystems occupy 4628 km2 and 1611 km2, respectively. Additionally an area of 24,136 km2 is covered by the inter-tidal mudflats. The average carbon sequestration rate by Indian mangroves is estimated to be 0.15 gTC. $km^{-2}.^{-1}$. Once sequestered, the carbon remains in the sediment for long time period under low oxygen availability. Additionally, mangrove traps large amount of anthropogenic nutrients from the estuarine and coastal water. Ammonium is the primary form of nitrogen in mangrove soils, in part as a result of anoxic soil conditions, and tree growth is supported mainly by ammonium uptake. Ammonium and inorganic P are the two most important precursors for the formation of algal bloom and associated coastal eutrophication.

By actively removing and inorganic N and P up to a certain limit, both mangrove and seagrass ecosystems act as a bioshield against nutrient enrichment and associated phenomenon in the coastal waters.

Predicted response of seagrass to climate change effects

In relation to the predicted impacts of climate change (e.g. rise in sea level, increase in CO2 in the atmosphere and water or acifification and rise in temperature), seagrass ecosystem could be a potential winner (Fig. 88). With sea level rise, the bed could just adjust upward, while its deeper edge is being eroded, so, the net effect is potentially nil. The same happens in relation to CO2 increase. Seagrass is a photosynthesizer, requiring oxygen in food manufacture, thereby lessening the amount of the otherwise harmful gas from the atmosphere and water. This process counteracts the reduction in calcification due to the acidic medium. With seawater warming, the fast-growing seagrass is given more subsidy to expand the bed through more reproduction. This is counterbalancing the effects of respiration. Hence, the net impact of global warming on seagrass is potentially zero. With slight variations especially in time scale involved, some of the statements above could be said for mangroves.

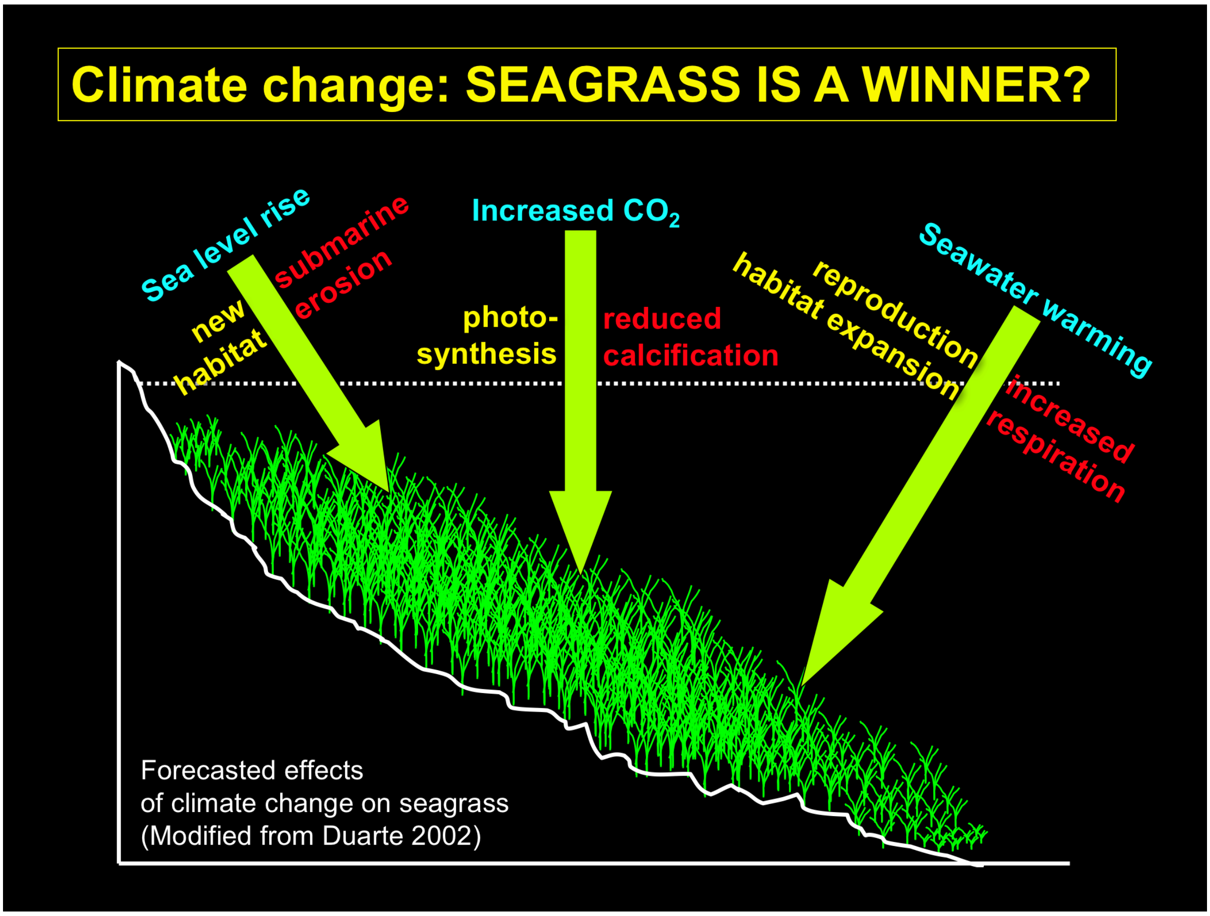


Fig. 88. Seagrass beds are predicted to sustain its ecosystem functions in relation to climate change effects.

In India, reduction or prevention of greenhouse gas emission to the atmosphere is the most important step for the solution of Climate Change Mitigation. Seagrass ecosystems have tremendous potential for C-Sequestration and long term storage. Seagrass along with mangrove and salt marsh account of upto 70% of Organic carbon in the Marine realm. 1 square km of a healthy seagrass meadow in the Indian coastal waters can store as much as 13.94 Gg C in the top 1 meter of the sediment. Similarly, 1 square km of a healthy seagrass meadow can sequester 0.44 Gg C in 1 year. A comparison between the net community productions (NCP) reported from various seagrass meadows around the globe was made and it was observed that the calculated mean NCP values from Palk Bay seagrass meadows (99.31±45.13 mM C m^{-2} d^{-1}) were well above the global mean NCP (27.17 mM C m^{-2} d^{-1}) reported from seagrass meadows (Duarte et al. 2010).

The study carried by the National Centre Sustainable Coastal Management (NCSCM) indicated that highly productive seagrass systems not only capture atmospheric CO_2, but they process large amounts of inorganic N and P, which are incorporated as the food material during the day time photosynthesis process.

Seagrass-mangrove connectivity

The coastal habitats (seagrass beds and mangroves) are closely connected by physical processes, nutrient transfer, animal migrations, plant dispersal, and human impacts. These subtle interconnections have become the subject and focus of major programs in Integrated Coastal Management (ICM) within a 'social-ecological system' framework, because they link the systems tightly, thus, acting as a shield to protect the coast, participation of the communities as a major contributing factor. These interconnections between the systems act as a 'bioshield', a feedback control mechanism maintaining coastal ecological processes and protecting the ecosystems and their services in the process (Fig. 89). Hence, with seagrass and mangroves, 'you destroy one, you destroy the other'.

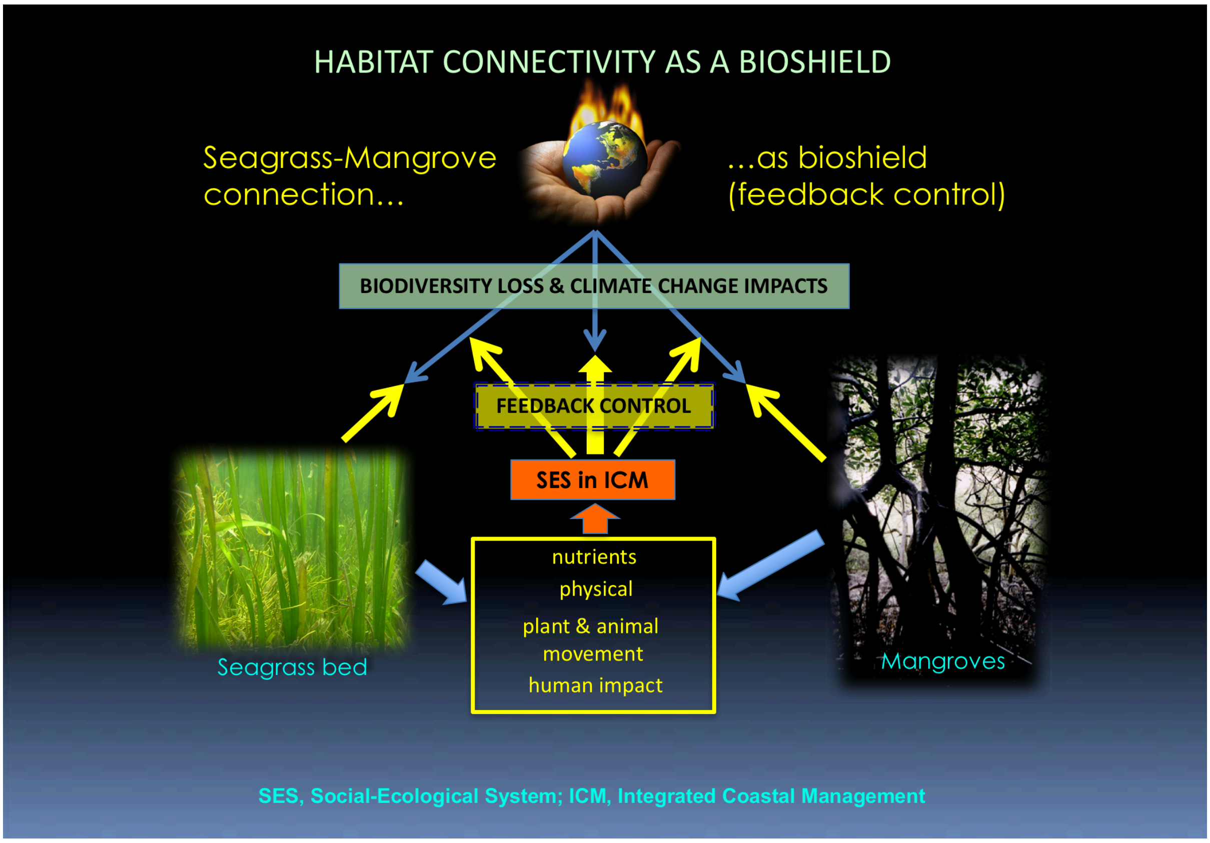


Fig. 89. Interconnections between seagrass beds and mangroves act as a 'bioshield' function protecting the coasts from biodiversity loss and climate change impacts

Mangroves as physical buffers

Along the coasts of the project study sites, a common scene are villages among mangroves or houses and small huts along shore fringes protected by mangroves (Fig. 90). These forests are not only important but crucial for the coastal areas because of their bioshield or stabilizing function in such highly populated zones, where the slightest ecological imbalance will take a heavy toll. Mangroves not only help in preventing soil erosion but also act as a catalyst in reclaiming land from the sea. The benefits we derive from mangroves as forests especially their value as "protector of shorelines" is enough to convince us to conserve them.

Fig. 90. Small houses abound along costs where these are protected by mangroves

Future Directions

This section of the report highlights the role of the SMBP, through its major findings, in providing guidance to science and policy vis-à-vis coastal conservation in the future. We thus enumerate these **"SMBP Guideposts"** below:

1. Further water quality assessment is necessary in plantation areas with direct effluent discharge to rivers. In addition, more in-depth investigations are needed if the suspected freshwater source is indeed groundwater. This would pose additional complications in terms of water quality analysis, and therefore a more comprehensive water cycle assessment will be necessary.
2. In Chilika Lagoon, further studies during the dry season (March to May) is necessary to determine the contribution of seagrasses to the trace gas emissions from the lagoon.
3. Based on increasing sensitivity (decreasing resistance) to a combined effect of nutrients, chlorophyll-a and siltation, we propose the following sequence of the species: *Enhalus acoroides* > *Thalassia hemprichii* >*Cymodocea rotundata* > *Halodule uninervis* > *C. serrulata* > *Halophila ovalis* > *Syringodium isoetifolium*. This would guide coastal developers and entrepreneurs options as to which species to utilize, conserve, or remove. The tolerance threshold of these species to turbidity and the biodiversity associated with the beds, while known for Bolinao, has been further supported by data from SMBP from other sites. In addition, in using seagrass to shield the coasts from erosion and impact of waves and wind, the species occurring first in the series are more desirable.
4. In relation to the collective response of seagrass communities to the gradients in nutrients and sedimentation, we propose that changes in the biological parameters in the study be considered in the search for indicators useful for a better understanding of fish farm, siltation and other disturbances' effects on the coastal environment.
5. The average carbon sequestration rate by Indian mangroves is estimated at 0.15 gTC. $km^{-2}.^{-1}$. Indonesia's blue carbon is a globally significant and vulnerable sink for

seagrass and mangrove carbon. This is substantial if one considers the amount of CO2 that the ecosystems could remove from the atmosphere, helping mitigate climate change impacts. This topic and research on it should be given more importance and activities on it intensified.

6. The mono-specific plantation of *R. stylosa* significantly reduces species richness and variety of the mangrove vegetation. The policy implication of this finding is worth looking into in the light of massive financial and institutional support the current mangrove reforestation program of the Philippines and Indonesia get, using only *Rhizophora.*
7. Future mangrove restoration schemes should utilize several and especially the indigenous and dominant species, maintain sufficient space between trees for normal growth, and create tidal creeks, in order to recover some of the key ecosystem characteristics and services of natural mangrove forests.
8. Prospectively, the project utilized the metabolomics approach in assessing both anthropogenic and environmental impacts on the seagrass species *Halophila ovalis*. This will offer seagrass researchers an additional analytical tool for use in seagrass monitoring. If successful, this study will provide a wealth of information regarding the response of seagrasses to environmental stressors. In addition, the metabolites identified in this study will also enable further exploration into seagrass biology and physiology. In a wider scale, utilizing genomics, transcriptomics and proteomic data together with metabolomics data can lead to the development of biological model for seagrasses in the future.
9. Future works on seagrass and mangroves should adopt the integrated approach and to include more targeted research on seagrass trophic systems, monitoring of environmental indicators that alert managers to early signs of eutrophication, remediation of existing eutrophic systems through nutrient reduction mechanisms and "…planning policies that identify and afford greater protection to ecologically-important habitats such as seagrass."
10. In coastal management, the priority should be to enhance remaining seagrass and mangroves and recover areas in sheltered waters that were illegally converted to private ownership and convert them again to mangroves or seagrass. This would improve the environment by recovering the ecosystem services of these vegetation including sequestering excess nutrients and fine sediment as well as providing a refuge for wild life.
11. In the light of project outcomes coupled with current findings of relevance to SMBP thrusts, we argue in favor of a growing consensus, which places seagrass-mangrove system conservation as priority, developing a model of the ecosystems focusing on their 'bioshield' functions in mitigating local and global changes along Indo-Pacific coasts.

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Appendices

Appendix 1. Activities undertaken at the project and other sites, emphasizing the topics where stakeholders needed more understanding, support and action.

Location	Title/ Type of Activity	Beneficiaries	Remarks
PRIMARY PROJECT SITES **Sites where both scientific and community-oriented activities were regularly undertaken (as approved)**			
Bolinao, Pangasinan			
(3 Oct 2011)	1st Consultation on the SMBP Project	17 participants: Local Gov't Units (7), Education (Secondary Level, 2), Environment (2), Fisheries (2), Resort Association (2), Fishermen's Association (2)	Introduced the project, identified where it can help in coastal development plans, how the latter could help the project; full support from sector obtained
(Jan 2012)	"Training Course on Water Quality Monitoring Using the Pack Test"	7 participants: 3 graduate students, 2 undergraduate; 2 environment sector	Designed for freshwaters, so refinement is still needed
(8-9 May 2012)	"Participatory Vulnerability Assessment" (Training Course)		Well accepted since seagrass is the most familiar resource in the area
(21 Sept 2013)	"Can Bolinao Prevent Fish Kills and Declines in *Padas* production?" (Focus Group Discussion)	38: Local Government Unit (6), fish cage/pen industry associations (7), fisheries sector	Audience accepted their 'mistake' but can't give up source of livelihood; question arose when argued that seagrass beds

		(4), environment (7) APN Project members (5) fish cage operators (2), giant clam, MSI projects (7)	should no longer be nurseries for giant clams
Mati, Davao Oriental			
(13 Dec 2011)	Introduction and use of the Pack Test for water quality monitoring	4 participants: 2 graduate students, 1 undergraduate; 1 environment sector	Oriented participants on the nature, mechanics and use of the Pack test
(15 Dec 2011)	1st Stakeholders' Consultation	38 participants: Local Gov't Unit (8), academe (5), tourism (3), Peoples' Org. (8), NGO (2), environment (3), Fisheries (2), Resort Owners (7),	Introduced the project, identified where we could help each other attain common objectives; identified graduate students to work on project topics for master's, PhD thesis; full support from sectors obtained
(5-7 Nov 2013)	"The APN-SMBP: Addressing Mutual Concerns In Mati, Davao Oriental" (Focus Group Discussion)	44: environment (15), students (11), tourism (6), NGOs (7) and Peoples' Organization (5)	Interest aroused on seagrass and mangroves as protector against storm surge
(25 Feb 2014)	"The APN-SMBP: Addressing Mutual Concerns in Mati, Davao Oriental" (Focus Group Discussion)	DOSCST Officials (3), graduate students (5), undergraduates (12)	To introduce the bioshield concept in the context of local ICZM
(5 Dec 2014)	"Coastal Ecosystems are the base of our livelihood and tourism resources" (Informal Discussion)	DENR (3), DOSCST (3), NGO (5),	Concern about the bay is expressed, especially in relation to the planned tourism activities; needs

			technical help
(16 April 2015)	"Initial Zoning Plan: Conservation and Sustainable Use of Mayo Bay and Its Resources" (Focus Group Discussion)	SB Members (5), Mayor's Office (5), DOSCST (7), Coast Guard (4), Tourism (3), DENR (4), BFAR (3), Amihan Boys (6), media (2)	The need to have a zoning plan for the bay is boasted by the drafting of a management plan integrated with the tourism master plan
(23 June 2015)	"Zoning Mayo Bay: Transforming Threats into Opportunities" (Focus Group Discussion)	Mayor's Office (3), SB Members (7), DOSCST (5), Coast Guard (6), Tourism (2), MENRO (2), BFAR (5), Amihan Boys (5), media (2)	Enough legislations exist for the protection of Mayo and Pujada Bays, but the implementation is the problem
(4 Nov 2015)	"A Road Map to a Sustainable Coastal Tourism and Livelihood Development in Mati" (Focus Group Discussion)	SB Officials (7), Mayor's Office (4), academe (7), NGOs (5), Environment (7), Fisheries (4), Tourism (5), Barangay (4)	Very positive feedback from the participants, especially recognizing the project's intention and concrete actions for Mati
(5 April 2016)	"How the Seagrass-Mangrove Research Project Outputs Benefit the Development Sectors of the City of Mati" (Focus Group Discussion)	<u>Morning</u> (DOSCST): Officials (4), teachers (5), students (graduate and undergraduate) (17) <u>Afternoon</u> (Municipal Hall): SB Officials (4), Mayor's Office (3), academe (6), NGOs (7), Environment (4), Fisheries (3), Tourism (4), Barangay (7)	Concern was raised regarding the possibility of a drastic change in government administration. How to address this issue became the focus of discussion

Malita, Davao del Sur			
(17 Dec 2011)	Introduction and use of the Pack Test for water quality monitoring (Training Course)	6 participants and 4 observers mostly graduate students	Oriented participants on the nature and use of the Pack test
(5 Nov 2013)	"The APN-SMBP: Addressing Mutual Concerns in Malita, Davao del Sur Part 1" (Focus Group Discussion)	SPAMAST Officials (3), graduate students (4), undergraduates (6), teachers (7)	To introduce the bioshield concept in the context of local ICZM
(26 Feb 2014)	"The APN-SMBP: Addressing Mutual Concerns in Malita, Davao del Sur Part 2" (Focus Group Discussion)	SPAMAST Officials (5), graduate students (8), undergraduates (11), LGUs (4), community (3)	To follow up discussions focused on seagrass as bioshield in relation to local issues e.g. power plant
(14 April 2015)	"Role of APN- SMPB Project & SPAMAST in The Sustainable Coastal Development of Malita, Davao Del Sur" (Focus Group Discussion)	SPAMAST officials (2), students (11), high school teachers outside SPAMAST (11)	Most of the information available to the participants are inaccurate and too general, since they come from the media
(9 Dec 2015)	"Seagrasses and Mangroves: Protecting and Sustaining Our Environment, Tourism and Livelihood" (Focus Group Discussion)	Barangay Captains (5), SB members (7), tourism (3), Power plant (2), SPAMAST Officials (7), graduate students (7), NGO (2), undergraduate students (8), CHED (4)	Requests more technical help to address the issue regarding the power plant's likely impacts
(5 May 2016)	"How the Seagrass and Mangrove Research Project Outputs Benefit the	CHED (4), Barangay Captains (4), tourism (3),	Request for immediate follow up of project efforts, materials

	Development Sectors of the Municipality of Malita" (Public Consultation)	Power plant (2), SPAMAST Officials (5), graduate students (7), undergraduate students (11), other schools (7), DENR (2)	for reference; acknowledges the project's help and commitment
SECONDARY PROJECT SITES (Philippines) Sites where the project was invited to present its outcome and only the community-oriented activities were undertaken (not originally scheduled)			
Batan, Batanes (12 April 2016)	"Coastal Ecosystems Mitigate the Impacts of Environmental Change in Batanes" (Focus Group Discussion)	PENRO (9), academe (2) Tourism (2)	Office personnel enthusiastic because seagrass and mangroves are not known in the area
Boracay, Malay (7-9 Sep 2015)	"SMBP: How it can help protect the coasts and prevent green tides in Boracay"	28 attendees: LGU (5), NGO (11), Resort Owners (4), SMBP (4), coast guard (4)	Audience particularly surprised in seagrass producing their white sand, could prevent green tides
San Lorenzo & Sibunag, Guimaras (10 Dec 2013)	"Seagrass and Mangroves as Bioshields, Protecting your Coasts from Natural Hazards" (Level 1 Training Course for Field Practitioners)	27 attendees: Local Government Units (Governor's Office to Barangay) (12), NGOs (3), POs (4), community (4), teachers (4)	Found directly relevant due to oil spill of 2006 which destroyed their coasts
(11 Dec 2013)	"Seagrass and Mangroves as Bioshields, Protecting your Coasts from Natural Hazards" (Level 2 Training Course for Decision Makers)	25 attendees; senior officials of the LGU (decision makers)	Still found it difficult to accept the bioshield concept to be that useful; wants hard engineering instead
Puerto Princesa, Palawan (8 April 2014)	"The Municipality of PPC & the APN Seagrass-Mangrove Bioshield Project: Addressing	31 attendees: LGU Officials (led by the Mayor, 14), DA-BFAR (7), DENR	Mayor was very vocal about the misdeeds of some of her constituents;

	Critical Coastal Environmental Issues (No problems, only decisions to make)" (FGD)	(3),Tourism Council (2), media (1), academe (3), PSDS (1)	requests them to improve performance by heading advise from the project.
Tacloban (26-27 March 2015)	"The Role of Natural Ecosystems in Building Resilience of Coastal Areas" (Workshop)	28 Members of the Local Press and LGU Information Officers in areas affected by the Super-Typhoon in 2013,	Commitment was raised on the part of the participants to help via more proper information
Quezon City (3 Oct 2011)			Introduced the project, identified where it can help in coastal development plans, how the latter could help the project; full support from sector obtained
(26-27 May 2016)	"The National Seagrass-Mangrove Bioshield Conference" Conference)	Total = 92: Gov't (33), NGO (11), academe (46), Int'l (2),	Much new information on the topic was exchanged; Only 80 were expected
INTERNATIONAL VENUES Where project personnel shared project outcomes with international audience			
Indonesia (22 - 23 March 2014)	"Training on Seagrass Restoration Methods" (Training course and conference)	42 (15 participants and 27 observers): fishermen, teachers, village government, LSM, tourism from Lancang and Pramuka Islands, National Park of Kepulauan Seribu and lecturers from UI and IPB; observers from academe	Training needed to address pollution and erosion issues from resorts
Japan 14 May – 10 June 2015	Staff training in Japan on acoustical analysis of dugong calls and feeding sounds	Project Staff (1)	Training extended to research in Mati

China (Shanghai, 13-17 Oct 2013)	"Effects of mono-specific plantation of *Rhizophora* stylus on the mangrove community and landscape"	Project Researcher (T. Asaeda)	
China (Shanghai, 13-17 Oct 2013)	Seagrass-Mangrove Ecosystems: Bioshield Against Biodiversity Loss and Impacts of Local and Global Change along Indo-Pacific Coasts"	SMBP Researchers	
China (Sanya City, 7-14 Nov 2014)	"Dugong grazing in seagrass beds in Davao del Sur, Philippines"	Project Staff (casual) (Monica Sarceda)	Training lessons learned applied to current research
China (Sanya City, 7-14 Nov 2014)	"Seagrass Factor in Meeting the Conservation Challenges of the 21st Century in SE Asian Coasts: From Science to Action"	Project Coordinator (MDFortes, Invited Keynote Speaker)	Shared outcomes of the project

Appendix 2: Percent cover (%), density (shoot.m^{-2}), number of leaves (l.sh^{-1}) biomass belowground, and aboveground biomass total (g.DW.m^{-2}) of the study sites.

Remarks	Station		
	A	B	C
Percent cover (%)			
May 2011	21.33 ± 3.06	19.50 ± 7.81	18.17 ± 7.59
August 2011	22.17 ± 5.68	27.24 ± 8.62	22.17 ± 5.58
December 2011	12.33 ± 4.87	21.00 ± 8.35	12.07 ± 5.90
Density (shoot/m^2)			
May 2011	85.47 ± 2.89	40.13 ± 10.82	72.13 ± 26.36
August 2011	81.20 ± 18.44	77.10 ± 24.91	78.00 ± 18.64
December 2011	58.13 ± 17.82	82.67 ± 23.47	56.55 ± 20.72
Number of leaves			

May 2011 August 2011 December 2011	4.17 ± 0.29 3.67 ± 0.61 4.93 ± 0.78	4.10 ± 0.20 3.76 ± 0.79 5.13 ± 0.90	3.67 ± 0.15 3.87 ± 0.72 5.00 ± 0.85
Biomass belowground (g.DW.m^{-2}) May 2011 August 2011 December 2011	541.84 ± 89.96 494.64 ± 251.70 430.17 ± 185.40	387.65 ± 65.11 396.49 ± 191.08 558.57 ± 213.28	1,082.27 ± 698.37 486.51 ± 222.69 461.86 ± 259.84
Biomass aboveground (gDW.m^{-2}) May 2011 August 2011 December 2011	176.52 ± 16.35 241.38 ± 93.58 277.89 ± 102.24	140.01 ± 62.28 448.32 ± 195.80 480.49 ± 148.33	184.68 ± 91.22 271.20 ± 110.44 284.71 ± 164.39
Biomass total (g.DW. m^{-2}) May 2011 August 2011 December 2011	718.36 ± 91.74 736.02 ± 320.95 708.07 ± 248.40	561.00 ± 105.75 844.81 ± 380.43 1,039.06 ± 324.63	1,269.94 ±786.8 739.71 ± 275.31 732.61 ± 371.57

Appendix 3 : Growth leaves (cm.d^{-1}) of *E. acoroides* at the study sites.

Time	**Leaves No.**	**Station**		
		A	**B**	**C**
May	1	1.38 ± 0.08	1.71 ± 0.16	1.55 ± 0.13
	2	1.37 ± 0.06	1.87 ± 0.11	1.71± 0.04
	3	1.20 ± 0.27	1.63 ± 0.01	1.27 ± 0.34
	4	0.84 ± 0.34	0.81 ± 0.02	1.12 ± 0.66
	5	0.46 ± 0.33	0.07 ± -	0.18 ± 0.25
	6	0.04 ± -	-	-
August	1	0.88 ± 0.49	1.18 ± 0.63	0.65 ± 0.51
	2	1.52 ± 0.40	1.81 ± 0.25	1.38 ± 0.40
	3	1.50 ± 0.48	1.76 ± 0.31	1.38 ± 0.41
	4	0.73 ± 0.48	0.97 ± 0.55	0.70 ± 0.61

	5	0.49 ± 0.34	0.13 ± 0.13	0.40 ± 0.49 ±
December	1 2 3 4 5 6	0.78 ± - 1.07 ± 0.17 1.06 ± 0.17 0.98 ± 0.24 0.74 ± 0.29 0.51 ± 0.29	1.23 ± 0.28 1.20 ± 0.31 1.07 ± 0.35 0.66 ± 0.41 0.19 ± 0.06 -	0.40 ± - 1.06 ± 0.26 1.06 ± 0.24 0.92 ± 0.32 0.63 ± 0.33 -

Appendix 4: Production of leaves (g.DW.m^{-2}.d^{-1}) of *E. acoroides* at the study sites.

Remarks	Station		
	A	B	C
May 2011	3.99 ± 0.58	3.38 ± 1.12	3.37 ± 1.12
August 2011	3.80 ± 1.56	3.95 ± 1.18	3.61 ± 1.72
December 2011	2.69 ± 0.66	3.84 ± 1.13	2.32 ± 0.91

Appendix 5: Litter fall leaves (g.DW.m^{-2}.d^{-1}) of *E. acoroides* at the study sites.

Time	Remarks	Station		
		A	B	C
May 2011	Water column	0.49 ± 0.35	0.96 ± 0.74	1.14 ± 0.96
	Sediment	0.26 ± 0.16	0.86 ± 0.86	0.66 ± 0.36
	Total	0.75 ± 0.51	1.82 ± 1.53	1.79 ± 1.31
August 2011	Water column	2.46 ± 0.28	4.73 ± 1.42	-
	Sediment	1.05 ± 0.25	2.18 ± 0.53	-
	Total	3.51 ± 0.53	6.91 ± 1.43	-
December 2011	Water column	0.93 ± 0.10	4.96 ± 1.29	0.80 ± 0.12
	Sediment	0.99 ± 0.11	4.99 ± 0.50	0.89 ± 0.20
	Total	1.93 ± 0.21	9.95 ± 0.85	1.68 ± 0.32

Appendix 6: Percentage survival growth of seedling (%) transplanting of *E. acoroides* in the planting units (9 and 25 shoots.m^{-2})

Time (2011)	Unit 9 shoots.m^{-2}	Unit 25 shoots.m^{-2} (%)
July	88.38 ± 4.37	90.73 ± 1.69
August	90.91 ± 6060	88.62 ± 3.17
September	87.88 ± 5.46	91.87 ± 1.41
October	85.86 ± 4.63	95.45 ± 1.23
November	94.95 ± 3.50	94.47 ± 0.75
December	94.44 ± 3.15	97.56 ± 0.98

Number of species and total number of individual fishes in the natural seagrass beds of *E. acoroides* is higher than that in transplant *E. acoroides* unit 9 and 25 shoots.m^{-2}.

Average number of new shoot in the seedling of *E. acoroides* after 6 months planting, one new shoot varied 7.00 to 13.33 shoots, two new shoots varied from 0.33 – 1.67 shoots and three new shoots 0.33 shoots (Appendix S7).

Appendix 7: Average number of new shoots in *E. acoroides* transplants after 6 months.

	Unit 9 shoots.m^{-2}		Unit 25 shoots.m^{-2}	
Remarks	X	Range	X	Range
1 shoots	13.33 ± 8.08	4 - 8	7.00 ± 3.46	5 - 11
2 shoots	1.67 ± 0.58	1 - 2	0.33 ± -	1
3 shoots	0.33 ± -	1	0	0

Appendix 8: Abiotic factors of the study sites, temperature (°C), depth (cm), current (m.sec^{-1}), grain size (mm), TOM (%), salinity (°/₀₀), light and nutrient (NH_3-N, NO_2-N, NO_3-N and PO_4-P). (Note: N = Natural, T = Transplant site).

Remarks	Station				
	A	B	C	N	T
Temperature(°C)					
Air					
May	31	32	31	30	30
August	33	33	30	-	-
Sept	33	33	30	33	34
Dec.	29	30	31	29	29

Water May August Sept Dec.	 32 29 29 29	 33 32 32 28	 31 31 31 29	 29 - 32 28	 31 - 33 29
Depth (cm) May August Sept Dec.	 40 40 40 60	 60 70 70 80	 70 60 60 70	 80 70 60 50	 80 70 60 60
Current (m.sec^{-1}) May August Sept Dec.	0.13 ± 0.04 0.04 ± 0.01 0.14 ± 0.02 0.11± 0.02	0 0 0.07 ± 0.01 0.10 ± 0.03	0.01 0.002 0 0.12 ± 0.01 0.12 ± 0.02	0.15 ± 0.01 0 0.09 ± 0.01 0.17 ± 0.02	0.03 ± 0.01 0 0.17 ± 0.02 0.17 ± 0.01
Grain size (mm) Mud (<0.063) Fine sand (0.125 – 0.250) Coarse sand (0.50 – 2.00) Gravel (>2.00)	 32.19 ± 5.10 39.28 ± 7.12 25.82 ± 10.05 2.71 ± 12.91	 53.27 ± 11.25 25.71 ± 8.54 17.40 ± 3.33 3.62 ± 2.01	 23.59 ± 5.21 45.98 ± 7.25 27.12. ± 3.89 3.31 ± 3.77	 7.15± 0.35 48.12 ± 13.05 39.65 ± 10.92 5.09 ± 2.96	 16.52 ± 5.73 38.80 ± 12.71 21.39 ± 8.13 23.29 ± 25.77
TOM (%)	4.99 ± 0.19	5.30 ± 0.45	4.16 ± 0.41	4.79 ± 0.20	4.49 ± 0.07
Light coefficient May	 1.15 ± 0.35	 1.59 ± 0.31	 0.83 ± 0.21	 -	 0.92 ± 0.23

Sept	0.63 ± 0.19	1.26 ± 0.22	1.34 ± 0.30	0.78 ± 0.49	0.62 ± 0.84
Dec.	1.45 ± 0.46	1.04 ± 0.36	1.10 ± 0.37	0.98 ± 0.16	0.71 ± 0.10
Salinity ($^{o}/_{oo}$)					
May	30.35 ± 0.06	30.68 ± 0.06	30.44 ± 0.01	30.40 ± 0.06	30.53 ± 0.16
Sept	31.66 ± 0.10	31.66 ± 0.05	31.95 ± 0.24	31.73 ± 0.07	31.65 ± 0.08
Dec.	-	-	-	-	-
Nutrient ($mg.l^{-1}$)					
Water column					
NH_3-N					
June	0.138	0.233	0.121	0.138	0.098
Sept	0.127	0.110	0.176	0.081	0.150
Dec.	0.095	0.118	0.112	0.089	0.076
NO_2-N					
June	< 0.002	0.002	0.006	< 0.002	< 0.002
Sept	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Dec.	0.003	0.003	0.026	0.002	0.003
NO_3-N					
June	0.008	0.003	0.020	0.008	0.018
Sept	0.026	0.053	0.012	0.081	0.026
Dec.	0.009	0.035	0.039	0.009	0.039
PO_4-P					
June	0.021	< 0.005	< 0.005	0.021	< 0.005
Sept	0.008	< 0.005	< 0.005	< 0.005	< 0.005
Dec.	0.027	0.016	0.026	0.025	0.015

Sediment					
NH_3-N					
June	0.493	0.439	0.348	0.341	0.256
Sept	0.557	0.210	0.266	0.298	0.160
Dec.	0.196	0.202	0.083	0.326	0.208
NO_2-N					
June	0.002	0.003	0.002	0.002	0.005
Sept	0.002	0.002	0.002	0.002	< 0.002
Dec.	0.019	0.004	0.003	0.005	0.004
NO_3-N					
June	0.004	0.034	0.009	0.027	0.022
Sept	0.076	0.037	0.051	0.092	0.040
Dec.	0.037	0.035	0.035	0.030	0.004
PO_4-P	0.033	0.008	0.031	0.061	< 0.005
June	0.006	0.009	< 0.005	0.008	0.018
Sept	0.027	0.021	0.016	0.023	0.024
Dec					

Appendix 9: Number of individual fishes in the natural, and the transplant sites (0, 9 and 25 shoots.m^{-2}). Note: L = Low tide, H = High tide.

Remarks	**No.**	**Species**	**June (L)**	**June (H)**	**August**	**Sept**	**Dec**
Natural	1	*Acreichthys tomentosus*	11	11	12	8	2
	2	*Aeoliscus strigatus*	-	1	-	-	-
	3	*Apogon lateralis*	9	-	-	-	-
	4	*A.margaritophorus*	1	1	6	12	6
	5	*A. quinquelineatus*	-	-	76	-	-
	6	*A. thermalis*	-	-	-	-	-
	7	*Atherina cf. nomorus*	-	1	-	-	-

	8	*Cheilodipterus isostigmus*	-	15	-	22	6
	9	*C. quenquilineatus*	45	-	-	-	-
	10	*Epinephelus fuscoguttatus*	1	1	-	-	-
	11	*Epinephelus sp*	2	3	-	1	-
	12	*Gerres oyena*	3	-	1	-	1
	13	*Halichoeres argus*	-	3	-	4	1
	14	*Istigobius sp*	-	-	-	1	1
	15	*Monacanthus chenensis*	-	-	1	-	-
	16	*Pelates quadrilineatus*	1	-	-	-	-
	17	*Pomacentrus sp*	-	-	4	2	-
	18	*Platax batavianus*	-	1	-	-	-
	19	*Platycephalus sp*	-	1	-	-	-
	20	*Pteroscirtes mitratus*	6	9	5	3	3
	21	*P. variabilis*	1	1	-	-	-
	22	*Scarus goban*	-	1	1	-	-
	23	*Siganus canaliculatus*	2	8	-	2	1
	24	*S. fuscessence*	2	2	-	-	-
	25	*Sphaeramia orbicularis*	10	82	67	92	18
	26	*Stethojulis strigiventer*	-	-	1	-	-
	27	*Stolephorus sp*	-	2	9	7	-
	28	*Syngnathoides biaculeatus*		-	1	-	-
Total		28	111	144	186	155	39
T- 0	1	*Acrechthys tomentosus*	-	-	1	-	-
	2	*Cheilodipterus isostigmus*	-	-	-	1	4
	3	*Dischistodus perspicillatus*	1	-	-	-	-
	4	*Echenogobius hayashii*	-	-	2	-	-
	5	*Epinephelus fuscutattus*	-	-	-	-	-
	6	*Epinephelus sp*	-	-	-	-	-
	7	*Gerres oyena*	-	-	-	-	7
	8	*Halichoeres argus*	-	-	-	-	-
	9	*Istigobius sp*	-	-	-	6	2
	10	*Onigocia spinosa*	-	-	-	2	-
	11	*Pteroscirtes mitratus*	1	-	-	-	-

	12	*Pseudomonacanthus maerurus*	1	-	-	-	-
	13	*Pseudorhombus sp*	-	-	-	-	-
	14	*Stolephorus sp*	-	-	-	-	-
	15	*Valencienna muralis*	-	2	-	-	-
Total		15	3	2	3	9	15
T – 9	1	*Acreichthys tomentosus*	3	-	-	3	-
	2	*Cheilodipterus isostigmus*	-	-	-	1	-
	3	*Dischistodus perspicillatus*	1	-	1	-	1
	4	*Echenogobius hayashii*	-	-	1	-	-
	5	*Epinephelus sp*	1	-	-	-	-
	6	*Gerres oyena*	-	-	-	-	1
	7	*Halichoeres argus*	-	1	2	-	-
	8	*H. leucurus*	2	-	-	-	-
	9	*H. scapularis*	-	-	-	-	-
	10	*Pseudorhombus sp*	-	1	-	-	-
	11	*Pteriscirtes mitratus*	5	1	1	3	-
	12	*Stolephorus sp*	-	30	-	1	2
	13	*Valenciennea muralis*	2	-	-	-	-
Total		13	16	34	5	8	4
T -25	1	*Acreichthys tomentosus*	-	3	1	2	-
	2	*Aeoliscus strigatus*	3	-	-	-	-
	3	*Chaerodon anchorago*	-	-	1	-	-
	4	*Cheilodipterus quenquilineatus*	1	-	-	-	-
	5	*Dischistodus perspicillatus*	-	3	-	-	3
	6	*Epinephelus sp*	-	1	-	-	-
	7	*Halichoeres argus*	-	5	3	-	2
	8	*H. chloropterus*	1	-	-	-	-
	9	*H. nigrescens*	-	1	-	-	-
	10	*H. scapularis*	-	-	-	1	-
	11	*Pseudomonacanthus macrurus*	-	1	-	-	-
	12	*Pteroscirtes mitratus*	4	1	-	2	-
	13	*P. variabilis*	1	-	-	-	-

	14	*Siganus canaliculatus*	1	-	-	-	-
	15	*Stolephorus sp*	-	-	-	11	-
	16	*Valenciennea muralis*	-	-	1	-	-
Total		16	11	16	6	16	5

Appendix 10: Total number individual of crustaceans the natural, and the the transplant sites (0, 9 and 25 shoots.m^{-2}). Note: L = Low tide, H = High tide.

Remarks	Species	June (L)	June (H)	August	Sept	Dec
Natural	*Acetes sp*	-	1	-	-	-
	Leucosia	-	-	1	-	-
	Metapenaeus sp	4	-	-	-	-
	Penaeus sp	34	27	-	-	-
T- 0	*Penaeus sp*	-	-	-	-	1
T – 9	*Penaeus sp*	9	1	-	-	-
T -25	*Penaeus sp*	16	1	-	-	-
Total		63	30	1	0	1

Appendix 11: Distribution and area (km^2) of mangrove, seagrass and coral reef ecosystems in the Gulf of Mannar Region, Tamil Nadu, India

S. No		Description	Area (Sq.Km)
1	Shingle Island	Total area of Island	0.189
		Coral Reef	0.144
		Seagrass	0.212
		Mangrove	0.012
2	Kurusadai Island	Total area of Island	0.806
3	Poomarichan Island	Total area of Island	0.233

4	Pullivasal Island	Total area of Island	0.542
		Coral Reef	3.585
		Mangrove	0.365
		Seagrass	3.979
5	Hare Island / Musal	Total area of Island	1.696
6	Manoli Island	Total area of Island	0.514
7	Manoli Putti Island	Total area of Island	0.058
		Coral Reef	10.603
		Seagrass	15.574
8	Mulli Island	Total area of Island	0.149
		Coral Reef	0.978
		Seagrass	0.409
9	Thalaiyari Island	Total area of Island	0.908
10	Valai Island	Total area of Island	0.092
		Mangrove	0.112
		Seagrass	6.737
		Coral Reef	3.843
11	Appa Island	Total area of Island	0.195
12	Appa Island	Total area of Island	0.104
		Mangrove	0.008
		Seagrass	0.632
		Coral Reef	1.186
13	Poovarasanpatti	Total area of Island	0.024
		Seagrass	0.077
		Coral Reef	0.720
14	Valimunai Island	Total area of Island	0.106
		Coral Reef	0.428

		Seagrass	0.168
15	Anaipar Island	Total area of Island	0.157
		Seagrass	0.256
		Coral Reef	0.549
16	Nallathanni Island	Total area of Island	1.148
		Seagrass	0.345
		Coral Reef	0.496
17	Puluvinnichalli Island	Total area of Island	0.107
		Coral Reef	0.264
		Seagrass	0.046
18	Upputhanni Island	Total area of Island	0.333
		Coral Reef	0.337
		Seagrass	0.076
19	Kariyachalli Island & Vilanguchalli	Total area of Island	0.108
		Seagrass	1.542
		Coral Reef	0.086
20	Koswari Island	Total area of Island	0.119
		Seagrass	1.147
		Coral Reef	0.179
21	Vaan Island	Total area of Island	0.107
		Coral Reef	0.120
		Seagrass	1.103
	Mandapam Coastal Waters	Reef	1.704
		Seagrass	22.393
	Rameswaram Coast & Palk Strait	Seagrass	20.841
		Mangrove	0.988

Appendix 12: Physico-chemical characteristic of surface waters Region in the Gulf of Mannar

S.No	S .station	pH	DO (mg/l)	Cond. (S/m)	TDS (g/L)	Alkalinity (mg$CaCO_3$/l)	Temp (°C)	Salinity	BOD (mg l^{-1})
1	8° 48.212'N; 78° 12.068'E	7.83	6.9	4.94	52.9	150	29.2	32.0	4.39
2	8° 49.911'N; 78° 14.075'E	7.93	7.0	5.05	54.4	170	29.7	32.7	3.28
3	8° 51.992'N; 78° 15.384'E	8.06	7.0	5.03	54.1	125	29.7	32.7	2.98
4	8° 53.411'N; 78° 16.257'E	8.19	7.2	5.03	53.9	160	29.8	32.7	3.98
5	8° 54.693'N; 78° 16.817'E	8.22	6.8	5.02	54.0	130	29.6	32.6	4.39
6	8° 55.359'N; 78° 16.197'E	8.25	7.1	5.04	54.3	150	29.8	32.7	4.69
7	8° 55.708'N; 78° 15.414'E	8.28	6.9	5.07	54.6	140	29.6	33.1	4.59
8	8° 56.562'N; 78° 14.926'E	8.45	7.0	5.07	54.9	150	29.7	33.0	3.18
9	8° 56.818'N; 78° 14.095'E	8.26	6.8	5.08	54.5	125	29.6	33.2	3.58
10	8° 56.006'N; 78° 13.594'E	8.25	7.0	5.09	54.7	130	30.0	33.0	3.48
11	8° 55.420'N; 78° 13.203'E	8.27	6.9	5.11	55.9	150	29.8	33.3	3.28
12	8° 54.665'N; 78° 12.909'E	8.33	7.0	5.16	55.6	130	29.8	33.2	3.28
13	8° 53.849'N; 78° 12.497'E	8.29	6.9	5.14	55.6	145	29.7	33.4	4.28
14	8° 53.296'N; 78° 13.328'E	8.28	7.2	5.12	55.4	145	30.0	33.4	4.58
15	8° 53.094'N; 78° 14.186'E	8.3	6.9	5.90	54.9	130	29.9	33.2	2.98
16	8° 52.633'N; 78° 14.186'E	8.28	7.0	5.08	54.8	140	29.8	33.1	5.19
17	8° 54.906'N; 78° 14.150'E	8.34	6.8	5.11	55.1	130	30.0	33.3	3.28
18	8° 54.215'N; 78° 15.133'E	8.37	6.9	4.98	53.5	145	29.7	33.4	5.29
19	8° 53.226'N; 78°	8.3	7.1	5.09	54.9	140	29.7	33.2	3.98

	15.368'E	4							
20	8° 51.797'N; 78° 14.596'E	8.3 1	6.9	5.08	54.8	130	29.9	32.7	3.78

Appendix 13. Accomplishments

Project personnel are identified by asterisks. In all citations they have been involved directly, sharing products of either the project or of other projects where they are also involved. Hence, acknowledgments to APN are given only where they are properly due).

Journal articles

Alongi, D. M., Murdiyarso, D., Fourqurean, J. W., Kauffman, J. B., Hutahaean, A., Crooks, S., Lovelock, C. E., Howard, J., Herr, D., Fortes, M. D*., Pidgeon, E., and Wagey, T., 2015. Indonesia's blue carbon: a globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecol. Management. 24(1), pp. 3-13.

Asaeda, T*., Barnuevo, A.*, Sanjaya, K., Fortes, MD.*, Kanesaka, Y., Wolanski, E*. (2016). Mangrove plantation over a limestone reef - Good for the ecology? Estuarine, Coastal and Shelf Science 173 (2016) 57-64.

Barnuevo, A., Asaeda, T., Sanjaya, K., Kanesaka, Y., Fortes, MD. Drawbacks of successful mangrove rehabilitation schemes: lessons learned from the large-scale mangrove plantations (Submitted)

Bonthu, S., Ganguly, D., Purvaja, R., Ramesh, R.*, Pattnaik, A., Wolanski, E.* Riverine detritus drives the fisheries in the tropical Chilika lagoon, India (Under review)

Fortes, M.D*. (2013). A Review: Biodiversity, Distribution and Conservation of Philippine Seagrasses. Philippine Journal of Science. 142: 95-111, Special Issue. ISSN 0031 – 7683.

Leopardas, V., Honda, K., Go, GA., Bolisay, K., Pantallano, AD., Uy, W., Fortes, MD*., Nakaoka, M. (2016). Variation in macrofaunal communities of sea grass beds along a pollution gradient in Bolinao, northwestern Philippines. Marine Pollution Bulletin 105 (2016) 310–318.

Mizuno, L.*, Asada, A.*, Matsumoto, Y.*, Sugimoto, K.*, Fujii, T.*, Yamamuro, M.*, Fortes, MD.*, Sarceda, M.*, Jimenez, L.* (2016). A new method for making a high-resolution optical seagrass map and quantification of dugong trail distribution: a field test at Mayo Bay, southeastern Philippines. (for peer review, submitted to Marine Mammal Science)

Books

Fortes, M.D.*, Fortes, E.G., Sarceda, M.B.*, Jimenez, L.A.*, Lucero, R.S.* (2016). Seagrasses: See How They Protect Us. A guide for community appreciation of seagrasses in the Philippines. Department of Science and Technology, Asia-Pacific Network for Global Change Research, National Research Council of the Philippines, U.P. Marine Science Institute CS. Quezon City, Philippines. 43 p.

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Chapter sections in a book

Fortes, MD and Salmo, SG. III. Mangroves as a natural bioshield. Chapter 4, Section 8 *In*: Fortes, MD and Salmo, SG III (eds). Mangroves in the Philippines: Responding to change. (in Press).

Fortes, MD and Salmo, SG. III. Mangroves as a blue carbon ecosystem. Chapter 4, Section 8 *In*: Fortes, MD and Salmo, SG III (eds). Mangroves in the Philippines: Responding to change. (in Press)

Articles in proceedings

Fortes, M. D., Go, G. A., Bolisay, K., Nakaoka, M., Uy, W. H., Lopez, M. R., Leopardas, V., Leriorato, J., Allyn Pantallano, A., Paciencia Jr., F., Watai, M., Honda, K., and Edralin, M. (2012). Seagrass response to mariculture-induced physico-chemical gradients in Bolinao, northwestern Philippines. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012, http://www.icrs2012.com/proceedings/manuscripts/ICRS2012_15B_3.pdf.

Gregory, K., Yamamuro, M. (2013). "Metabolic analysis of the seagrass (*Halophila ovalis*)" The 47th Japan Society on Water Environment, March 2013

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Mochizuki, M., Asada, A., Ura, T., Yamamuro, M., Fortes, MD., Jimenez, LA. (2013). Off-line observation system based on acoustic video camera for understanding behavior of underwater life, Proceedings of Underwater Technology 2013, IEEE international, DOI information: 10.1109/UT.2013.6519828.

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Fortes, MD. (2014). Seagrass Factor in Meeting the Conservation Challenges of the 21st Century in SE Asian Coasts: From Science to Action. *In*: Proc. 11th International Seagrass Biology Workshop, Sanya City, Hainan, China, 6-10 November 2014. (KEYNOTE PRESENTATION)

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Fortes, MD. (2014). Seagrass Role in Coastal Protection in Southeast Asian Coasts. Paper presented at the Workshop, Status Seagrass Research in Indonesia: Past, Present and Future. 22 - 23 March 2014, Pulau Pari, Jakarta, Indonesia. (KEYNOTE PRESENTATION)

Fortes, MD. (2015). Science-Policy Link: Community Resilience Against Climate Change Impacts In the Philippines. Paper presented at the First Colleges and University Public Service Conference, Los Banos, Laguna, 26-27 November 2015. (ORAL PRESSENTATION)

Fortes, MD. (2015). The role of Natural Ecosystems in Building Resilience in Coastal communities. Media Workshop for Members of the Local Press and LGU Information Officers in RAPID Areas. Tacloban City, 26-27 March 2015. (ORAL PRESENTATION)

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Fortes, MD. (2016). Framing the future of seagrass carbon studies in the Philippines. *In*: Fortes, MD and Salmo, SG.III. (eds.) (2016). Proceedings of the national Seagrass – Mangrove Bioshield Conference. DOST/APN/ADMU/NRCP. Marine Science Institute CS, UP Diliman, QC. 26-27 May 2016. (ORAL PRESENTATION)

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Fortes, MD., Asaeda, T., Jimenez, LA, King, G., Kiswara, W., Lucero, RS., Mizuno, K., Mukai, H., Mochizuki, M., Ramachandran, R., Sarceda, MM., Wolanski, E., Yamamuro. M. (2016). Seagrasses and Mangroves: Bioshield Against Biodiversity Loss and Impacts of Local and Global Change Along Indo-Pacific Coasts. (POSTER)

Fortes, MD and S. Salmo III. (eds.). (2016). Proceedings of the National Seagrass – Mangrove Bioshield Conference. DOST/APN/ADMU/NRCP. Marine Science Institute CS, UP Diliman, QC. 26-27 May 2016**.** (In CD, distributed to all 92 participants)

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Sarceda, MB., Miguel D. Fortes, Ruth S. Lucero, Hiroshi Mukai, Jellie Rose Baring and Donna Marie Rillas. (2016). Dugong grazing in seagrass beds and their behavior in Malita, Philippines. *In*: Huang, X. (ed.). Proc. 11th International Seagrass Biology Workshop, Sanya City, Hainan, China, 6-10 November 2014. (POSTER PRESENTATION)

Posters for general public display (at least 20 copies each, distributed to stakeholders)

"Seagrass and Mangrove Ecosystems: Bioshields Against Biodiversity Loss and Impacts of Changes Along Indo-Pacific Coasts (SMBP)"

"Bolinao is at risk from these 6 issues…SMBP helps to address them"

Brochure

"Seagrass and Mangrove Ecosystems: Bioshields Against Biodiversity Loss and Impacts of Changes Along Indo-Pacific Coasts (SMBP)"

Video

"The coasts of Mati …the future we want" (a 15-minute CD video in MP4 format)

Funding sources outside the APN

The following helped in providing, procuring and facilitating availability of the funds and in-kind support used in the implementation of the project:

Agency, Institution, etc.	Nature of contribution	Amount (roughly)
Local Government Units:	In-kind plus:	--
Bolinao	Conf venue, discounts (boat rent)	US$ 230.00
Mati	Meals (4x), snacks (7x)	US$ 590.00
Malita	Meals (3x) + discounts (boat rent)	US$ 350.00
Boracay	Meals (1x) + venue, vehicle, fare	US$ 120.00
Tacloban	Snacks (2x) + vehicles, boats	US$ 190.00
Local colleges/schools:	In-kind (lab & meeting rooms, vehicles, utility personnel)	(not applicable)
Department of Science & Technology	Co-sponsorship fund in a national conference	US$ 4,350.00
Ateneo de Manila Univ.	Co-sponsorship fund in a national conference	US$ 2,500.00
Dept. of Environment & Natural Resources	Workshop, reading materials, facilitation of permits, endorsements, exhibit displays	--
JICA – JST Project CECAM	Equipment use, expert advise	--
Our mother institutions	Lab facilities, equipment, vehicles, water, electricity, utility personnel	--

List of Young Scientists

1. Gregory King (Graduate Student, University of Tokyo, Kashiwa Campus, E-mail: kinxiel@gmail.com)

   "I have to thank my sensei Professor M. Yamamuro, and APN for such life-changing opportunity to study metabolomics in seagrasses. It is opening a whole new world for me, especially now that I am back to my university in the Philippines."

2. Ms. Monica Sarceda (Graduate Student, Marine Science Institute CS, University of the Philippines, m3bs29@gmail.com)

   "The project has shown me how much can be done for the local communities if the science I have learned and will learn could be applied and translated into coastal resource management, specifically using seagrass ecology, goods and services. It has and will help me in pursuing my career in wanting to provide and maintain sustainable resources management for our communities here in the Philippines."

3. Ms. Maria Felez B. Matignao (Faculty Member, SPAMAST, Malita, Davao del Sur, +63 930 532 7390, hayatty1981@yahoo.com.ph)

   "So happy I was involved in collecting data on seagrass. Now I graduated with MSc with seagrass as thesis. It has improved my current teaching in SPAMAST. Thank you so much APN and Sir Mike!"

4. Jellie Rose Baring (Project Assistant, Bureau of Fisheries and Aquatic Resources R-XI, +63 949 668 4654)
5. Donna Marie Rillas (Student, SPAMAST, Malita, Davao del Sur, +63 905 937 1995)

   "This is for the two of us, Jellie Rose and Donna: At first, we thought watching dugongs was boring, but when they appeared very often, playing, it was fascinating! Maraming Salamat! (Thank you very much!). Our experience is not much related to what we are doing yet, but we hope someday…God Bless! Thank you, Dr. Fortes!"

Glossary of Terms

AGB – Aboveground Biomass

APN – Asia Pacific Network for Global Change Research

BGB – Belowground Biomass

BOD – Biological Oxygen Demand

BSDS – Bolinao Seagrass Demonstration Site

COD – Chemical Oxygen Demand

CCVI – Coastal community vulnerability index

DBH – Diameter at Breast Height

DIDSON – Dual Frequency Identification Sonar

DOSCST – Davao Oriental College of Science and Technology

DPSIR – Driver – Pressure – State - Impact – Response

EEA – European Environment Agency

FGD – Focus Group Discussion

ICM or ICRM – Integrated Coastal Management or Integrated Coastal Resources Management

IDSS – Integrated Decision Support system

IUCN – International Union for the Conservation of Nature and Natural Resources

LGU – Local Government Unit

MEA – Millennium Ecosystem Assessment

NaGISA – Natural Geography in Shore Areas

NGO – Non-Governmental Organizations

PAR – Photosynthetically Active Radiation

SeagrassNet - Global monitoring and information network for seagrass meadows

SES – Social Ecological System

SMBP – Seagrass-Mangrove Bioshield Project

SPAMAST – Southern Philippines Agri-Business Aquatic and Marine School of Technology

SST – Sea Surface Temperature

UNDP – United Nations Development Programme

UNEP – United Nations Environment Programme

Selected articles, books, cover slides of relevant presentations and video (Appendix 13 gives the more complete list)

Journal Articles

Takashi Asaeda, Abner Barnuevo, Kelum Sanjaya, Miguel D. Fortes, Yoshikazu Kanesaka, Eric Wolanski. (2016). Mangrove plantation over a limestone reef e Good for the ecology? Estuarine, Coastal and Shelf Science 173 (2016) 57-64.

Estuarine, Coastal and Shelf Science 173 (2016) 57–64

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Mangrove plantation over a limestone reef – Good for the ecology?

Takashi Asaeda [a, b, *], Abner Barnuevo [b], Kelum Sanjaya [a], Miguel D. Fortes [c], Yoshikazu Kanesaka [d], Eric Wolanski [e]

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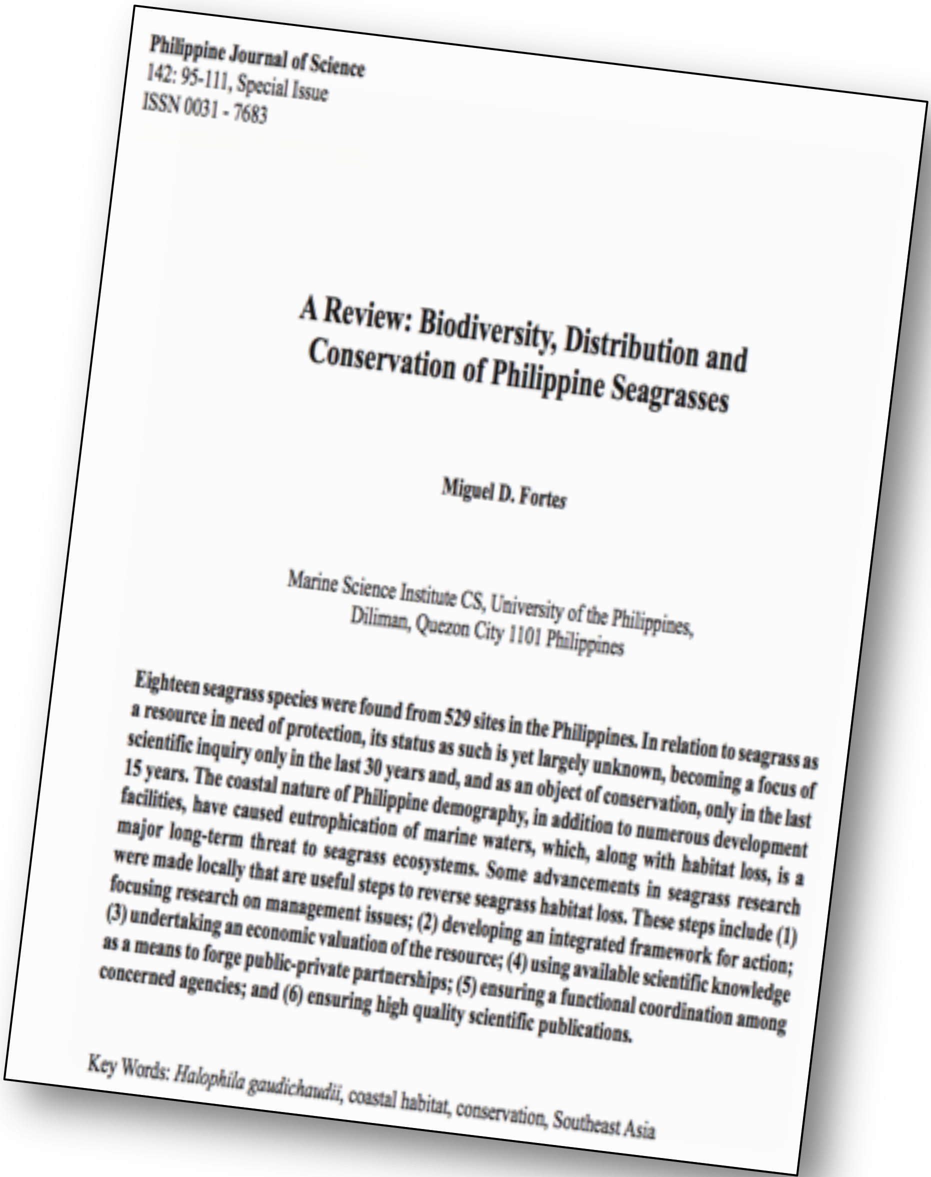
ABSTRACT

There have been efforts to restore degraded tropical and subtropical mangrove forests. While there have been many failures, there have been some successes but these were seldom evaluated to test to what level the created mangrove wetlands reproduce the characteristics of the natural ecosystem and thus what ecosystem services they can deliver. We provide such a detailed assessment for the case of Olango

Fortes, MD. (2013). A Review: Biodiversity, Distribution and Conservation of Philippine Seagrasses. Philippine Journal of Science 142: 95-111, Special Issue ISSN 0031 – 7683.



Philippine Journal of Science
142: 95-111, Special Issue
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A Review: Biodiversity, Distribution and Conservation of Philippine Seagrasses

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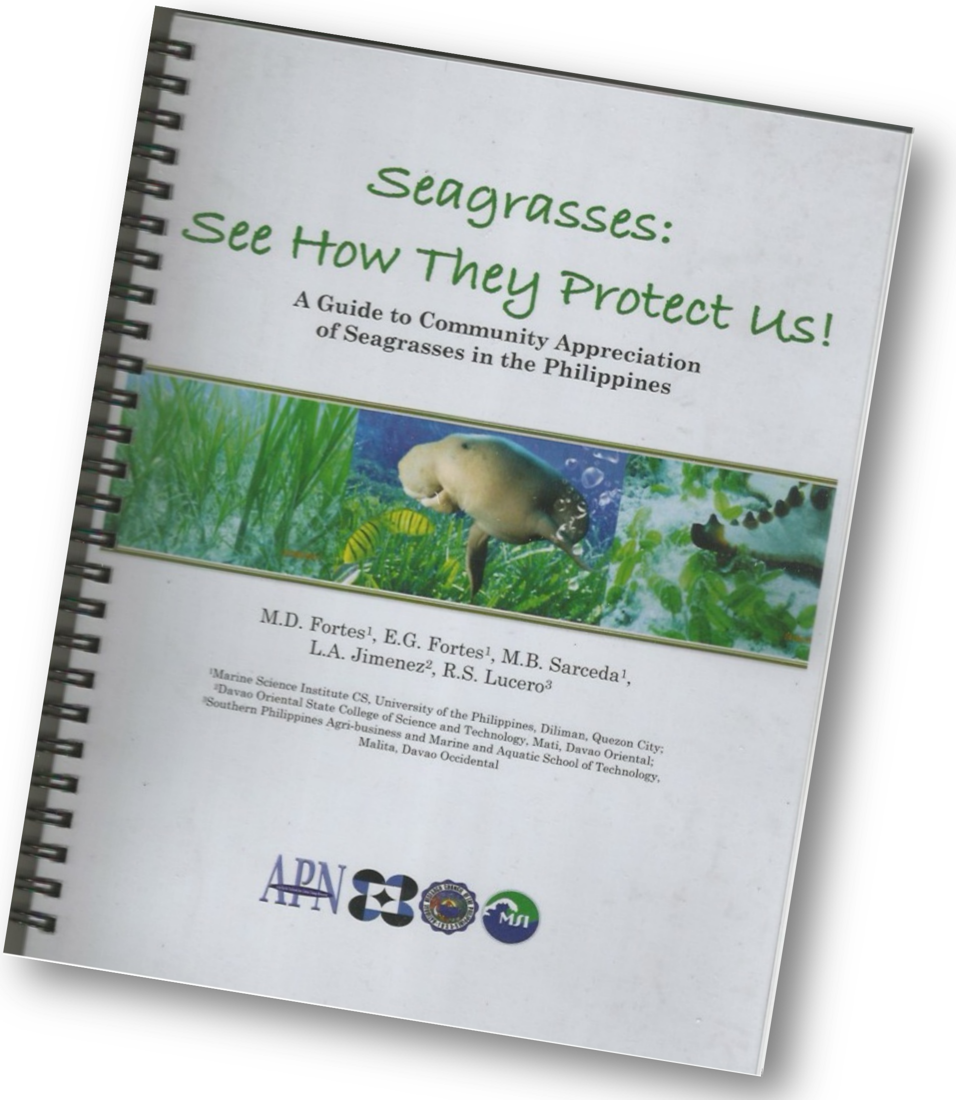
Eighteen seagrass species were found from 529 sites in the Philippines. In relation to seagrass as a resource in need of protection, its status as such is yet largely unknown, becoming a focus of scientific inquiry only in the last 30 years and, and as an object of conservation, only in the last 15 years. The coastal nature of Philippine demography, in addition to numerous development facilities, have caused eutrophication of marine waters, which, along with habitat loss, is a major long-term threat to seagrass ecosystems. Some advancements in seagrass research were made locally that are useful steps to reverse seagrass habitat loss. These steps include (1) focusing research on management issues; (2) developing an integrated framework for action; (3) undertaking an economic valuation of the resource; (4) using available scientific knowledge as a means to forge public-private partnerships; (5) ensuring a functional coordination among concerned agencies; and (6) ensuring high quality scientific publications.

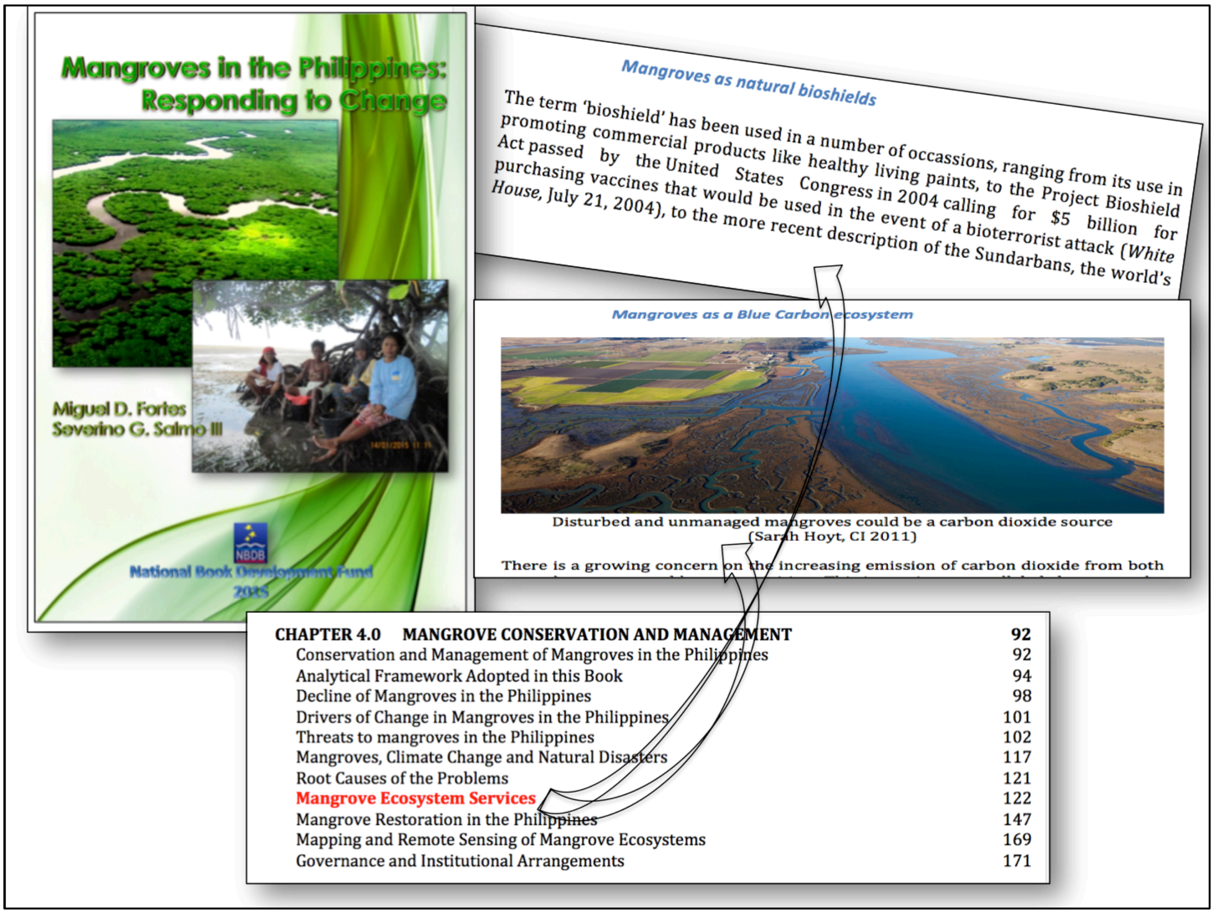
Key Words: *Halophila gaudichaudii*, coastal habitat, conservation, Southeast Asia

Book

Fortes, M.D., Fortes, E.G., Sarceda, M.B., Jimenez, L.A., Lucero, R.S. (2016). Seagrasses: See How They Protect Us. A guide for community appreciation of seagrasses in the Philippines. Asia-Pacific Network for Global Change Research, Department of Science and Technology, National Research Council of the Philippines, U.P. Marine Science Institute CS. Quezon City, Philippines. 43 p.



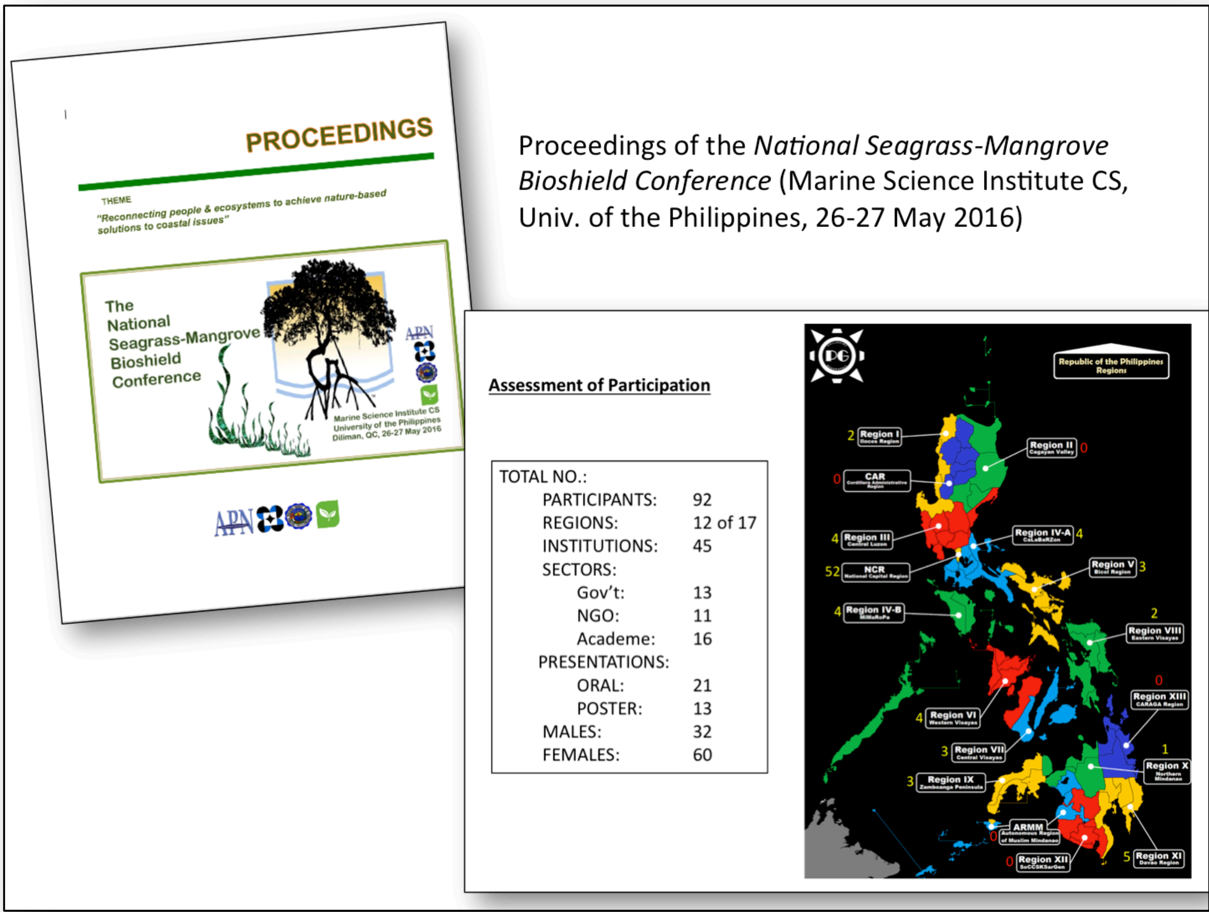
Book chapter sections



Mangroves as natural bioshields and *Mangroves as a Blue Carbon ecosystem* are sections under *Mangrove Ecosystem Services* of Chapter 4 in the book entitled, **Mangroves in the Philippines: Responding to Change,** authored by M.D. Fortes and S. G. Salmo III. Coming out late 2016, the book gives the most comprehensive account of local mangrove resources, wirh 7 chapters, 269 pages with 71 colored photographs.

Proceedings of a National Conference

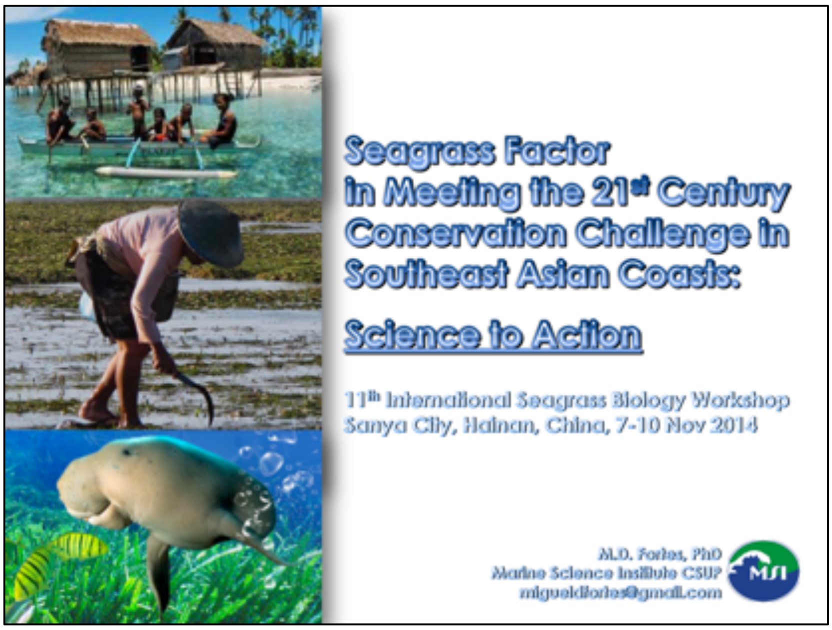
(Abstracts of papers and posters are included in the proceedings)



Brochure (tri-fold, only the front and the back pages are shown)

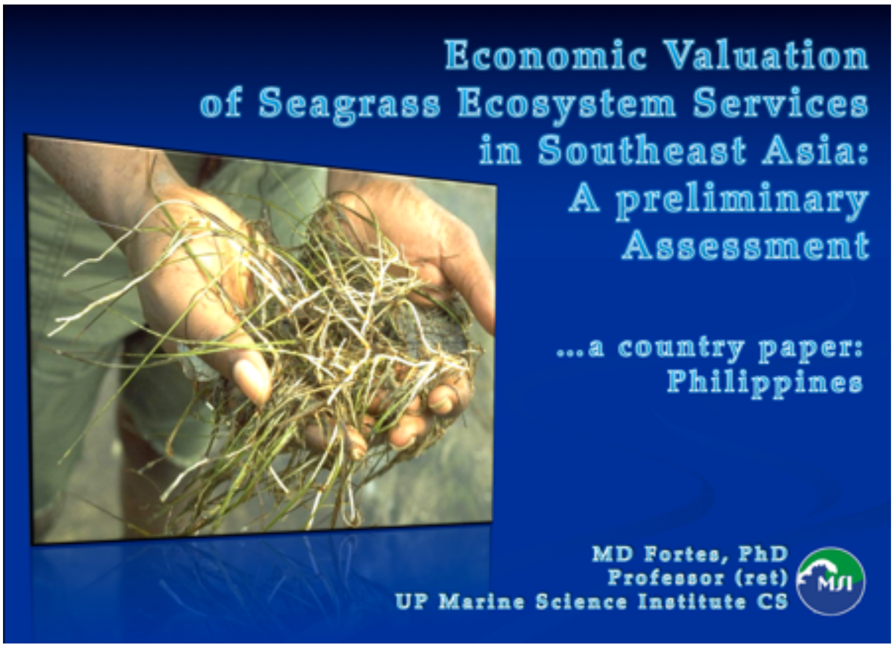
International Symposia/Meetings

Fortes, MD. (2014). Seagrass Factor in Meeting the Conservation Challenges of the 21st Century in SE Asian Coasts: From Science to Action. *In*: Proc. 11th International Seagrass Biology Workshop, Sanya City, Hainan, China, 6-10 November 2014. **(KEYNOTE PRESENTATION)**

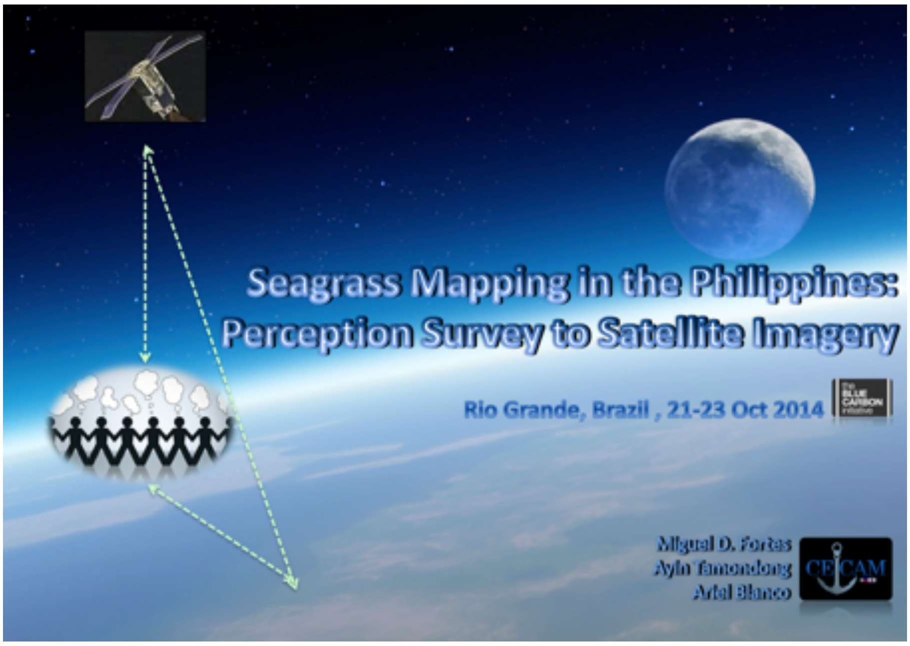


Fortes, MD. (2014). Seagrass Factor in Coastal Conservation in Southeast Asia. Hawaii Pacific University, Honolulu, Hawaii, 4 September 2014. **(INVITED PAPER as an Affiliate Faculty)**

Fortes, MD. (2014). Seagrass Ecosystem Services and their Economic Valuation in SE Asia: A Preliminary Assessment. Paper presented at the Workshop on Climate Change Impact on Seagrass and Salt Marsh Ecosystems in South and South East Asian Coasts. Bintulu, Sarawak, Malaysia3-4 April 2014. **(ORAL PRESENTATION)**



Fortes, MD. (2014). Seagrass Mapping in the Philippines: Perception Survey to Satellite Imagery. Rio Grande, Brazil, 21-23 October 2014 **(ORAL PRESENTATION)**



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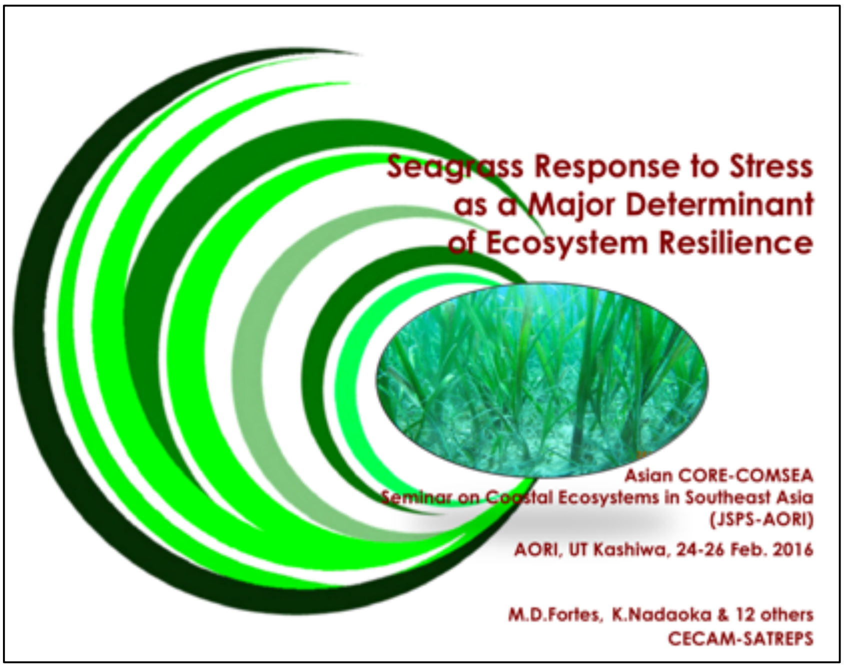
Fortes, MD., K. Nadaoka, and 12 others. (2016). Seagrass Response to Stress as a Major Determinant of Ecosystem Resilience in Philippine Coastal Environment. Paper presented at the Asian CORE Seminar, University of Tokyo, Kashiwa campus, Japan, 24–26 February, 2016**. (ORAL PRESENTATION)**



Sarceda, MB., Miguel D. Fortes, Ruth S. Lucero, Hiroshi Mukai, Jellie Rose Baring and Donna Marie Rillas. (2016). Dugong grazing in seagrass beds and their behavior in Malita, Philippines. *In*: Huang, X. (ed.). Proc. 11th International Seagrass Biology Workshop, Sanya City, Hainan, China, 6-10 November 2014. **(POSTER PRESENTATION)**

Dugong grazing in seagrass beds in Davao del Sur, Philippines

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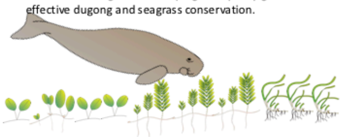
Introduction & significance

Dugong (*Dugong dugon*) makes distinct trails through seagrass beds during feeding indicated by the tracks of vegetation removed. This study is to determine whether a causal relationship exists between the abundance of dugong feeding trails and seagrass cover in the area. This is undertaken in order to assess the potential effects of:

- Climate variability on seawater parameters (temperature, sea level), frequency and intensity of storms;
- Effluents from the nearby coal-fired power plant on the feeding behavior of dugongs; and
- The above changes in developing local policy guidelines for effective dugong and seagrass conservation.



Methods

In New Argao, Malita, Davao del Sur, Philippines (Fig. 1), the abundance of dugong feeding trails in seagrass beds were observed and photographed inside 0.25-square meter quadrats (Fig. 2.) from December 2011 - June 2014. These quadrats were set along bottom gradients (5-17 m) where dugongs frequent in order to determine changes in % cover of seagrass (=dugong trail) and area ungrazed. This will roughly indicate the amount of plant biomass that goes into consumption in proportion to the total area of seagrass. In determining the relative age of the feeding trails, we used the following characteristics:

- Older feeding trails: edges indistinct; with signs of seagrass growth; no distinct depression (Fig. 3)
- Newer feeding trails: edges very distinct; completely devoid of seagrass growth; uprooted seagrass freshly looking; bottom substrate clearly discernable (Fig. 4)

Seagrass bed distribution was mapped using transect quadrat method and scuba (Fig. 5, with the results).

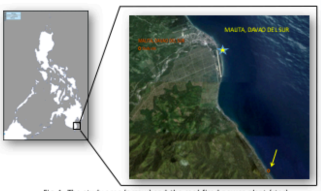


Fig. 1. The study area (arrow) and the coal-fired power plant (star)

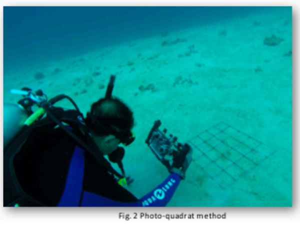


Fig. 2 Photo-quadrat method

Results

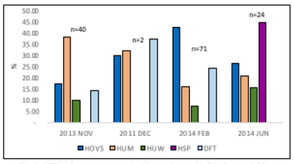


Fig. 6. DFT and seagrass cover inside quadrat in Malita, Davao del Sur.

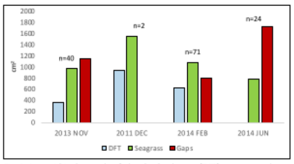


Fig. 4. Area within the quadrat fed on by the dugong (DFT), seagrass and gaps

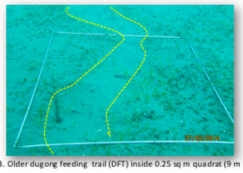


Fig. 3. Older dugong feeding trail (DFT) inside 0.25 sq m quadrat (9 m depth)

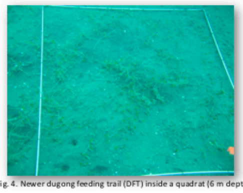


Fig. 4. Newer dugong feeding trail (DFT) inside a quadrat (6 m depth)

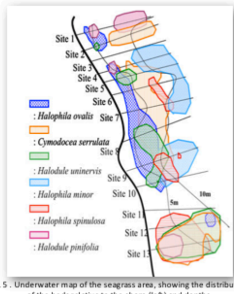


Fig. 5 . Underwater map of the seagrass area, showing the distribution of the beds relative to the shore (left) and depths (After Mukai 2012).

Discussion

In Malita, dugongs tend to feed more during the early, colder months of the year and completely stopped feeding in the middle of the year. This is manifest in the % cover of *Halophila ovalis* (HOVS) and *H. minor* (HUM). H. *spinulosa* (HSP) appeared only in the middle part of the year (June, Fig. 3).

It is interesting to note that in Fig. 4 the trend as shown in Fig. 3 is generally the same when area (cm^2) of DFT and seagrass is considered. Hence, the area of seagrass grazed in the later part of the year tends to increase 'til December and decrease 'til the colder months of the year (Feb) until dugong grazing is no longer observed, in the middle part of the year (June).

The area of seagrass ungrazed observations made on the space (gaps) appear to be differently controlled. Although physical factors like sand burial may be a contributory factor.

It should be noted that the observation periods were not continuous so the need for more and regular observations is evident.

Conclusion

- No clear relationship exists between the seagrass cover and the frequency of dugong feeding trails in the area.
- Further studies are needed to acquire more definitive information especially on the seagrass cover-dugong feeding trail relationship.

Acknowledgements

Department of Science and Technology

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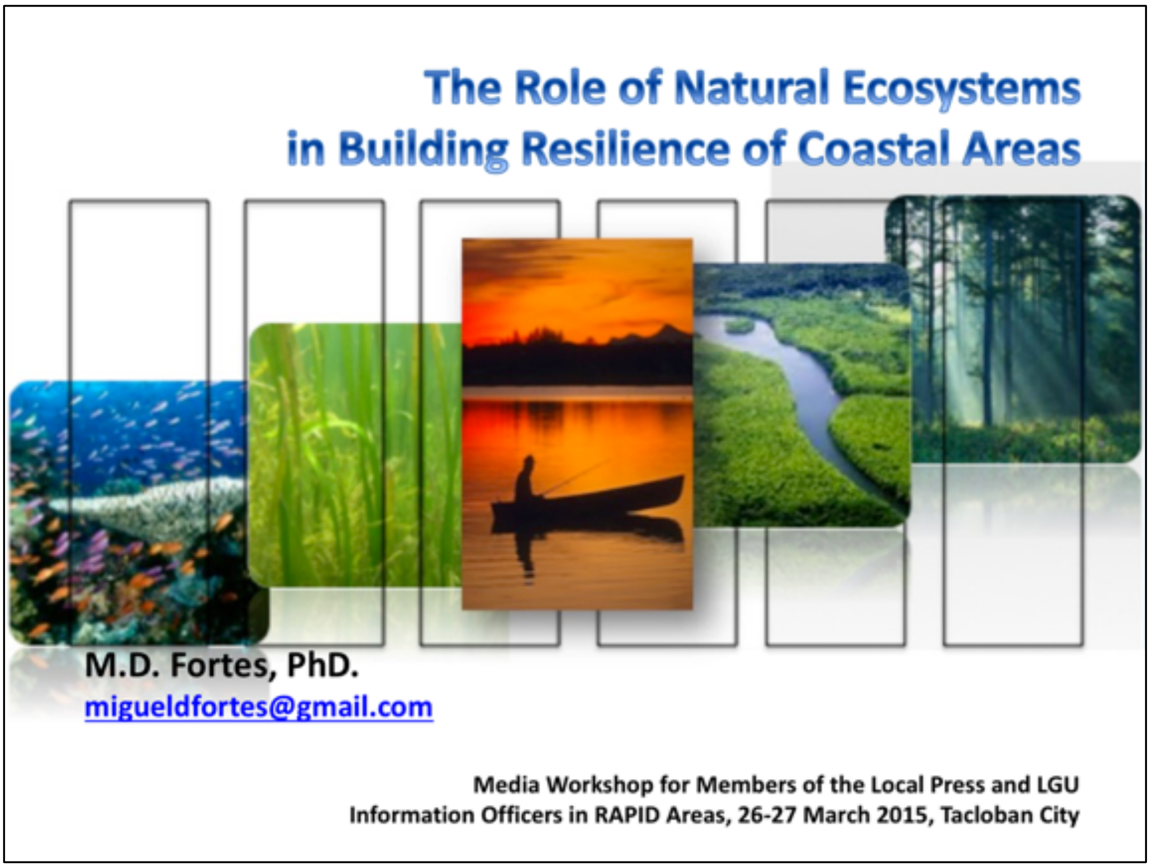
National Conference

Fortes, MD. (2015). The role of Natural Ecosystems in Building Resilience in Coastal communities. Media Workshop for Members of the Local Press and LGU Information Officers in RAPID Areas. Tacloban City, 26-27 March 2015. **(ORAL PRESENTATION)**



Fortes, MD. (2015). Science-Policy Link: Community Resilience Against Climate Change Impacts In the Philippines. Paper presented at the First Colleges and University Public Service Conference, Los Banos, Laguna, 26-27 November 2015. **(ORAL PRESENTATION)**

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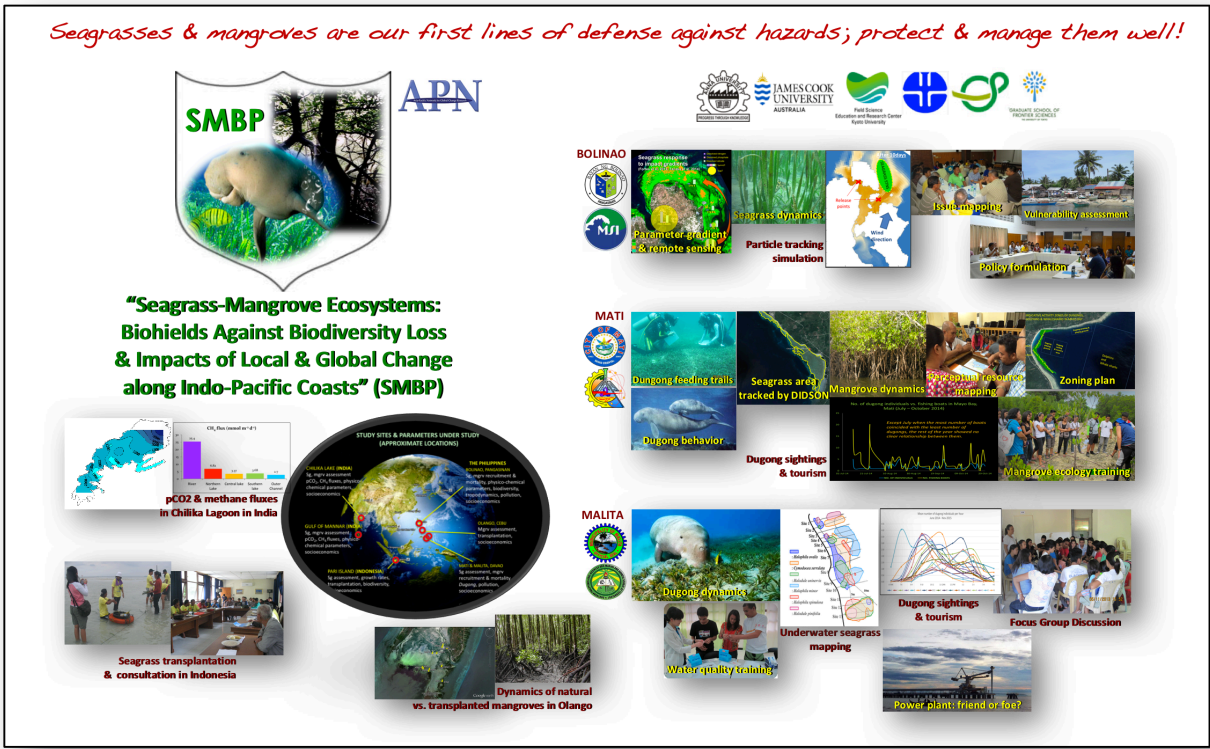
Fortes, MD. (2016). Seagrass and Mangrove Factor in Community Resilience *In*: Fortes, MD and Salmo, SG.III. (eds.) (2016). Proceedings of the National Seagrass – Mangrove Bioshield Conference. DOST/APN/ADMU/NRCP. Marine Science Institute CS, UP Diliman, QC. 26-27 May 2016**. (PLENARY PRESENTATION)**

Fortes, MD and S. Salmo III. (eds.). (2016). Proceedings of the National Seagrass – Mangrove Bioshield Conference. DOST/APN/ADMU/NRCP. Marine Science Institute CS, UP Diliman, QC. 26-27 May 2016**. (In CD, distributed to all 92 participants)**

Posters (for general public display)

Fortes, MD. (2016). Seagrass and Mangroves: Bioshield Against Biodiversity Loss and Impacts of Local and Global Change Along Indo-Pacific Coasts. (POSTER, distributed to all key personnel and posted in 6 sheds at the three project sites, 5 libraries in Metro Manila, and to some participants at the FGDs on site).



Fortes, MD., Asaeda, T., Jimenez, LA, King, G., Kiswara, W., Lucero, RS., Mizuno, K., Mukai, H., Mochizuki, M., Ramachandran, R., Sarceda, MM., Wolanski, E., Yamamuro. M. (2016). Seagrasses and Mangroves: Bioshield Against Biodiversity Loss and Impacts of Local and Global Change Along Indo-Pacific Coasts. **(POSTER)**

Seagrasses and Mangroves: Bioshield Against Biodiversity Loss and Impacts of Local and Global Change Along Indo-Pacific Coasts

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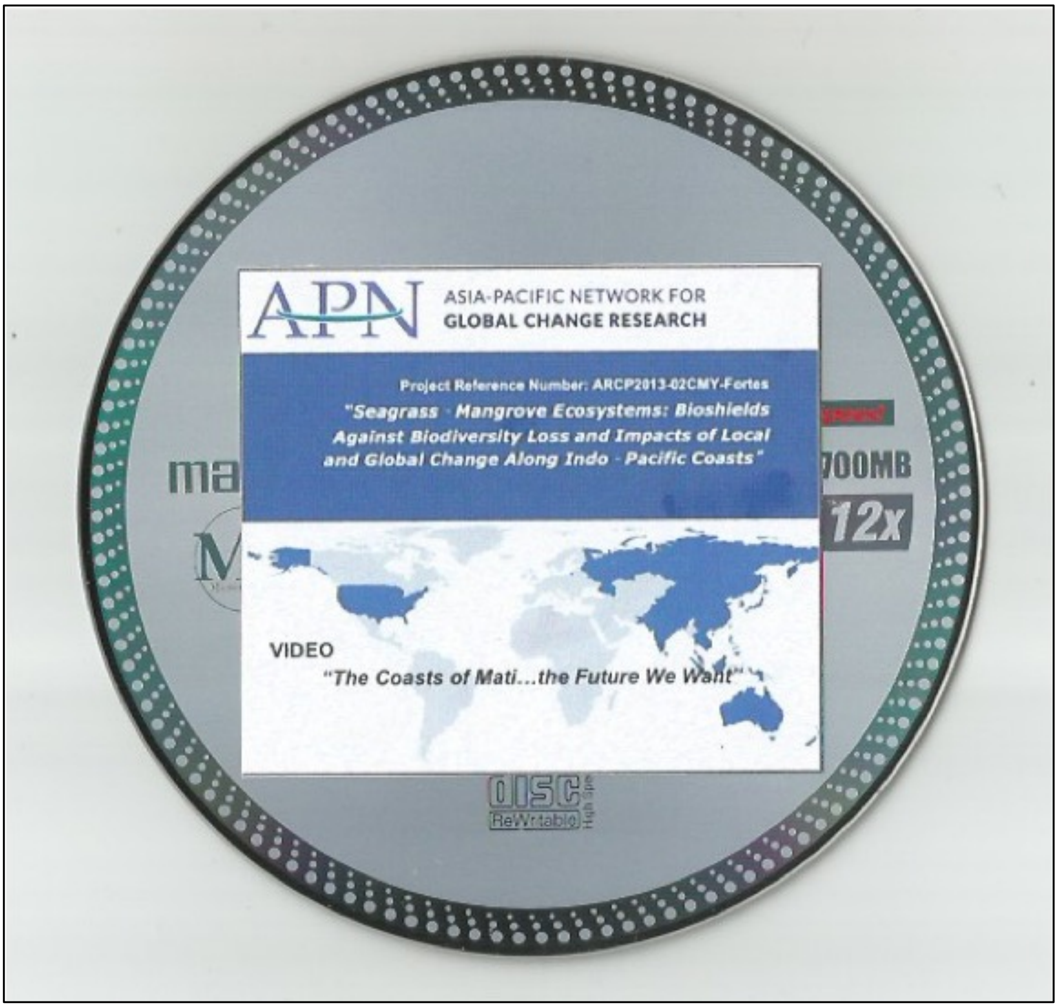
At seagrass and mangrove sites in the Philippines, India and Indonesia, we determined the nutrients, biodiversity, plant, macroinvertebrate and fish density, plant biomass and growth rates. These were correlated with key disturbance parameters, both natural and human-induced, including unsound laws. The results indicate a potential collective response of the ecosystems to act as bioshield, protecting and sustaining the productivity of the communities from the negative impacts of fish cage effluents and climate change. In addition, using the acoustic video camera DIDSON, we observed the underwater behavior of *Dugong dugon* (dugong) and obtained 3D video images of the bottom, giving rough estimates of seagrass density and distribution. In the case of mangroves, mono-specific plantation of *R. stylosa* significantly reduced species richness and variety of the mangrove vegetation. The policy implication of this finding is worth looking into in the light of massive financial and institutional support the current mangrove reforestation program of the Philippines and Indonesia get, using only *Rhizophora*. Thus, we argue in favor of a growing consensus, which places seagrass-mangrove system conservation as priority, developing a model of the ecosystems focusing on their 'bioshield' functions in mitigating local and global changes along Indo-Pacific coasts.

The concept of bioshield is visualized in the figure above. In its context, the role our projects play is to study how the issues and threats to the ecosystems could be fully understood so that the results could help reduce their impacts. This way, the long-term bioshield effects of the ecosystems are sustained, thereby facilitating their recovery and restore their services if disturbed. These services are the ecosystems' inherent properties, which, when fully understood, accepted, and adapted to by human communities, eventually ensure coastal environmental resilience and sustaianbility.

Video CD



Video of the major concerns of the APN SMBP with Mati, Davao Oriental, Philippines, as the model. Distributed 15 copies to Mati LGU, DOSCST, Amihan Boys, Resort Owners' Association, Governor's Office, Tourism Office