SOCIAL-ECOLOGICAL APPROACHES TO TROPICAL
ESTUARINE CONSERVATION

Dissertation Proposal

Ph. D. in Environmental Sciences and Resources

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1.0 GENERAL INTRODUCTION

Most estuaries around the world have shown increasing symptoms of stress and persistent degradations (Gray 1997; Kennish 2002). Recent literature review has estimated that about 90% of formerly important estuarine species have been depleted, approximately 65% of seagrass and wetland habitats have been destroyed, along with degraded water quality and accelerated species invasions (Prandle 2011).

Despite the obvious ecological and economic importance that estuaries have to offer (Barbier et al. 2011), there are few existing reserves established to protect estuarine ecological processes and functions. The protection of estuaries represents an enormous challenge due to increasing intensity and diversity of activities taking place (e.g. port and shipping, tourism and recreation, industrial development, artisanal fisheries and increasing coastal population) and the corresponding cross-sectoral conflicts among stakeholders (Hanna 1999; Gregory & Wellman 2001; Schneider et al. 2003; Lubell 2004; Safford, Carlson, & Hart 2009). The terrestrial and aquatic resource governing agencies also frequently overlap in their jurisdictions at the land-sea interface region which confound effective coastal protection planning (Leschine et al. 2003; Schneider et al. 2003; Safford et al. 2009).

In Malaysia, there are 14 ministries and 27 departments overseeing the sea and coastal zone management. Nevertheless, little progress has been made to resolve cross-sectoral management issues. The adoption of an Integrated Coastal Management (ICM) policy in the early 90’s, with its underlying objectives to incorporate multiple use of coastal zones through integrated planning at both the local and national levels, were met with little success (bin Basiron 2000). The failures were attributed to limited capacity development among the stakeholders and strong centralist political influence which favor short-term (private) economic interest (Pomeroy 1995; Siry 2006). Centralized political structure
presents significant impediment to grassroots management, participatory approaches or co-management practices (Centellas 2000; Kirya 2007; Abdul Jalil 2009).

In the absence of effective coastal management programs, terrestrially derived pollutants in the form of coastal plumes (Nichol 1993; Freeman et al. 2008), Polychlorinated Biphenyls (PCBs) (Sauer et al. 1988), heavy metals (Ismail, Badri, & Noor Ramlan 1993), Polycyclic Aromatic Hydrocarbons (PAHs) (Zakaria et al. 2002; Sakari et al. 2008), and the synergistic effects of these and other industrial waste which remain largely unrecorded, continue to predominate in estuarine waters. The tropical marine ecosystem is more vulnerable to such threats in view of the warm, humid climatic condition and soil biogeochemical properties that accelerate nutrient loss and release of soil-bound toxic substances through bleaching, deforestation and erosion (Schlesinger 1997), which in turn compromise marine ecosystem productivity (Granek et al. 2009) and negatively impact the socio-economic conditions of coastal communities (Pomeroy & Carlos 1997).

Tropical estuarine systems have evolved the resilience to cope with some of these land-based threats, primarily due to the presence of mangrove vegetation that buffer pollutants such as sewage effluents (Corredor & Morell 1994), sediments (Furukawa, Wolanski, & Mueller 1997) and heavy metals (Harbison 1986). Unfortunately, widespread mangrove deforestation has now left the world with only half its mangroves compared to several decades earlier (FAO, 2007), rendering nearshore habitats more exposed to man-made (Fortes, 1988) as well as natural threats such as coastal erosion (Mazda et al. 2002; Thampanya et al. 2006). Nevertheless, such cross-system threats are still little studied (Granek & Frasier 2007; Granek & Ruttenberg 2008).

Environmental management and sustainable development problems require an interdisciplinary approach that links both the ecological as well as the social systems (Berkes et al. 2000b). Reliance on modern science per se has been unsuccessful in addressing resource management problems. The collapse in the Atlantic Cod fishery (Holling et al. 1998) exemplifies one of the many contemporary resource management
crises due to overemphasizing the Western science (e.g. maximum sustainable yield) in designing policies for management. On the contrary, Traditional Ecological Knowledge (TEK), local or customary knowledge - is an ecological prudence encoded in a system of religious belief or social convention that has not only proven cost-effective in delivering locally viable and reliable means for resource management, but also the process of incorporating TEK helps to empower participatory management approaches and generate more support from the grassroots communities (Berkes et al. 2000b). TEK bridges the gap between social and ecological systems and can be effectively adapted for contemporary resource management, as revealed by a growing body of literature (Gadgil et al. 1993).

Several case studies in the marine realm that can lay claim to success through the application of TEK included marine reserve design in Oceania (Aswani & Lauer 2006), parrotfish protection in the Solomon Islands (Aswani & Hamilton 2004), folk taxonomy and systematics in Micronesia, reserve design in Belize, species knowledge for conservation in Kiribati (Drew 2005), cetacean conservation (Huntington 2000) and fishery management in Brazil (Silvano & Valbo-Jørgensen 2008). In the SE Asian region, however, documentation on TEK is surprisingly scarce (even in terrestrial systems) despite the region’s rich cultural and endogenous technology that evolved over centuries (Kurien 1998). It is fear that such intrinsic knowledge could potentially be lost (Zent 2001).

To address the social ecological challenges to estuarine conservation in the tropical region stated above, I combine both social and ecological approaches by 1) integrating TEK with modern sciences to identify high conservation priority areas, and evaluate the efficiency of TEK in capturing the ecological processes; 2) engaging stakeholders in a participatory workshop in order to gauge their perceptions, attitudes and the underlying social mechanisms that affect their decisions in estuarine ecological protection, and 3) to investigate the magnitude of the effects of mangrove clearing on an adjacent seagrass ecosystem. The Pulai River Estuary in Malaysia is used as a case study.
I hypothesize that the use of TEK from my study region will be capable of generating scientifically defensible data which is urgent to conserve the remnant ecological areas in light of pending development plans. The inputs of TEK will help build the capacity of our resource governing institutions, which are relatively novel, less well-coordinated and have limited technical and funding support (Pedersen et al. 2005), to oversee estuarine protection in a nested institutional framework advocating participatory management. Finally, understanding how the loss of mangrove buffer could significantly impact the adjacent seagrass ecosystem, and consequently the estuarine fisheries, could create more impetus for the local authorities to avoid mangrove deforestation in future development plans. This piece of research should have wide applications in the tropical regions facing similar situations such as the Pulai River Estuary (PRE).

1.1 RESEARCH DESIGN OVERVIEW

My dissertation consists of three chapters (Table 1). In Chapter 1, I use a Before-After-Control-Impact (BACI) approach to examine the changes in seagrass biomass, morphology and nutrient levels in areas subject to dredging activity preceded by mangrove clearing. While the implicit effects of mangrove clearing (sediment burial, nutrient overloads) may mask seagrass’ responses to dredging, this situation nevertheless creates a unique opportunity to scrutinize the synergistic effects of both the land and sea-based disturbances, if any. I hypothesize that seagrasses at disturbed areas will exhibit lower biomass, lower shoot and leave densities, longer leaves and higher N and P contents in the leaf tissues (Duarte 1990). I also hypothesize that not only will different seagrass species exhibit different responses to the above disturbance, the responses should reveal a trend along a gradient of distance from the centre of disturbance.

In Chapter 2, I intend to investigate which areas in the estuary are characterized by high social and ecological conservation priorities. Biophysical data on habitat distribution and diversity, distribution of existing as well as proposed development areas, and fishers’ knowledge on social and ecologically important areas will be used. The datasets will be compiled in GIS layers, analyzed and used to generate potential conservation scenarios. I
will examine how well fishers’ knowledge can be applied to explain estuarine habitat productivity. In my hypothesis, I anticipate that nearshore habitats will yield relatively high conservation priorities compared to the surrounding areas, and that estuarine habitat productivity can be adequately explained by fishers’ knowledge.

Chapter 3 builds upon data generated on estuarine conservation options in Chapter 2. A multi-stakeholder participatory workshop will be held to gauge the stakeholders’ attitudes, perceptions and the underlying social mechanisms which influence decisions on choosing the preferred estuarine protection goals. I hypothesize that resource users, managers, scientists and conservationists will favor conservation of ecologically important areas, while stakeholders whose socio-economic interests are in conflict with the former will favor otherwise. The key to this participatory workshop is to include all the relevant stakeholder groups, with emphasis on transforming the knowledge of the grassroots (fishers) communities, in a transparent decision-making process.

It is hope that the practical approaches undertaken in my research will help establish an ecosystem-based management framework for estuarine protection in my study area. The outcomes from this research are expected to facilitate a co-learning process for adaptive management and to address other socio-ecological challenges in regions with similar geo-political realities.
Figure 1: Conceptual Framework of Research Design
### Table 1: A summary of research topics and dissertation status

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Hypotheses</th>
<th>Expected Outcomes</th>
<th>Status</th>
</tr>
</thead>
</table>
| 1       | Impacts of mangroves clearing and dredging activity on tropical seagrasses | - Seagrasses at disturbed area will exhibit lower biomass, lower shoot and leave densities, longer leaves and higher N and P contents.  
- Different species respond differently to the type of disturbances.  
- Responses follow a trend along a gradient of distance from the centre of disturbances. | - Develop seagrass health indicators for early detection of adverse disturbances.  
- Promote land-sea interface conservation.  
- Understanding synergistic stressors. | Completed:  
Field sampling; with perhaps another sampling in June 2012.  
In progress:  
Nutrient analysis  
Data analysis |
| 2       | Integrating traditional ecological knowledge with natural science in a participatory GIS-based estuarine conservation planning. | - Nearshore habitats yield relatively higher conservation priorities  
- Estuarine habitat productivity can be adequately explained by fishers’ knowledge. | - Emphasize the need for nearshore habitat protection.  
- Demonstrate the integrity of TEK in contemporary resource management. | Completed:  
All data collection  
In progress:  
Spatial data analysis.  
Satellite image analysis. |
| 3       | Stakeholders’ views, perceptions and attitudes in a GIS-based participatory approach towards estuarine resources and conservation planning. | Resource-dependent users will favor conservation of ecologically important areas, while stakeholders whose socio-economic interests are in conflict with the former will favor otherwise. | - Promote transparency in a participatory management.  
- Understanding underlying social mechanism for estuarine protection.  
- Reflect community goals and priorities. | Completed:  
All data collection  
In progress:  
Qualitative data analysis |
2.0 CHAPTER 1: IMPACTS OF MANGROVES CLEARING AND DREDGING ACTIVITY ON TROPICAL SEAGRASSES

2.1 INTRODUCTION

Mangroves are transitional habitats between land and sea. One of the vital ecological functions mangroves provide is their ability to buffer sediment transport from terrestrial realms (Furukawa et al. 1997) thus significantly promoting the physical and biotic health of nearshore marine habitats.

Thus far, the magnitude of the effects of mangrove clearings on nearshore marine habitats is poorly understood owing to a lack of relevant research. A handful of studies point out that cleared mangrove areas suffer from consequences of higher algal biomass and richness, higher temperature, lower light penetration and reduced sediment organic content (Granek & Ruttenberg 2008) and lower zooplankton richness relative to intact mangroves (Granek & Frasier 2007). It was cautioned that mangrove loss can also potentially compromise nutrient subsidies to adjacent reef habitats (Granek et al. 2009) and seagrass beds (Slim et al. 1996).

Seagrass meadows represent a closely connected ecosystem with mangroves. Their ability to trap sediment derivatives from mangroves, and role as transient habitats for mangrove and reef fishes, have been highlighted in a number of studies (Furukawa et al. 1997; Marguillier et al. 1997; Dorenbosch et al. 2004; Nagelkerken & Van der Velde 2004; Bouillon et al. 2007).

As seagrasses are particularly sensitive to light reduction (Short & Wyllie-Echeverria 1996; Eldridge, Kaldy, & Burd 2004; Orth et al. 2006), one can expect that the physical and biotic environment in seagrass ecosystems will inevitably be affected when mangroves are cleared due to increased sedimentation and siltation run-off. The degradation of seagrass ecosystems can lead to significant declines in marine productivity (Zieman and Wetzel, 1980; McArthur & Boland, 2006)) and the loss of ecosystem functions e.g. nutrient recycling (Touchette & Burkholder 2000), fisheries (Heck, Hays, & Orth 2003) and endangered species (Williams and Heck, 2001).
Despite the widespread documentation on the importance of mangroves and seagrasses, both ecosystems have suffered significant declines and damage. Approximately 50% of the world’s mangroves have been cleared to date (FAO, 2007) while an estimated 33,000 km² of global seagrass area has been lost (Short & Wyllie-Echeverria 1996).

Linked mangrove-seagrass ecosystems provide an excellent model to examine land-sea interface issues in view of their close proximity and connectivity. I hypothesize that seagrasses adjacent to cleared mangrove sites will be adversely impacted. I use seagrass biomass, shoot density, rhizome diameter and leaf tissue nutrient content as health indices in an attempt to find correlation with changes in water turbidity and water nutrient concentrations as possible drivers associated with mangrove clearing.

Previous literature indicates that seagrass shoot length generally increases as an indirect response to high turbidity, but shoot density, percent cover and biomass are significantly reduced (Vermaat et al. 1997; Bach et al. 1998; Tuya et al. 2002; Fyfe & Davis 2007). Tissue nutrient content is a consistent indicator as seagrasses from low-nutrient habitats contain significantly higher C:N ratios and vice versa (Touchette & Burkholder 2000), especially in the leaf where nutrient uptake affinities are higher than the root tissue (Pederson et al., 1997; Lee and Dunton, 1999) corresponding to increase enzymatic activities (Ferrat, Pergent-Martini, & Rome 2003).

Smaller seagrass species appears to exhibit lower tolerance to reduced light attenuation and sediment burial. In a study on tropical seagrass species, Bach et al. (1998) noted that species’ decreasing tolerance to siltation is in a sequence of Enhalus acoroides > Cymodocea serrulata > Halodule uninervis > Thalassia hemprichii > Halophila ovalis > Cymodocea rotundata > Syringodium isoetifolium. In an experimental study, H. ovalis recorded 50% shoot mortality in 2 cm burial while no significant effects were observed on larger species (Cabaco, Santos, & Duarte 2008). Recommendations were made so that short-term sedimentation on seagrass meadows over time spans of two months should not exceed 5 cm (Vermaat et al. 1997) and that the leaf size and rhizome diameter should be employed as predictors in response to increased sediment burial (Cabaco et al. 2008).
Sediment sulphide, which is associated with an increase in the input of organic matter, can impose toxicity to seagrasses as sulphide invades into the roots and moves to the other tissues through the lacuna thus causing reduced growth and mortality (Frederiksen et al. 2007). The accumulation of organic matter at the rate of 7-10 cm is deemed lethal to *T. testudinum* and causes unsuitable conditions for seagrass recolonization for up to 2.5 yrs (Eldridge et al. 2004).

My hypotheses are:

- Smaller seagrass species that have lower canopy height will sustain significant reduction in biomass in view of light attenuation closer to the bottom and low carbohydrate storage capacity in contrast to larger species (Vermaat et al. 1997; Bach et al. 1998).
- Seagrasses occur at cleared mangrove sites will sustain higher N in the leaf tissue and as driven by higher nutrient availability in proximity to the disturbed site. Seagrasses from low-nutrient habitats have significantly higher C:N and C:P ratios than plants from high-nutrient conditions (Duarte 1990).
- Turbidity at the dredged site is expected to be higher, therefore seagrasses will sustain longer shoot leaves; but lower shoot density, percent cover and biomass. This may be due to sediment re-suspension inflicting light attenuation in the seagrass areas, resulting in reduced seagrass shoot density, biomass and rhizome reserves but a rapid increase in shoot length to extract sunlight (Tuya et al. 2002; Ruiz & Romero 2003).

These multi-level effects on seagrasses mentioned in my hypotheses will be examined across a range of environmental gradients such as turbidity, salinity, temperature, depth, dissolved oxygen, pH and nutrients (nitrate, nitrite and phosphate) at the Pulai River Estuary in Malaysia. By using seagrass health indices, I anticipate detection of significant differences in seagrass conditions between intact and cleared mangrove sites, with those at the intact sites being in a healthier state.
Figure 2: Conceptual model of seagrass loss and degradations due to anthropogenic activity

2.2 MATERIALS AND METHODS

2.2.1 Study Site

The proposed study area is located at the Pulai River Estuary (1°21′17.95″N; 103°32′22.70″ E), Malaysia. PRE is characterized as a coastal plain alluvium estuary with stable, year-round salinity that ranges between 26 and 30 psu in the middle and lower reaches (Anon, 1999) with a maximum tidal range of 3.5 m. There are a total of eight seagrass species recorded at the estuary but the proposed sampling stations consist only of the larger *Enhalus acoroides* and a smaller *Halophila ovalis*. 
Figure 3: (Left) Map showing the monitoring sites at the Pulai River Estuary. Stn 1 (inset) represents intermediate disturbed site adjacent to Stn 2 where all mangroves have been cleared; while Stn 3 is a reference site with intact mangroves. (Right) Enlarged inset picture showing locations of dredging, pier construction and seagrass meadow.

Three sampling sites (Figure 3) were selected (Stn1, Stn2 and Stn3) on the basis that they are identical in terms of seagrass and algal species, depth and sediment types. Seagrass meadows to the south (Stn1) still retain mangrove as a buffer while Stn2 was cleared of mangroves in July 2009. Dredging occurred from Sept 2010 through Dec 2010 at Stn 2 followed by pier construction which ended in April 2012.

Stn1 represents an intermediate disturbed site where some mangroves have been cleared while Stn3, approximately 8 km from the disturbed area, is used as a control site with intact mangroves. Stn2 had loss all its mangroves by 2010. The salinity differences among these sites are minimal (within 1-2 psu). Seagrass meadows further upstream were not chosen due to lower salinity and the potential spurious effects of mariculture activities. Three sampling stations were established
at each site. The frequency of field sampling was on a monthly basis between July-Dec 2010, and at three-month intervals from March to Dec 2011.

### 2.2.2 Seagrass Collection and Measurements

Given the high turbidity in the sampling areas, the use of *in situ* observation could not be implemented. Therefore, triplicates of seagrasses (including macroalgal) samples were collected (including roots) from each station from three haphazardly placed 0.5 X 0.5 m frames. Samples were kept in freezer below 4°C for laboratory analyses on biomass, shoot density, morphology and nutrient contents.

Plant were rinsed, scrapped off epiphytes and epibionts and sieved off sediment. Shoot density will be counted as the total number of shoots and the number of leaves per shoot. Shoot length, petiole or vertical stem and sheath length were measured. Seagrass rhizome diameter were measured with a calliper with a precision of 0.001 cm (Figure 4).

Samples were separated from underground and non-photosynthetic parts (leaf blades, leaf sheaths vs roots plus rhizomes, except in the case of *H. ovalis*, which were separated into leaves plus petioles, and rhizomes plus roots). The biomass of seagrasses, macroalgae were determined by drying the samples at 60°C for 48 h and weighed (Terrados et al. 1999).

### 2.2.3 Water quality

Water quality parameters were sampled *in situ* (salinity, temperature, TSS, dissolved oxygen and pH) using Hach Multiparameter Probes. Three water samples (100 ml each) were collected at each station during outgoing tides in polyethylene water sampling bags (preserved in silicate acetate) and immediately packed in an ice-filled insulated container and frozen (in an upright position) for nutrient analyses within 48 h. Water quality analyses for turbidity and nutrients followed methods described in Parson (1987).
2.2.4 Plant nutrient contents

Seagrasses leaf tips were taken from new leaf to minimize leaf age effect on nutrient contents (Alcoverro, Cerbian, & Ballesteros 2001) and grounded into powder using agar mortar. The ash free dry weight of the material were determined following combustion for 4 h at 450°C. N:P content in seagrass leaves were analysed using spectrophotometer DR5000 following Hach protocols. Total Organic Carbon will be measured on the particles collected on precombusted filters using a TOC analyzer Carruthers (2005).

![Seagrass morphology](www.seagrasswatch.org)

Figure 4: Seagrass morphology. Source: www.seagrasswatch.org

2.2.5 DATA ANALYSES

Data description and exploration were carried out to examine the responses of seagrass species and their morphology toward environmental gradients. Non-normality data were log-transformed prior to using any parametric test such as ANOVA to compare differences in seagrass biomass, morphological characteristics and nutrient contents across sites. Seagrass responses were examined along a gradient of distances from the centre of the disturbed site. Non-Metric Dimensional Scaling (NMDS) will be employed to identify the potential indicators for nutrient
enrichment. All data analyses were done using the statistical software package R (R development core team, 2008) and Ms. Excel.

2.3 PROJECT OUTCOMES

Since there is virtually no study on the response of seagrasses toward mangrove clearing, my study will advance our understanding on the vital links between mangroves and the adjacent nearshore habitats. This understanding can in turn serve as a powerful tool to lobby for the preservation of an intact mangrove buffer along the coastlines as an effective strategy to manage marine ecosystems.

In addition, using seagrass health conditions is a cost-effective approach that provides early indication of coastal degradations. For instance, a trigger point approach (possibly based on C:N:P contents, shoot density and length) can be employed as indicators to initiate management intervention. The development of such indicators can potentially be applied to mitigate other anthropogenic threats to nearshore ecosystems (Hemminga, Marba, & Stapel 1999).

2.4 MAJOR FINDINGS THUS FAR


There is a clear trend of increasing seagrass biomass in *E. acoroides* with increasing distance from disturbed site. The control exhibited an average 48% higher biomass compared to the disturbed site. There are some differences in seagrass morphological characters between sites notably shoot and leaf densities but it is still early to draw any conclusive remarks prior to the completion of my data analysis. The smaller *H. ovalis* had dissapeared from the disturbed site since the onset of dredging and only recovered in Dec 2011. At this point of the analysis, it is still not clear whether mangrove clearing or dredging exert more profound impact on seagrasses. Water quality data did not present significant difference across sites.
In Progress:

Data analysis and laboratory analysis on nutrient contents

*For more detailed findings please refer to Appendix.*

*Target Journal: Biological Conservation*

*To be submitted: Nov 2012*
3.0 CHAPTER 2: INTEGRATING TRADITIONAL ECOLOGICAL KNOWLEDGE WITH NATURAL SCIENCES IN A PARTICIPATORY GIS-BASED ESTUARINE CONSERVATION PLANNING

3.1 INTRODUCTION

The application of Traditional Ecological Knowledge (TEK) in natural resource management has received increasing attention in recent decades, largely due to the failures of mainstream resource management that forces scientists and managers to seek alternative solutions. In contrast to contemporary resource management that focuses on a single species or population, TEK is holistic and employs an ecosystem-based approach. More importantly, TEK has proven its ability to foster sustainable resource management across the spatial and temporal scale (Menzies 2006).

The calls for integration of TEK into contemporary resource management (Johannes 1993) are hardly surprising considering the obvious advantages TEK has to offer. Indigenous people stored large amounts of physical and ecological details in their collective memory (Aberley 1993) that equipped TEK with ready and reliable means for local resource management (Aswani & Lauer 2006), especially in the absence of scientific data which are time-consuming and expensive to generate (Ferguson & Messier 1997; Berkes, Colding, & Folke 2000a; Huntington 2000; Folke 2004). TEK also reflects community’s goals thus helping to empower participatory management approaches and generate more support from the grassroots communities (Berkes et al. 2000a). Nevertheless, TEK has its limitations. The locally developed knowledge means that its application beyond the immediate context of the study region would be irrelevant (Menzies, 2006).

TEK is more widely documented, if not evolved, in terrestrial systems. Few scientific journals are available on the application of TEK in the marine realm. A handful of these include marine reserve design Asinara Island (Villa, Tunesi, & Agardy 2002), British Columbia (Ban et al. 2008), Oceania (Aswani and Lauer, 2006), parrotfish protection in the Solomon Islands (Aswani and Hamilton, 2004), folk taxonomy and systematics in Micronesia, integrated coastal zone
management in Belize (Mumby et al. 1995), species knowledge for conservation in Kiribati (Drew 2005), cetacean conservation (Huntington 2000) and fishery management in Brazil (Begossi 2001; Silvano & Begossi 2005).

Ironically, documentation on TEK in the Indo-Pacific is surprisingly scarce despite the region’s rich cultural and endogenous technology that evolved over centuries and although much of the local knowledge in this region is still operational (Kurien 1998). The information gap on TEK is particularly evident for estuaries where there is hardly any case study available. The severity of habitat degradations (Gray 1997; Kennish 2002) and complications of cross-sectoral management issues in estuaries warrants participatory management (Hanna 1999; Gregory & Wellman 2001; Schneider et al. 2003; Lubell 2004; Safford et al. 2009) and as such TEK can potentially be very useful.

There are existing challenges for integrating TEK into contemporary resource management. Not only do researchers face technical obstacles on how TEK, which is often available in non-written context and encoded in cultural practice, can be translated into modern management tools, the interpretation and application of TEK itself requires understanding of the cultural context within which TEK is produced and maintained. Another challenge is the requirement for rigorous verification of TEK in the modern scientific framework. These shortcomings probably explained why many current regulations and practices do not provide the effective mechanism for the integration of TEK into active management (Menzies 2006).

The ultimate goal of this study is to demonstrate how TEK can be deployed as a tool that integrates natural and social systems in resource management planning and execution. In order to do so, I 1) verify how TEK is useful in identifying productive habitats through the use of spatial analysis. Local fishers have first-hand experience and knowledge of the environment that they exploit, including direct assessment of fish stocks, spawning and nursery areas. The cognitive maps derived from artisanal fishers represent their TEK which can be converted into geo-spatial representations so that productive habitats can be distinctly conceptualized, and further verified using ecological data. I hypothesize that TEK adequately identify productive habitats using data
derived from ecological studies, and that nearshore habitats will yield higher productivity, and consequently, conservation priorities.

The research findings are expected to generate strong implications to lobby for the protection of nearshore habitats in support of land-sea interface conservation, as well as to promote an effective mechanism for integrating TEK into future resource management in a data-poor region facing increasing pressure for development.

3.2 METHODS
3.2.1 BIOPHYSICAL PROFILE

The study area is located at the Pulai River Estuary (1°21'17.95''N; 103°32'22.70'' E), Malaysia which lies on the opposite side of the western portion of Singapore. Characterized as a coastal plain alluvium type, the estuary is approximately 20 km in length and 2 km wide at the river mouth. There are numerous tributaries along the main river occupied by riverine mangroves (9,126 ha of Ramsar Site to the upper reaches). Extending into the straits are seagrasses, coral reefs, rocky shores and mudflats. The Pulai River Estuary was hailed as one of the most productive estuaries in the Peninsular Malaysia (Anon 1999) (Figure 5).

The lower reaches of the Pulai River Estuary are subject to various large-scale industrial development since the beginning of the year 2000. These include the port and shipping, coal-fired powerplant, petrochemical and maritime industries, artificial bunkering islands and several medium-sized factories. Such developments had adversely affected the social and ecological wellbeing of the estuary.

3.2.2 SOCIO-ECONOMIC PROFILE

There are approximately 600 artisanal fishers at the Pulai River Estuary. The majority of the fishers are the Malay people who employ gill nets, cast nets, hooks and line, and fish traps. The Malay fishers’ occupation of the estuary probably trace back to three to four generations.
On the other hand, there is an indigenous group called the Seletar or sea gypsies, who resided in boathouses prior to relocation on land in the 1950’s. Historical record of the Seletar’s occupation of the estuary can be traced back to as early as the 5th century, when they were the major suppliers of exotic marine products for the Chinese market. The Seletar people also provided a naval force for successive Malay kingdoms and during that period of time, some of them had royal status (Chou 2003). The fishing gear the Seletar employ are more primeval, encompassing tools such as “pompong”, “hand-pick” and hooks. The species targeted by the Seletar people are more diverse, ranging from shellfishes to dugongs and crocodiles. The Seletar derive their shelter and medications entirely from mangrove resources.

Both the Malay and the indigenous Seletar fishers differ to some extent in their cultural contexts. The Malays, who are strictly Muslim, perceive certain places like fjords and islands, as taboos while the Seletar fishers viewed them as sacred sites. The Seletar fishers practice ritual respects by offering glutinous rice to the supernatural beings. This is accompanied by chanting before they began fishing. Harvest is perceived by the fishers as fish stocks made themselves available for catch. The Malay fishers apparently had similar ritual practice in the past, but have now been dismissed by the younger generations. As a matter of fact, the Seletar’s ritual practice is also increasingly eroded primarily due to the introduction of modern fishing gear and influence of Christianity which views such practice as perpetuating witchcraft. Sustainable harvest by the Seletar people is probably underpinned by the belief that overharvesting may aggravate the supernatural spirits which makes them fall ill or encounter misfortune. For the Malay fishers, fishing intensity is self-regulatory as per compliance to the Islamic teaching on self-complacency. During the Ramadhan period, fishing effort is significantly reduced which may provide some relief on fish stocks.

3.2.1 DATA COLLECTION

TEK was sampled from active and experienced artisanal fishers (N=97) who resided in 11 coastal villages scattered around the Pulai River Estuary. The interviews were conducted between 2010 and 2011. A base map, divided into 2 x 2 km planning units (400 ha each), with
the justification that some fishers had difficulty mapping areas on a finer scale; while larger planning units tend to cluster biophysical features which may mask the underlying relationships this study intend to investigate, was used for delineating fishing, spawning and nursery areas. Mental mapping technique was employed (Huntington 1998) where fishers marked important fishing, spawning and nursery areas on a paper map. Fishers who cannot identify features on the map were facilitated by the researcher to elicit an oral account and provided tacit and intuitive information.

Figure 5: Biophysical and social features of the Pulai River Estuary. Inset picture depicts an ongoing development of a petrochemical station.
The biophysical features of the estuary were extracted from satellite images (SPOT 5: year 2008; bandwidths: 4) obtained from the Malaysian Remote Sensing Center (MACRES). Ground-truthing was carried to verify these features. To elicit data on habitat productivity, the acreage of each habitat type in the estuary (coastal phytoplankton, mudflat microphytobenthos, coral reef, seaweeds, seagrasses and mangroves) were calculated in ArcGIS and multiplied by the corresponding Net Primary Productivity (NPP) values using data derived from available sources (Duarte & Cebrian 1996)[Table 1]. As coastal phytoplankton density tends to exhibit high spatial variations, hyperspectral bands from satellite imagery will be classified to elicit the spatial variations in coastal phytoplankton productivity.

Figure 6: Classifications of hyperspectral bands yield reflectance levels from suspended sediment in coastal waters in contrast with low reflectance from river plumes. TM1 (blue wavelength identifies organic plumes containing yellow substance).

3.2.3 SATELLITE IMAGERY PROCESSING

Remote sensing of sea color yields information on water-quality parameters, such as the concentration of phytoplankton pigments, suspended sediment, and yellow substance in the euphotic layer. Coastal waters are often referred to as case 2 water in contrast to case 1 in the
ocean water. The correlation of coastal water phytoplankton, suspended sediment and yellow substance may exhibit large spatial and temporal variations as a result of local phenomena such as river drainage, bottom re-suspension, and urban and industrial effluents.

Chlorophyll is the main constituent responsible for spatial and temporal variations of reflectance spectra in oceanic, coastal and shelf waters. Coastal waters often contain varying amounts of dissolved organic carbon and nonliving particulate matter that make interpretation of reflectance spectra more difficult. Hyperspectral analysis using visible wavebands are dominated by absorption of blue and red light by chlorophyll. Green vegetation gives higher reflectance to green light. A decrease in chlorophyll content will give rise to increased reflectance in the blue and red wavebands. The Near Infrared (NIR) waveband is dominated by reflectance from the cell water interface and as cell structure collapses due to stress, reflectance in the NIR wavebands decreases (Han, 1997).

Chlorophyll-a exhibit strong absorption between 400-500 nm (blue) and at 680 nm (red), and reflectance maximums at 550 nm (green) and 700 nm(NIR) (Han, 1997). At the Pensacola Bay, the ratio of ETM+ 1/ETM+3 was found to be most effective in estimating chlorophyll-a (Han & Jordan 2005). One study close to the Pulai River Estuary established that the blue wavelength is found to be sufficient to segregate DOM, sediment-dominated and clear waters. In this regard, DOM exhibit low reflectance (Nichol 1993) and can potentially serve as a function for productivity (Baines & Pace 1991; Thomas 1997; Karl et al. 1998).

Tools to extract chlorophyll-\(a\), from ocean colour data from satellite sensors are being actively developed. These include the CZCS (Coastal Zone Color Scanner), SeaWiFS (Sea Viewing Wide Field-of-View Sensor) and OCTS (Ocean Colour and Temperature Scanner) as well as theoretical models that allow ocean colour to be expressed as a function of the inherent optical properties of seawater, such as the absorption coefficient and the backscattering coefficient (Sathyendranath et al. 2001). However, these tools are more successfully applied for deep ocean (Case 1) waters (Han & Jordan 2005). Band ratioing still proves to be the most advantageous approach because it allows compensation for variations from atmospheric influences (Jensen,
At this stage, my study is exploring which tool (above) are most conducive to extract chlorophyll-a data from the satellite images.

3.2.4 SPATIAL QUANTITATIVE ANALYSES

To develop model specification for habitat productivity, the independent variables consist of productive fishing, spawning and nursery areas. Spearman Rank Test was employed to examine the relationship between habitat productivity and the independent variables. Prior to developing the multiple regression models, all variables were examined for data normality and distribution and transformations were made to meet normality. A diagnostic check was performed on the multiple regression model to examine if the model meets the underlying assumptions (linearity, normal residuals, equal variance, influential data points, independent residuals, multicollinearity and spatial autocorrelation) (Zar 1999).

Using GeoDa, spatial lag model was developed to address spatial structure while a spatial error model is appropriate to address structure in the residual term with maximum likelihood used as the fitting method (Anselin et al. 2006). Geographically Weighted Regression (GWR) was also employed using ArcMap 10 in the Spatial Statistic Tools. GWR is a fairly recent contribution to modelling spatially heterogeneous processes. The underlying idea of GWR is that parameters may be estimated anywhere in the study area given a dependent variable and a set of one or more independent variables which have been measured at places whose location is known. Nearer locations are assigned greater weight in the estimation than observations which are further away. Since observations are clustered, the densities of observations are non-uniformly distributed around the study area thus an adaptive kernel was employed. Regression coefficients are then mapped as raster surfaces and this offers a sophisticated basis to quantify and dissect spatial patterns across a study area. The three models are compared for their fitness in terms of the adjusted $R^2$ and Aikake Information Criterion (AIC). Lower AIC by 3 in the model indicates a better fit (Fotheringham, Brunsdon, & Charlton 2002).
3.3 MAJOR FINDINGS THUS FAR

The findings argue that the coastlines along the Pulai River Estuary are important predictors for habitat productivity, which is consistent with where mangroves, seagrasses and mudflats are aggregated. Using Geographically Weighted Regression, it was established that TEK explained approximately 50% of habitat productivity in the estuary.

*Please refer to Appendix for preliminary results and more detailed information.*

*In Progress:*

- Sourcing for net primary productivity values from the literatures for the related ecosystems closer to my study site.
- Extracting phytoplankton densities and DOM from the satellite imagery.
- These two steps will very likely to improve TEK explanatory power on habitat productivity.

*Target Journal: Ambio*

*To be submitted: Aug 2012*
4.0 CHAPTER 3: STAKEHOLDERS’ VIEWS, PERCEPTIONS AND ATTITUDES IN A GIS-BASED APPROACH TOWARDS ESTUARINE RESOURCES AND CONSERVATION PLANNING

4.1 INTRODUCTION

The social dimension challenges to resource conservation and planning in marine areas, as opposed to terrestrial system, are underpinned by open access which complicates institutional management arrangements (see (Gordon 1954; Hardin 1968) exceptions for regions where traditional sea tenures persist e.g. Oceania, Philippines; (Pomeroy & Carlos 1997; Johannes 2003). As human demands on ocean resources escalate, there is a growing need and urgency for the development of multiple-use management strategies. In the last few decades, management strategies such as Marine Protected Areas (MPAs), marine reserves and Integrated Coastal Management Zone (ICZM) have been implemented across the globe.

However, little attentions and efforts have been made to address estuarine protection, despite the obvious ecological and economic importance that estuaries have to offer (Barbier et al. 2011). The challenges for estuarine protection are presumed to be greater, where the intensity and diversity of activities taking place (e.g., port and shipping, tourism and recreation, industrial development, artisanal fisheries and increasing coastal population) and the corresponding cross-sectoral conflicts among stakeholders (Hanna 1999; Gregory & Wellman 2001; Schneider et al. 2003; Lubell 2004; Safford et al. 2009) are more prominent. The terrestrial and aquatic resource governing agencies also frequently overlap in their jurisdictions at the land-sea interface which confound effective coastal protection planning (Schneider et al. 2003; Safford et al. 2009).

Management intervention that involves a shift in property rights from open access invariably provokes conflicts among, and between, user groups who have differing socio-economic interests. Conflicts are no less common in the process of MPA establishment (See Fortner & Lyon 1985; Kriwoken & Haward 1991; Cocklin, Craw, & McAuley 1998; Suman, Shivlani, & Walter Milon 1999; White, Courtney, & Salamanca 2002; Middlebrook & Williamson 2006; Stump & Kriwoken 2006; Chang, Hwung, & Chuang 2011) as driven by differences in
stakeholders’ perceptions and attitudes. In Tasmania, 39% of commercial fishers rejected the idea of MPA expansion citing concerns over the limitations imposed on their fishing areas (Stump & Kriwoken 2006). In the Florida Keys, marine zoning garnered the highest support from environmental groups, while dive operators and fisher groups were less supportive fearing their existing rights would be limited or excluded (Suman et al. 1999). The degree that each community depended on marine resources for income, and the influence of individuals within the communities, also contribute significantly to differences in attitudes among the villages in Fiji (Middlebrook & Williamson 2006). Cognitive differences among the stakeholders were also found during MPA establishment in Taiwan (Chang et al. 2011).

The nature of conflicts can be divided into internal as well as external (Pendzich et al. 1994). Internal conflicts are frequently observed among the local communities and this includes inequities in terms of access to resources, variations in caste, class and gender. On the other hand, external conflicts can be driven by political and economic influences. When local or traditional mechanisms to regulate access to natural resources are not recognized by the state or state agencies, resource management is unlikely to yield success. The presence of powerful private enterprises significantly downplays the rights of resource user groups (Buckles 1999; Suman et al. 1999) especially in regions where political climate does not favor democratic and participatory process (Niamir-Fuller & others 1999). Although the balance of power among stakeholders is crucial for effective resource protection (Hjortsø et al. 2005; Bruckmeier & Höjlarsen 2008), in reality, such balance is difficult to achieve in view of other problems e.g., bribes and political violence which complicate the situation.

Understanding perceptions and attitudes of stakeholders are of paramount importance in order to foster effective resource management planning. In Fiji MPAs, it was conjectured that larger zoning of marine reserve could have been drawn if careful prior social and economic analyses were conducted at the early stage (Suman et al. 1999). Through participation in the decision-making process, people can actively understand their roles and responsibility in the MPA establishment thus avoiding conflicts at a later stage (Chang et al. 2011). Participatory management provides the transparency in facilitating effective communication between communities and interest groups, and enhances the ability to solve problems (De Marchi &
Grassroots resource users can benefit profoundly through participatory management due to their lacking the means to articulate their perspectives. Once the attitudes and perceptions are understood, outreach programs and information dissemination strategies can be designed accordingly for the targeted stakeholder groups (Suman et al. 1999).

In recent years, participatory GIS has gained increasing popularity as a promising tool to facilitate the convergence of stakeholders in decision making regarding resource management (Maguire et al. 1991) and community empowerment (Poole 1997). In this study, I incorporate a participatory GIS workshop in order to canvas stakeholders’ attitudes, perceptions and the key issues which influence their decisions on choosing the preferred ecological conservation goals in a tropical estuary. I hypothesize that resource users, managers, scientists and conservationist will favor conservation of ecologically important areas, while stakeholders whose socio-economic interest are in conflict with the former will favor otherwise. The key to this participatory workshop is to include all the relevant stakeholder groups, with emphasis on transforming the knowledge of the marginalized communities for joint-learning, in a transparent decision-making process with the potential of reducing conflicts in the future.

4.2 BACKGROUND

4.2.1 INSTITUTIONAL FRAMEWORK

Malaysia’s political institution is closely modeled after the Westminster parliamentary system. While some political analysts attribute Malaysia’s political system as democratic-authoritarian (Lim & Stern 2002), others claimed that an authoritarian regime was widely practiced between 1980s and 2000s (Mauzy & Milne 1999; Nathan 2006).

There are 14 ministries and 27 departments overseeing ocean and coastal zone management. Nevertheless, little progress has been made to resolve cross-sectoral management issues. The adoption of an Integrated Coastal Management (ICM) policy in the early 90’s, with its underlying objectives to incorporate multiple use of coastal zones through integrated planning at
both the local and national levels, were met with little success (Basiron, 2000). The failures were attributed to limited capacity development among the stakeholders and strong centralist political influence which favor short-term (private) economic interest (Pederson, 2005, Siry, 2006; Pomeroy, 1995).

4.2.1 BIODIVERSITY AND ECOSYSTEM

The Pulai River Estuary represents excellent ecosystem integrity and an important socio-economic resource and wildlife habitat. It contains the largest block of mangrove forest in the state and the largest remaining intact riverine mangrove area in Peninsular Malaysia accounting for 9,126 hectares. With its associated seagrass beds, intertidal mudflats and inland freshwater riverine forest it represents one of the best examples of a lowland tropical river basin in Malaysia. Sungai Pulai is rich in its mangrove diversity consisting of a total of twenty-four species even though the majority is *Rhizophora mucronata* and *Bruguiera parviflora* stands. The forestry practices that are being carried out are sustainable and are managed well. The extensive riverine mangroves support a rich biological diversity of fauna comprising 7 amphibians, 12 reptiles, 55 birds, 26 mammals and 111 fish species (Ramakrishna, Murugadas, & Sim 2001).

4.2.2 KEY PLAYERS AND DEVELOPMENT ISSUES

The majority of the communities who reside around PRE are fishers. Presently fishing and agriculture accounted for 45% of their livelihood, followed by manufacturing (35%) and civil service (8%). The Malays are the dominant ethnic group (over 95%) One population of indigenous group known as the Seletar or Sea Gypsies currently resides in the upstream of the PRE. This group is intrinsically and culturally bound to the mangrove resources.

In 1990s, major infrastructure projects such as the Second Crossing to Singapore and the Port of Tanjung Pelepas were spurred by the Malaysian Government’s VISION 2020\(^1\)(a national vision,

\(^1\) **Vision 2020** is a Malaysian ideology introduced by the former Prime Minister of Malaysia, Mahathir bin Mohamad during the tabling of the Sixth Malaysia Plan in 1991. The vision calls for the nation to achieve a self-sufficient industrialized nation by the year 2020, encompasses all aspects of life, from economic prosperity, social well-being,
Malaysia’s blueprint to become a fully developed nation by the year 2020) which was the ideology of the then Prime Minister Mahathir. The Port of Tanjung Pelepas was slated for development in five phases and scheduled to establish 12 berths completed by the year 2020. Privatization was allowed and a 60-year concession was awarded to Seaport Terminal (Johor) to support the development and by encouraging Malaysian banks to arrange financing. Seaport was granted a RM 2 billion loan by syndicate bank and 800 ha of Free Zone Status by the Government. The port’s master plan and preliminary design were completed within just a couple of years (1995-1996), enabling the project to start in 1997 and have its first staged completion in 1999 (Renkema & Kinlan 2000).

The reclamation of the port on mangroves, seagrass and mud banks contributed to dramatic declines in fishing yield because the site used to be the richest fish aggregating area. The conditions were exacerbated when the port started its operation where cargo vessel navigation substantially reduced accessible fishing areas, and in 2003 the second stage development extended the port 2 km seaward.

In 2003, a coal-fired powerplant was installed on a 41-acre abandoned shrimp pond on the western side of the river mouth. A couple of years later, the petroleum storage bunkering island was reclaimed seaward next to the coal-fired powerplant. This project further reduced the available fishing areas and fisheries resources. Further development was fueled by the Iskandar Malaysia (IM) in 2006 to manufacture electrical and electronic (E&E), chemical and chemical products (petrochemical, plastics, oleo chemicals) and food processing sub-sectors.

4.3 METHODS

4.3.1 DATA COLLECTION
Data collection derives from 1) participant observation\(^2\), 2) five-point questionnaires with anchor points [1: strongly disagree to 5 strongly agree and 1: least important to 5 very important], 3) focus group discussion.

Stakeholder groups were represented by fishers, local representatives, NGOs, scientific community, resource managers, politicians and industrial players. Prior to the commencement of the participatory / consensus building workshop, cognitive mapping was carried out to map stakeholders’ perceptions on resource conservation. A focus group discussion allowed facilitators to provide background information on the workshop, and to answer any question of interest from the participants. Stakeholders were then divided into respective groups and asked to brainstorm to provide justifications on the decisions of their preferred ecological conservation goals (See Ban et al. 2008; Figure 7). In the final step, individual stakeholders were asked to provide undisclosed decisions as to their personal ecological conservation goals.

Data collected on habitat diversity, fishing, spawning and nursery areas, cultural taboos and endangered species distributions (Refer to Chapter 1) were represented as GIS layers. Map overlay procedures following map algebra, spatial statistics, spatial querying and algorithms were performed to establish five conservation scenarios with ecological conservation criteria ranging from 10% to 50%. Other social ecological criteria were held constant (Figure 8).

![Diagram](image.png)

Figure 7: Consensus building and cognitive mapping tailored in the focus group discussion during participatory process

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\(^2\) Participant observation is the process in which an investigator establishes an sustains a many-sided and relatively long-term relationship with a human association in its natural setting for the purpose of developing a scientific understanding of that association. (Lofland and Lofland, 1995).
Figure 8: Ecological conservation goals using habitat diversity, spawning and nursery areas, and endangered species criteria. Other criteria are held constant.

4.3.2 DATA ANALYSIS

Both quantitative and qualitative analyses were used. Factor loading was used to analyze the differences in stakeholders and individuals’ perceptions on the importance of marine ecosystems (Kellert et al. 2000). For inter-group comparisons on differences in attitudes toward resource conservation and choices of ecological conservation goals, Kruskal-Wallis test or ANOVA will be employed to determine the statistical significance depending on the data normality. A similarity matrix from questionnaires data will be employed to generate multi-dimensional scaling ordination plots that will represent similarity between the attitudes and perceptions of the stakeholder groups and tested for significance with an ANOSIM and pair-wise tests and corrected using Bonferonni procedure (Clarke & Warwick 2001). Qualitative data will be generated based on narratives of the participants and observer impression during the focus group discussion.

4.4 MAJOR FINDINGS THUS FAR
The majority of stakeholders favored the largest available conservation option corresponding to conserving 50% of the ecological criteria. The least conservation goal (10% ecological criteria) was selected by industrial players. On an individual basis, the majority (73%) still preferred the largest ecological criteria. There was influential participant among the NGOs who had close connection with the industrial players and was able to dominate the group’s decision, causing the other NGOs to conform to choosing only 20% ecological criteria. Nevertheless this workshop was able to simulate the outcomes when all groups were brought together and helped understand group interactive patterns. Two attempts were made by a political associate to ban the workshop. The intervention caused the absence of village representatives and low sample size for fishers who were warned against showing up at the workshop.

In Progress:

- Statistical analyses for inter-comparison of attitudes and perceptions between stakeholder groups
- Factor analysis on resource perceptions
- Qualitative analysis on the key issues influencing stakeholders’ decisions

Please refer to Appendix for preliminary results and more detailed findings.

Target Journal: Society and Natural Resources

Target Submission Date: Aug 2012
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6.0 REFERENCES


7.0 APPENDICES

7.1 CHAPTER 1 Preliminary Results

The highest estimate for habitat productivity was derived from coastal phytoplankton (22,152 g C/m²/d; **Table 2**). This is unsurprising given the expansive water surface in the study region. Mangroves, substantiated by high NPP, contribute to significant productivity despite low area coverage. Relative to seagrass, seaweed and coral reef, the total contribution of habitat productivity from mudflat microphytobenthos appears more significant (755.16 g C/m²/d).

<table>
<thead>
<tr>
<th>Habitat Category</th>
<th>NPP g C/m²/d*</th>
<th>Unit Area at Pulai River Estuary (ha)</th>
<th>Estimated Habitat productivity (g C/m²/d)</th>
</tr>
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<tr>
<td>Coastal phytoplankton</td>
<td>1.0</td>
<td>22,152</td>
<td>22,152</td>
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<tr>
<td>Mudflat microphytobenthos</td>
<td>0.5</td>
<td>1510.31</td>
<td>755.16</td>
</tr>
<tr>
<td>Coral reef algae</td>
<td>2.5</td>
<td>8.61</td>
<td>21.53</td>
</tr>
<tr>
<td>Seaweed</td>
<td>1</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Seagrasses</td>
<td>1.5</td>
<td>116.65</td>
<td>174.98</td>
</tr>
<tr>
<td>Mangroves</td>
<td>2.5</td>
<td>721.91</td>
<td>1804.78</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24512.43</strong></td>
<td></td>
<td><strong>24911.38</strong></td>
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*Medium values of NPP (Duarte and Cebrian. 1996)*

It appears that fishers’ perceptions on the importance for productive fishing areas, nursery and spawning areas varied considerably over the study region (**Figure 9**). Fishing activity was spread out on the water interface with the main channel of the estuary being most intensely utilized for fishing. On the other hand, spawning area was most profound on the Merambong Island which harbors coral reef and rocky ecosystems although strong clustering was observed along the coastal mangroves and seagrass habitats. Nursery area also included the Merambong Island and aggregate more strongly along the nearshore habitats.
Figure 9: Planning units ranked by their importance according to (A) productive fishing areas, (B) spawning areas, and (C) nursery areas as revealed by artisanal fishers (N=97).

Table 3: Summary statistics for habitat productivity, fishing, spawning and nursery areas.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>Std. Dev.</th>
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<td>Habitat productivity</td>
<td>249113364.7</td>
<td>99.27</td>
<td>4872420</td>
<td>3037968</td>
<td>1573666</td>
</tr>
<tr>
<td>Fishing area</td>
<td>583</td>
<td>0</td>
<td>45</td>
<td>7.11</td>
<td>10.30</td>
</tr>
<tr>
<td>Spawning area</td>
<td>252</td>
<td>0</td>
<td>18</td>
<td>3.07</td>
<td>4.59</td>
</tr>
<tr>
<td>Nursery area</td>
<td>205</td>
<td>0</td>
<td>12</td>
<td>2.50</td>
<td>3.33</td>
</tr>
</tbody>
</table>

The initial relationships between habitat productivity with productive fishing ($r^2 = 0.26$), nursery ($r^2 = 0.07$) and spawning areas ($r^2 = 0.03$) were examined via Spearman Rank test and found to exhibit weak to almost no correlations. All variables were log-transformed prior to developing a multiregression model. Boxplots indicate significant outliers in habitat productivity while the other variables were skewed, giving hint to traditional OLS model may not be appropriate.

Model Development and Comparison

The model development began with the OLS model using fishing area, spawning and nursery areas as the independent variables for habitat productivity. The multiple regression model developed can be written as $\text{habitat productivity} = 13.82 + 0.58 \text{ Fishing area} + 0.29 \text{ Nursery}$
area – 0.59 Spawning area, with an adjusted coefficient of determinants, $R^2$ of 0.09. Not only
does this model poorly explained habitat productivity, the coefficient estimates for spawning and
nursery areas were also not statistically significant. It also appears highly questionable with
regard to nursery area exhibiting a negative sign with habitat productivity. A subsequent
regression diagnostic check revealed that this model was biased, based on the facts that the
residuals were not normally distributed (Jacque Bera, $p = 0.002$) with numerous negative values.
Koenker-Basset test ($p = 0.43$) indicates that heteroskedascity is not an issue. Strong spatial
autocorrelation in the residuals was detected (Moran’s $I = 8.73$, $p <0.01$) suggesting that the
value of the dependent variable in one spatial unit is affected by the independent variables in
nearby units, resulting in biased estimates of the regression parameters (Fotheringham, Brunsdon,
and Charlton 2002; Brunsdon, Fotheringham, and Charlton 1996).

To deal with this issue, I proceed with developing a spatial regression model. Since the residuals
were not normally distributed, Robust Lagrange Multiplier was used as an indicator for model
selection. The lower significance value in Robust LM renders spatial lag model favourable over
spatial error model. The model can be written as habitat productivity = 6.72 + 0.50 lag for
habitat productivity + 0.43 Fishing area + 0.11nursery area - 0.26 Spawning area +random
error. Fishing area remained the strongest predictor for habitat productivity. The $R^2$ has increased
to 0.28. Interesting enough, when untransformed variables were employed for the spatial lag
model, a much higher $R^2$ (0.55) was observed (Table 4).

<table>
<thead>
<tr>
<th></th>
<th>R²</th>
<th>AIC</th>
<th>Moran's I</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Untransformed</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLS</td>
<td>0.007</td>
<td>2576</td>
<td>8.73*</td>
</tr>
<tr>
<td>Spatial Lag</td>
<td>0.55</td>
<td>2529</td>
<td>0.02</td>
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<tr>
<td>GWR</td>
<td>0.51</td>
<td>2527.9</td>
<td>0.0008</td>
</tr>
<tr>
<td><strong>Log-transformed</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLS</td>
<td>0.09</td>
<td>329</td>
<td>0.25*</td>
</tr>
<tr>
<td>Spatial Lag</td>
<td>0.28</td>
<td>318</td>
<td>-0.017</td>
</tr>
<tr>
<td>GWR</td>
<td>0.41</td>
<td>301.7</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 4: Comparison on performances for OLS, spatial lag and GWR models.
Geographical Weighted Regression (GWR) was subsequently developed using both the untransformed and transformed variables. Compared to the OLS model, GWR model improved on both the $R^2$ (0.51 in GWR vs 0.007 in OLS) as well as the AIC (2528 vs 2576) significantly (Table 4). When compared to the spatial lag model, GWR shows improvement only for the transformed variables. The AIC value for untransformed variables did not exceed the spatial lag model by 3, while the $R^2$ was also slightly lower. The effect of spatial autocorrelation was successfully removed in both the spatial lag and GWR models. In a nutshell, GWR improves the model better for transformed variables while the spatial lag model yield a better fit for the untransformed model.

Further mapping on the standardized residuals and the regression coefficients reveal apparent spatial patterns in the study area. The standardized residual shows the unusually high residuals in certain areas while in others plagued by negative influences. In general, areas with high habitat productivity had large positive residuals (standardized residuals ranging between 0.5 to 2.5) which are seen mainly around coastal mangrove areas. By examining the coefficients, the fishing areas are clustered on the western portion of the estuary while the spawning areas extend from mangroves to southward; nursery areas tend to cluster strongly along the eastern portion of the shoreline encompassing most mangroves and seagrasses.
DISCUSSION

The findings of this piece of research underscore the efficacy of spatial regression model and GWR in investigating relationships in spatial data. Global (OLS) model failed to account for spatial dependencies, which confound the relationships between habitat productivity and the independent variables. In contrast, the spatial lag model and GWR were able to remove spatial autocorrelation thus allowing the model to be better explained. GWR, in particular, is a local spatial technique deemed effective in exploring spatial non-stationarity (Brunsdon, Fotheringham, & Charlton 1996; Fotheringham et al. 2002).

Local coefficient estimates derived from GWR reveal clustering along the coastlines, suggesting that coastline along the estuary is an important predictor for habitat productivity. This finding is consistent with empirical observations that the Pulai River Estuary coastlines are fringed by mangroves, seagrasses and mudflats (Anon 1999), which contribute to relatively high net primary production per unit area. Coral reef, on the other, is found only further offshore with
limited distribution confined within one planning unit. The local coefficient estimates from GWR also indicates heterogeneity in habitats distribution.

Fishing areas appear to be a stronger predictor for habitat productivity relative to spawning and nursery areas. This situation is likely caused by the uneven number of observations gathered through the interviews. About 80% of artisanal fishers were able to positively identify fishing areas, while only about 40% of them could identify spawning and nursery areas. A larger number of observations reduce the standard error of the estimate and improve the coefficient of the associated variable (Brunsdon et al. 1996). Future sampling design should take precautions in avoiding such pitfall and some calibration of samples may be necessary prior to conducting data analysis.

Although GWR improves the explanatory power of the variables, there are noticeable over-predictions for fishing areas on the western portion of the estuary, and spawning areas along the southern stretch of the Merambong Island. This issue warrant closer inspection to discover possible reasons. Significance test in GWR is still subject to continue research. (Fotheringham et al. 2002) suggest using a Bonferroni correction to the significance level; but was rendered overly conservative, and a test procedure such as the Benjamini-Hochberg False Discovery Rate might be more appropriate (Thissen, Steinberg, & Kuang 2002). Such debate is beyond the scope of examination and discussion in this paper.

It is noteworthy that in the GWR model, the untransformed data confers higher explanatory power compared to the transformed data. The residual boxplots reveal that the residual errors in transformed data (Shapiro-Wilk: $W = 0.7216$, p-value = 3.575e-11) was more significant compared to the untransformed data ($W = 0.8166$, p-value = 1.058e-08). For log-transformed differences, the relaxation of the normality assumption could potentially conceal the spatial non-stationarity of the modelled relationships in GWR (Yu, Peterson, & Reid 2009) but in this paper the transformation experience suggests otherwise. No explanation could be offered at this point.

A major issue in the models developed is that the spawning area exhibits negative sign, indicating that a decrease in the value of the spawning area will increase habitat productivity.
This scenario can probably be referred to the Simpson's paradox" - reversal of signs of directional associations that sometimes occurs when data are aggregated. The negative sign should be interpreted as the "partial" relationship between habitat productivity and spawning area.

Coastal phytoplankton contributes to the highest net primary productivity relative to all other existing habitats, given the large portion of water interface in the Pulai River Estuary. Strong influence of coastal phytoplankton productivity in the model would be expected. In this study, coastal phytoplankton productivity was assumed homogenous throughout the study area. Such assumption may have undermined the actual relationships in the model. To help improve the explanatory power of TEK, satellite image data can be employed to provide more reliable estimates of coastal phytoplankton productivity using chlorophyll a densities (Tucker & Sellers 1986; Babin, Morel, & Gentili 1996). Estuarine sediment dynamics and hydrologic patterns may also play significant roles in influencing estuarine productivity (Dyer 1998) but these data would be time and cost intensive to establish.
7.2 CHAPTER 2 Preliminary Results

Socio-economic use and ecological importance of the estuary were collapsed using the “weighted overlay” function in ArcGIS 10 and generated five conservation options (Fig 5). These options are based on ecological conservation goals ranging from 10% to 50% while holding the other criteria constant (Fig 6). Areas overlapped with existing development are excluded from selections.

Fig 5: Conservation options generated allow stakeholders to decide on their preferred conservation scenario.

Fig 6: The ecological criteria used to generate conservation options is composed of endangered species, habitat diversity, spawning and nursery grounds.

Table 1: Preferred conservation options as voted by stakeholder groups and individuals.

<table>
<thead>
<tr>
<th>Option</th>
<th>Group vote by</th>
<th>% Individual vote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fishers, Government agencies, researchers, politicians</td>
<td>58%</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>None</td>
<td>6%</td>
</tr>
<tr>
<td>4</td>
<td>NGOs</td>
<td>6%</td>
</tr>
<tr>
<td>5</td>
<td>Industrial players</td>
<td>9%</td>
</tr>
</tbody>
</table>

Key findings:
1. The majority of stakeholders favored the largest available conservation options by selecting option 1, which corresponds to conserving 50% of the ecological criteria.
2. Option 4 (20%) was selected by the environmental NGOs.
3. The least conservation goal (Option 5: 10% ecological criteria) was selected by industrial players.
4. On individual basis, the majority (58%) still preferred Option 1.

Additional notes:
- The decision of the NGOs group on Option 4 came as a surprise. It was later on figured out that the cause was attributed to an influential and progressive participant who had close connection with the industrial players and was able to dominate the group’s decision.
- Two attempts were made by a political associate to ban the workshop. The intervention had caused the absence of village representatives and low sample size for fishers who were warned against showing up at the workshop.

A multi-stakeholders participatory workshop was held to incorporate feedbacks, capture attitudes and perceptions from the different groups in the process of selecting preferred conservation options.
7.3 CHAPTER 3 Preliminary Results

Figure (above) showing increasing seagrass biomass along a gradient of distance from disturbed site and (below) during the dredging period, seagrass biomass from all sites appeared to have declined.
No significant pattern observed on water quality parameters between sites.

Seagrass biomass correspond strongly with shoot and leaf densities.

Note: Log-transformed; Spearman
Shoot and leaf densities appear greater at the control site but do not exhibit the gradients as observed in seagrass biomass. In general leaf densities were higher at the control site.
Leaf length at sites located further away from disturbance appears to be higher. Sheath length and rhizome diameter appears to be uniform across sites.
8.0 Committee Comments and Suggestions

Integrates chapters so they are better fit together

Write a more thorough introduction and conclusion

Changing the sequence of chapters

Collect TEK on impacts

Overall contributions – highlight novel findings

BACI – refer to Underwoods

Chapter 1: drop OLS