CHAPTER 2

LITERATURE REVIEW

2.1 Global Seagrass Distribution

Seagrass are specialized marine flowering plants that have adapted to the near shore environment of most of the world's continents (Short et al., 2001), except Antarctica (den Hartog, 1970). According to den Hartog (1970), the great age of seagrasses is reflected in the geographical distribution of recent genera. Based on his well-known monograph (1970) and a few taxonomic works that have been carried out after that, currently 60 species of seagrass in 12 genera are recognized. Of the 12 seagrass genera recognized at present, seven (7) are tropical (Larkum *et al*. 1989). The seven (7) tropical representatives are *Halodule, Cymodocea, Syringodium, Thalassodendron, Enhalus, Thalassia and Halophila,* and the five (5) temperate representatives are *Zostera, Phyllospadix, Heterozostera, Posidonia and Amphibolis*.

It is interesting to note that the seven (7) genera regarded as tropical seagrasses not homogeneously distributed in the tropics. They are found concentrated in two large areas, one comprising the Indo-west Pacific and the other, the Caribbean and the Pacific Coast of Central America (Phang, 2000). Fortes (1989) considered the Indo-west Pacific as the centre of generic richness and diversity of seagrasses as well as of mangroves and coral reefs. All seven (7) seagrasses considered as tropical genera can be found in the Indo-west Pacific while the Caribbean and the Pacific Coast of Central America shows the presence of four (4) genera (*Halodule, Syringodium, Thalassia* and *Halophila*).

2.2 Seagrass Diversity and Distribution in Malaysia

On the basis of seagrass diversity, Malaysia belongs to the Indo-West Pacific region. The first recorded collection of a seagrass in Malaya was made by Beccari in 1866, who collected *Cymodocea serrulata* from Johor, Peninsular Malaysia (den Hartog 1970). Started with den Hartog (1970) report of seven species (*Cymodocea rotundata* Erhrenb. and Hemp. ex. Aschers., *C. serrulata* (R. Br.), *Enhalus acoroides* L. *f.* Royle, *Thalassia hemprichii* Erhrenb., *Halophila ovalis* (R. Br.) Hook, *H. beccarii* Aschers., and *H. spinulosa* (R. Br.) Aschers) from Johor, Negri Sembilan, Pulau Pangkor, Pulau Langkawi and Sarawak, Phang's updates (2000) bring the tally of seagrass species in Malaysian waters to 15 species. All seven (7) Genera of tropical seagrass are found in Malaysian waters.

In Peninsular Malaysia, seagrasses are more common along the west coast where the coastal habitats consist mainly mangrove, sandy-muddy beaches or mudflats, which provide substrate that are more suitable for seagrass growth. Much of the west coast of Peninsular Malaysia is of the sandy-muddy type due to the heavily silted water brought in by the rivers, and its sheltered condition due to its close proximity to Sumatra (Phang, 1989). Records of seagrasses on the east coast of Peninsular Malaysia are mainly from the southern islands of Pulau Tinggi, Pulau Besar and Pulau Sibu in Johor (Japar, 1994), and further up north, around Pulau Redang (Phang, 2000).

In Malaysia, research on seagrasses has concentrated primarily on documenting the species present and their distribution (see Japar Sidik et al., 1995; 1999; 2006). Phang (1989; 2000) has carried out studies on the taxonomy and distribution of seagrass resources. The 15 seagrass species recorded at present for Malaysia and for various states including Sabah and Sarawak are given in Table 2.1, and also been visualized into map [Figure 2.1 (a) and Figure 2.1 (b)]. The most widespread species are *Halodule* *uninervis* and *Halophila ovalis,* whose ranges span both the west and east coast of Peninsular Malaysia, as well as East Malaysia. *Halophila ovata* and *Ruppia maritima* have been recorded in Sabah and Penang, respectively (Phang 2000).

2.3 Factors Determining the Distribution of Seagrasses

Factors controlling seagrass distribution and condition are of increasing interest to the scientific community due to their ecological and economic value (Duarte, 1999). An extensive body of literature exists on seagrasses and factors influencing their growth, depth limit, and distribution. A number of general parameters have been set as critical to whether seagrass will occur along any stretch of coastline. These include physical parameters that regulate the physiological activity of seagrass (temperature, salinity, waves, currents, depth, substrate and day length), natural phenomena that limit the photosynthetic activity of the plants (light, nutrients, epiphytes and diseases) and anthropogenic inputs that inhibit the access to available plant resources (nutrient and sediment loading).

Abal and Dennison (1996) concluded that the distribution and growth of seagrasses is regulated by a variety of water quality factors such as temperature, salinity, nutrient availability, substratum characteristics, turbidity and submarine irradiance. Other factors that can determine the suitability of a site for seagrasses should be added to the list. However, different species of seagrasses have different habitat requirements. Livingston et al. (1998) determine a hierarchy of habitat requirements for three species of seagrass (*Halodule wrightii, S. filiforme and T. testudinum*). Salinity, temperature and depth restraints are important habitat variables that control seagrass growth; when such variables are not limiting, light, sediment and nutrient characteristics become important in the determination of the distribution of seagrass in coastal areas.

Table 2.1: Species of seagrasses recorded from Malaysia waters

FAMILY & SPECIES	LOCATION									
	Peninsular Malaysia								East Malaysia	
	Kedah	Pulau Pinang	Perak	Negeri Sembilan	Melaka	Johor	Terengganu	Kelantan	Sabah	Sarawak
Cymodocea rotundata	X	-	-	X	-	X	-	-	X	-
Cymodocea serrulata	X	-	-	X	X	X	-	-	X	-
Halodule pinifolia	X	-	-	X	-	X	X	X	X	-
Halodule uninervis	X	-	X	X	X	X	X	-	X	-
Syringodium isoetifolium	-	-	-	-	-	X	X	-	X	-
Thalassodendron ciliatum	-	-	-	-	-	-	-	-	X	-
Enhalus acoroides	-	X	-	X	X	X	-	-	X	-
Halophila decipiens	-	-	-	X	-	-	X	-	X	X
Halophila ovalis	X	X	X	X	-	X	X	-	X	-
Halophila minor	X	X	X	X	-	X	X	-	X	-
Halophila spinulosa	-	-	-	-	-	X	-	-	X	-
Halophila beccarii	-	-	-	-	-	X	X	X	-	X
Halophila ovata	-	-	-	-	-	-	-	-	X	-
Thalassia hemprichii	-	-	-	X	X	X	-	X	X	-
Ruppia maritima	-	X	-	-	-	-	-	-	-	
Total	6	4	3	9	4	11	7	3	13	2

(Source: Den Hartog, 1970; Norhadi, 1993; Japar Sidik et al., 1995; 1999; 2006; Phang, 2000)

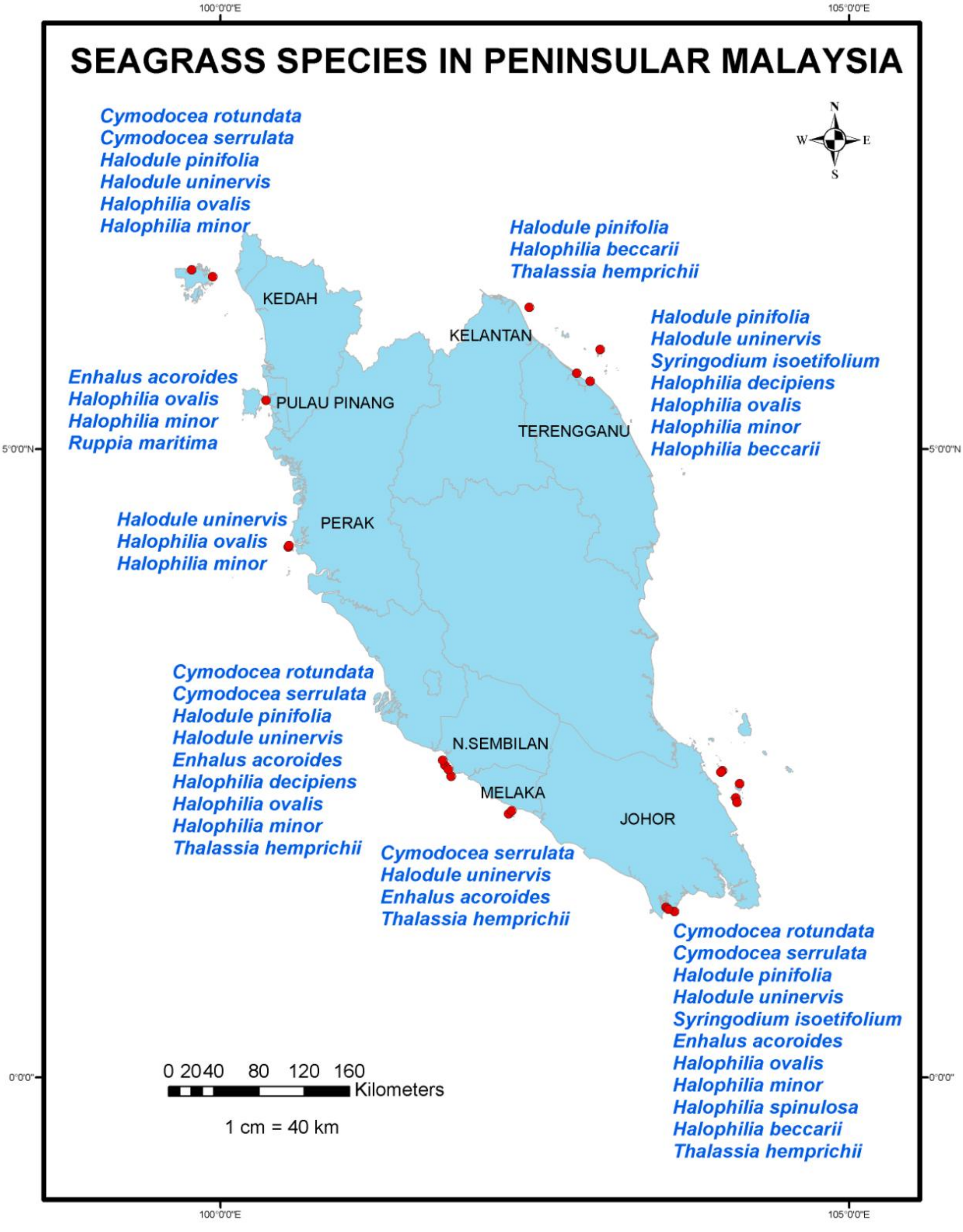

Figure 2.1 (a): Map of seagrass species in Peninsular Malaysia

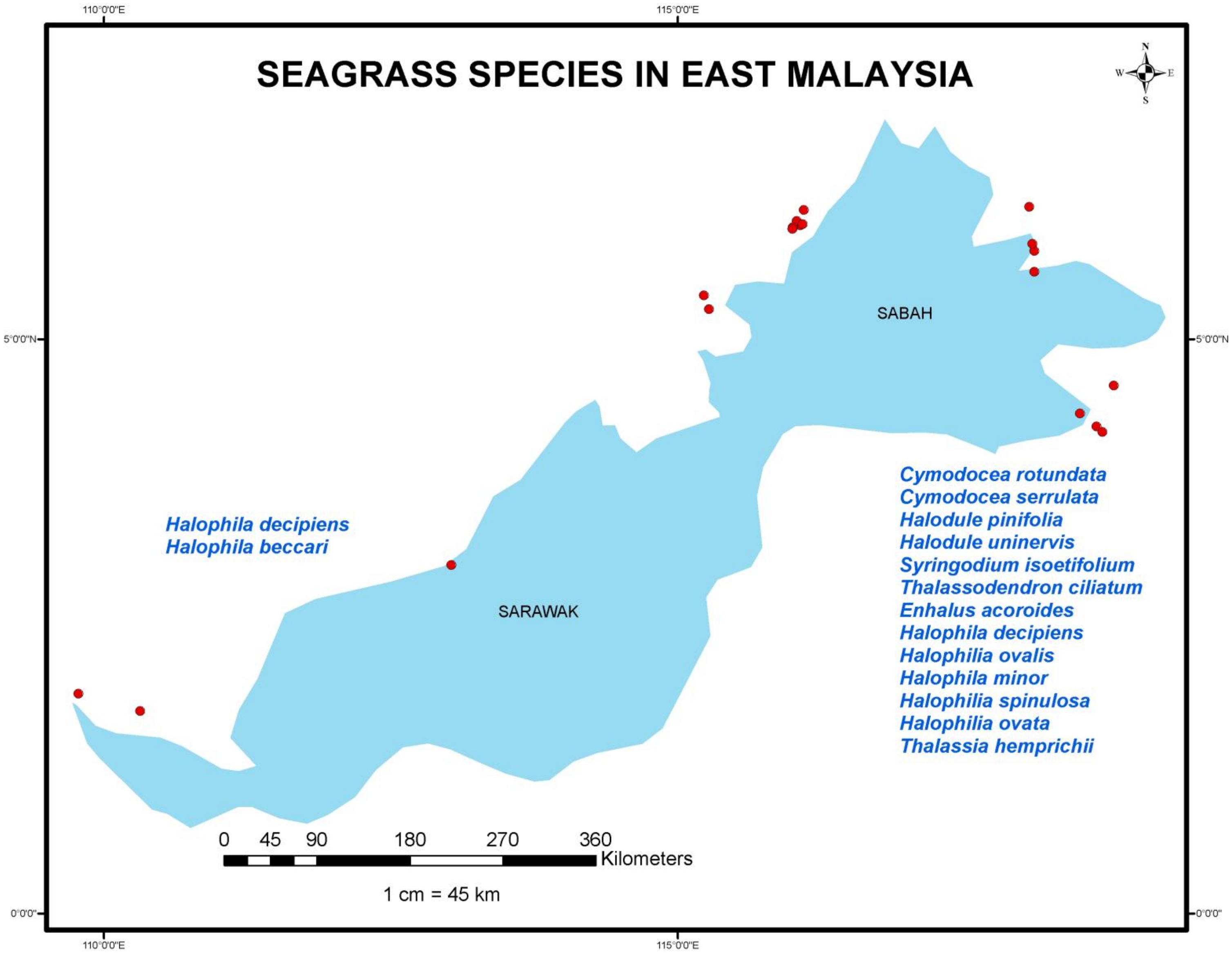

Figure 2.1 (b): Map of seagrass species in East Malaysia

2.3.1 Light

Light has been identified as the major factor controlling the distribution and abundance of marine (seagrasses), estuarine, and freshwater flowering plants, also called submerged aquatic vegetation (SAV) (Dennison et al., 1993; Hall et al., 1999). Therefore, biological and chemical parameters that alter light availability are commonly listed as SAV habitat requirements. Knowledge of the relationship between commonly measured water quality parameters like chlorophyll concentration and turbidity has been used to predict light penetration in the water column and to define the water quality limits for survival of SAV such as seagrass. For example, SAV is persistent in water >1 m deep in Chesapeake Bay only in areas where median concentrations of chlorophyll and suspended solids were <15 mg/L and <15 mg/L, respectively (Dennison et al., 1993).

A refinement of this ‘‘habitat requirements’’ approach has been developed to predict the distribution of subtropical seagrasses in the Indian River Lagoon, Florida, as a function of multiple optically important water quality variables (Gallegos and Kenworthy, 1996). While it is an important determinant of the persistence of SAV, light availability is only one of a number of environmental factors that set the bounds of the habitat requirements of SAV (Koch, 2001).

2.3.2 Turbidity

Globally, seagrass declines are often attributed to increased light stress induced by eutrophication in temperate environments and turbidity in tropical environments (Shepherd et al., 1989). Turbidity of the water column will have a direct effect on the quality and quantity of light. Increased in turbidity and sedimentation reduce water clarity, will decrease light penetration in the water column and affect the health and productivity of seagrass communities (Giessen et al., 1990; Abal and Dennison, 1996).

The total suspended solid (TSS) is one of the conventional pollutant, and one of the water quality measurements, the indicative of turbid conditions. TSS contains solid particles result from urban runoff and agricultural land, industrial wastes, bank erosion or wastewater discharges. Higher TSS mean water is more input of solid particles.

2.3.3 Temperature

The effects of temperature on seagrasses are more obvious in temperate regions as compared to tropical countries where the range of variation in temperature is relatively small (Walker and Cambridge, 1995; Freeman et al., 2008). Walker and Cambridge (1995) explained that the effects of temperature on seagrasses could largely due to instantaneous physiological responses, relating to the individual species' thermal tolerances and their optimum temperatures for photosynthesis, respiration and, growth. Differences between seagrass species in their response to temperature in part establish species tolerance conditions and influence their adaptability, or plasticity. Species plasticity is a major determinant of species distribution (Short et al., 2001).

2.3.4 Salinity

The long-term sustainability of seagrasses, particularly in the subtropics and tropics, depends on their ability to adapt to shifts in salinity regimes influenced by anthropogenic modifications of upstream hydrology, as well as long term temperature increases predicted to be associated with future climate change (Short and Neckles, 1999). Although there are major concerns world-wide on increased salinity in coastal estuaries, there is little quantitative information on the specific upper salinity tolerance of tropical and subtropical seagrass species (Koch et al., 2007).

Tropical species that have evolved under intermittent or chronic exposure to hyper salinity, where salinity is gradually increased through evaporative process, should have higher salinity tolerances. However, tropical species are living at the edge of their upper physiological limits of salinity (Walker et al., 1988; Koch et al., 2007), so further increases in salinity as a result of climate change and freshwater extraction may have significant consequences for tropical seagrasses, particularly in estuaries with restricted circulation and high rates of evaporation. Koch et al. (2007) found three tropical seagrass species that been examined for hyper salinity tolerance to be highly tolerant of high salinity, and concluded that hyper salinity probably does not solely cause die-off events in Florida Bay. Conclusion was also made that high salinity can modify carbon and O_2 balance in the plant, and potentially affecting the long-term health of the seagrass community.

2.3.5 pH

Seagrasses use CO_2 for photosynthesis rather than bicarbonate like most marine macroalgae, so certain species could benefit leading to ecological regime shifts. As pH increases, CO_2 concentration decreases, and photosynthetic capacity becomes dependent on the use of HCO_3^-. The efficiency in the use of this source of dissolved inorganic carbon varies greatly from one plant group to another resulting in a similarly diverse pattern of response to increasing pH.

2.3.6 Nutrient

It is well known that the availability of nutrient resources affects the growth, distribution, morphology and seasonal cycling of seagrass communities by indirectly affecting light attenuation to the seagrass plants (Short et al., 1995). Cultural eutrophication or nutrient over-enrichment, especially of nitrogen and phosphorus, has degraded many coastal waters and has been invoked as a major cause of seagrass disappearance worldwide (Short and Wyllie-Echeverria, 1996). Excessive nutrient loads (which reduce available light and inhibit physiological processes such as photosynthesis) lead to eutrophication, and the general pattern of change in such situations involves a shift from large macrophytes (including seagrasses) towards fast-growing macroalgae and phytoplankton (including harmful species that occur in blooms).

However, tropical seagrass ecosystems have been identified as nutrient limited and their response is to experience enhanced growth rather than any negative impacts associated with elevated nutrients as reported in temperate regions (Mellors et al., 2005). Herbert and Fourqurean (2009) confirmed that tropical seagrass meadows show increased productivity during the wet season caused by nutrient runoff, suggesting that most tropical seagrass meadows are nutrient rather than light-limited. Seagrasses also have the ability to act as bio-sink for nutrients, sometimes containing high levels of tissue nitrogen and phosphorous (Mellor et al., 2005.).

2.3.7 Heavy metal

Anthropogenic sources of metals which come from industrial and municipal waste products, urban and agricultural runoff, fine sediments eroded from catchments, atmospheric deposition increase metal concentrations to higher than background levels. Anthropogenic chemicals, such as heavy metals, represent one of the most toxic threats to seagrass meadows (Schlacher-Hoenlinger and Schlacher, 1998). The contribution of toxic chemicals to seagrass declines is largely unknown and has been investigated less frequently than the effects attributable to nutrient enrichment which is considered the primary cause of seagrass declines (Lewis et al., 2007).

Several studies have demonstrated the ability of many seagrass species to bioaccumulate heavy metals from contaminated water or sediments (Short and Wyllie-Echeverria, 1996). The potential impact of heavy metals on seagrasses is two-fold, firstly via uptake into the plants themselves, and secondly (and indirectly) where the inhibition of grazers impacted by the toxic effects of the metals results in denser epiphyte growth.

2.4 Geographic Information System

2.4.1 Basic Concept

A Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geospatial data (Chang, 2008). It is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986). The ability of GIS to handle and process geospatial data distinguishes GIS from other information systems. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.

GIS requires the following four components to work with geospatial data:

- computer system (includes the operating system to run GIS);
- GIS software;
- people (GIS professionals and user); and
- data.

Geospatial data (also called geographically referenced data) are data that describe both the locations and the characteristics of spatial features such as roads, land parcels, and vegetation stand on the Earth’s surface (Chang, 2008). There are two (2) geographic data components in GIS i.e. spatial data and attribute data. The locations represent spatial data whereas the characteristics are attribute data (ESRI, 2003).

Conversion of real world geographical variation into discrete objects is done through data models. It represents the linkage between the real world domain of geographic data and computer representation of these features. There are two (2) types of data model in GIS; Raster and Vector. The raster data model uses a grid (a set of cells located by coordinate) to represent the spatial variation of a feature. The vector data model uses line segments or points represented by their explicit x, y coordinates to construct spatial features of point, lines and areas.

2.4.2 GIS Functions

For any application there are five generic questions a GIS can answer:

- Location - What exists at a particular site or location?
- Condition - Where are certain conditions met? It can identify locations where certain conditions exist.
- Trends - What changes have occurred over time and where have these changes occurred?
- Patterns - What are the social, economic, or environmental impacts of a particular change in the use of land?
- Modeling - What will happen if the existing land use for a particular site is altered to another type of use?

The analysis capabilities of the GIS provide the answers to the five basic questions defined above. Aronoff (1989) described four major GIS analysis capabilities:

(i) maintenance and analysis of spatial data;

(ii) maintenance and analysis of attribute data;

(iii) integrated analysis of spatial and attribute data; and

(iv) output formatting.

The first two functions deal with maintaining the data and the fourth function is for producing output from the system. The real power of the GIS is its ability to integrate the analysis of spatial and attribute data. Spatial data can be stored as raster or vector structures. Some analytical functions can work equally well with raster or vector data, some analytical functions will perform better with raster data, and some functions will perform better with vector data. GIS systems of the future will have improved user interfaces and expert systems to advise the user on how to utilize the existing database and software to obtain the desired resource information (see Chang, 2008).

2.4.3 GIS Application in Biological Diversity

An aspect of nature conservation that deserves special attention in the context of GIS is analysis, measurement and planning related to biodiversity (Aspinall, 1995). Since the beginning, GIS has been important in natural resources management, such as land use planning, timber management, wildlife habitat analysis, and natural hazard assessment (Chang, 2008). Salem (2003) discussed potential applications of GIS for mapping and modelling biodiversity, and describes the three functions of GIS that are important for biodiversity modelling as below:

(i) Terrain analysis - can be used to identify micro, meso and macro terrain indices;

(ii) Data integration - can be used to determine the environmental characteristics of known habitats of species; and

(iii) Data visualisation - uses maps, graphs and statistics to make the enormous amount of data that can be derived on a species habitat easy to understanding.

Since majority of countries have now signed the Convention on Biological Diversity (CBD) (UNEP, 1992), therefore every nation have the motivation to develop national information management strategies (needs, sources, means of collection, management and accessibility). Even though no country yet has a perfect information management system, with appropriate information available to whomever needs it (Harrison, 1995), there have been significant developments over the years.

Article 7 of the CBD commits each contracting party ‘as far as possible and as appropriate’ to identify components of biological diversity important for its ‘conservation and sustainable use’ (UNEP, 1992). In order for a country to comply fully with this article, it is necessary to inventory the organisms present within their territories (country studies). An inventory is a prerequisite for assessments of conservation status and sustainable utilization, and for prescribing appropriate actions. A particular value of inventories is to identify organisms which can be used as bio-indicators of ecosystem health and provide early warning of changes in protected and other areas. To match with the need of CBD and the current greater concern for sustainable use of resources, and conservation and monitoring of biodiversity, GIS plays an important role as a tool for environmental management.

2.5 Application of GIS in Seagrass Habitat Management

GIS is a useful tool that is widely used for application in countless natural resources and their management. The application of GIS can be for planning, management, process modelling, inventory and assessment to enable end-users to have requisite information for decision-making.

2.5.1 Mapping the Seagrass Distribution

Seagrass resources can be mapped using a range of approaches from in situ observation to remote sensing. Earlier standards for seagrass mapping, e.g. Philips and McRoy (1990) are being superseded as improvements in navigation and remote sensing technology and sampling design lead to more efficient and precise methods for mapping. McKenzie et al. (2001) describe some considerations that must be made (e.g. scale, level of accuracy required, and survey strategy) when mapping seagrasses and present the most commonly used methods as below:

(i) Remote sensing; satellite image were used to locate possible seagrass sites and to estimate the extent before ground-truthing;

(ii) Aerial survey and photography, followed by ground-truthing, diver/video observations; and GPS (global positioning system) to determine location and extent and coverage pattern of seagrass meadow; and

(iii) Ground truthing: scuba diving; benthic grab; line transect-quadrat; underwater photography.

The most important information that is required for management of seagrass resources is their distribution, i.e. a map (McKenzie, 2008). The simplest way to map the distribution of seagrasses is to draw the meadows on paper from the GPS positions of the ground truth sites. The problem with this type of mapping is that the final map in a format that does not allow manipulation and transformation. The layout of the paper map is permanent. McKenzie et al. (2001) recommended that all data from the survey to be transferred to a digital format and a GIS be used. Mapping seagrass meadow with GIS can help to identify emergent patterns or relationships in geographically referenced data. Lehmann and Lachavanne (1997) give further reading on the application of GIS to aquatic botany which starts in the late of 1980s.

2.5.2 Modelling with GIS

Lathrop et al. (2001) mentioned about a number of approaches that have been used to examine factors controlling seagrass distribution including mesocosms, models, and mapping combined with measures of water quality. Field surveys and more recently remote sensing techniques including aerial photography and satellite imagery have been used to map the distribution of seagrasses throughout an estuary or coastal system (Ferguson and Korfmacher, 1997; Robbins, 1997; Ward et al., 1997). Numerous models have been developed to describe seagrass growth, survival, and/or potential habitat. These models range from primarily optically based (Duarte 1991; Gallegos 1994) to a combination of optical and water quality criteria (Dennison et al. 1993) to dynamic ecosystem simulation models (Madden and Kemp 1996). Each seagrass model usually has been developed or recalibrated using both water quality data and seagrass distribution information from one particular estuary or coastal system. In some cases prediction of the presence/absence of seagrasses has been compared at a few additional sites in that system. However, all the mentioned models have not been applied to an independent coastal system or incorporated into a GIS approach to test the model extensively throughout the coastal system for which the model was originally developed (Lathrop, 2001). Later, due to the ecological importance of seagrasses, Lathrop (2001) demonstrated the use of GIS in mapping and modeling of seagrasses to examine their spatial distributions.

In order to protect and preserve seagrass, periodic mapping and monitoring of seagrass habitats needs to be initiated globally (Short and Wyllie-Echeverria 1996). However, monitoring data by themselves do not provide the information needed by resource managers to exercise adequate environmental management. Rather, explorations of the relationship between driving environmental variables (for example water quality) and ecological response variables (such as benthic habitat structure) can provide models that represent potential tools for resource managers (Fourqurean *et al.* 2003). These fundamentals can be accurately achieved with GIS applications.

2.5.3 Geodatabase

The geodatabase is the common data storage and management framework for ArcGIS. It combines "geo" (spatial data) with "database" (data repository) to create a central data repository for spatial data storage and management. It can be leveraged in desktop, server, or mobile environments and allows user to store GIS data in a central location for easy access and management.

The geodatabase has two major concepts as describe below:

(i) a geodatabase is a physical store of geographic information inside a database management system (DBMS); and

(ii) a geodatabase has a data model that supports transactional views of the database (versioning) that also supports objects with attributes and behaviour. Behaviour describes how an object (feature) can be edited and displayed. Behaviour includes, but is not limited to, relationships, validation rules, subtypes, and default values. With associated behaviours data entry can be regulated more efficiently, and data contamination issues can be avoided (ESRI, http://www.esri.com/geodatabase).

A key feature of the geodatabase is that all data (vector, raster, metadata, measures, CAD, etc.) is stored together in a commercial off-the-shelf DBMS. The geodatabase is the natural solution for handling the growing amount of digital spatial data and at the same time meets the need to leverage this data among the growing numbers of GIS users. This gives organizations the power to have an integrated data management policy covering all data, which can significantly simplify support and maintenance as well as reduce costs.

Geodatabase offer many advantages for GIS users. The range of functionality available is extensive and includes centralized data storage, support for advanced feature geometry, and more accurate data entry and editing through the use of subtypes, attribute domains, and validation rules. Much of this functionality is not available with shapefiles or coverages. The geodatabase includes a variety of sophisticated editing features that allow the GIS analysis to be more efficient and less time consuming. Geodatabase can be created and managed easily using the standard tools in ArcCatalog, and ArcMap provides simple tools to work with geodatabase. The advanced features described above are also available for those users with demanding application requirements.

With all the capabilities and advantages of geodatabase as mention above, environmental managers (who usually handle big amount of data for conservation programs) are advice to ‘migrate to geodatabase’ as a most practical and constructive action to do. Further discussion, on how to build the geodatabase and its application in coastal management is in Chapter 3 and Chapter 4 of this dissertation.