WETLAND ECOLOGY AT SALAYA CAMPUS AND ITS IMPORTANCE FOR IMPROVING ECOLOGICAL LITERACY

CHUTAMAS SUKHONTAPATIPAK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY (BIOLOGY)
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....
Miss Chutamas Sukhontapatipak
Candidate

....
Assoc.Prof. Sompoad Srikosamatara,
Ph.D.(Zoology)
Major-Advisor

....
Prof. Warren Y. Brockelman,
Ph.D.(Zoology)
Co-Advisor

....
Asst.Prof. John R. Milne,
Ph.D.(Entomology)
Co-Advisor

....
Prof. Banchong Mahaisavariya,
M.D.
Dean
Faculty of Graduate Studies

....
Assoc.Prof. Prayad Pokethitiyook,
Ph.D.(Chemical Engineering)
Chair
Doctor of Philosophy Program in Biology
Faculty of Science

Thesis
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on
24 September, 2008

....
Miss Chutamas Sukhontapatipak
Candidate

....
Ms. Saranarat Kanjanavanit,
Ph.D.(Geography)
Chair

....
Assoc.Prof. Sompoad Srikosamatara,
Ph.D.(Zoology)
Member

....
Asst.Prof. John R. Milne,
Ph.D.(Entomology)
Member

....
Prof. Warren Y. Brockelman,
Ph.D.(Zoology)
Member

....
Prof. Banchong Mahaisavariya,
M.D.
Dean
Faculty of Graduate Studies
Mahidol University

....
Prof. Skorn Mongkolsuk,
Ph.D.
Dean
Faculty of Science
Mahidol University

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Chutamas Sukhontapatipak

WETLAND ECOLOGY AT SALAYA CAMPUS AND ITS IMPORTANCE FOR IMPROVING ECOLOGICAL LITERACY

CHUTAMAS SUKHONTAPATIPAK 4337453 SCBI/D

Ph.D. (BIOLOGY)

THESIS ADVISORS: SOMPOAD SRIKOSAMATARA, Ph.D., WARREN Y. BLOCKELMAN, Ph.D., JOHN R. MILNE, Ph.D.

ABSTRACT

The value of fragmented wetlands for ecological services and education are foreseen. The wetlands are located at Salaya Campus, Mahidol University, Nakhon Pathom Province. Ecosystem health, functions, and value, as perceived by university students and staff, were explored. Plants and aquatic macroinvertebrate communities of the campus wetlands were surveyed during October, 2006 to September, 2007. Ecological knowledge from the wetlands was integrated in an Ecology class for 3rd year biology students. The educational function of the wetlands was evaluated and a recent ambitious master plan of Salaya Campus was reviewed.

Two types of wetlands, i.e. wet meadow and freshwater marsh, were found on Salaya Campus. From shallow to deep water, seven plant zones occurred in the wet meadow, including the tree zone, *Pluchea indica*-dominated zone, *Imperata cylindrica*-dominated zone, mixed sedges & grasses zone, *Brachiaria mutica*-dominated zone, *Phragmites vallatoria*-dominated zone, and *Typha angustifolia*-dominated zone, respectively. Only four zones occurred in the freshwater marsh, in which the *T. angustifolia*-dominated zone covered the largest area. Relating to wetland plants and sediments, snails and Chironomids are common in both types of wetlands. Multiple indices for the campus wetland bioassessment showed sensitivity of most functional vegetation indices and Lymnaeidae index in distinguishing the differences between the two wetlands. They indicated impacts of *T. angustifolia* distribution and mild nutrient enrichment in the freshwater marsh, and also the invasion of exotic grass *B. mutica* (Forssk.) Stapf. in the wet meadow. With 60% additional wetland-based ecological exercises in Ecology class, both ecological knowledge and students' attitudes toward the campus wetlands were significantly improved. However, knowledge of wetland ecology underlying the developing campus landscape was required in the campus master plan.

To conserve wetlands on campus, reintroduction of a high profile species, firefly, and additional nature reserve of the wet meadow in north-east side of the university are proposed. Ecological knowledge of wetlands should be integrated into campus management, and the university community should participate in management, education, and research.

KEY WORDS: WETLAND/ SALAYA CAMPUS/ BIOASESSMENT/
ECOLOGICAL LITERACY/ CAMPUS ECOLOGY

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นิเวศวิทยาของพื้นที่ชุ่มน้ำวิทยาเขตศาลายาและความสำคัญต่อการพัฒนาความรู้พื้นฐานทางนิเวศ (WETLAND ECOLOGY AT SALAYA CAMPUS AND ITS IMPORTANCE FOR IMPROVING ECOLOGICAL LITERACY)

จุฑามาศ สุคนธปฏิภาค 4337453 SCBI/D

ปร.ด. (ชีววิทยา)

คณะกรรมการควบคุมวิทยานิพนธ์: สมโภชน์ ศรีโกสามาตร, Ph.D., วรเรณ วาย บรอคเคลแมน, Ph.D., จอห์น อาร์ มิลน์, Ph.D.

บทคัดย่อ

คุณค่าทางนิเวศวิทยาและทางการศึกษาของพื้นที่ชุ่มน้ำมหาวิทยาลัยมหิดล วิทยาเขตศาลายา จ. นครปฐม ถูกประเมินโดยการสำรวจชุมชนพืชและสัตว์ไม่มีกระดูกสันหลังขนาดใหญ่ในน้ำ ระหว่างเดือนตุลาคม 2549 ถึงกันยายน 2550 โดยได้บูรณาการความรู้นิเวศวิทยาของพื้นที่ชุ่มน้ำกับวิชานิเวศวิทยาระดับปริญญาตรี และได้ทำการทบทวนการดำเนินการจัดการวิทยาเขตศาลายากับหลักการนิเวศวิทยาของสถานศึกษาตามมาตรฐานสากล

พื้นที่ชุ่มน้ำวิทยาเขตศาลายาประกอบด้วยทุ่งหญ้าชื้นแฉะและทุ่งน้ำจืด ชุมชนพืชในทุ่งหญ้าชื้นแฉะแบ่งได้เป็น 7 เขต เรียงจากระดับน้ำตื้นไปลึก ได้แก่ เขตไม้ยืนต้น เขตขลู่ เขตหญ้าคา เขตกกผสมหญ้า เขตหญ้าขน เขตแขม และเขตธูปฤาษี ขณะที่ทุ่งน้ำจืดมีชุมชนพืชเพียง 4 เขต โดยมีเขตธูปฤาษีครอบคลุมพื้นที่มากที่สุด หอยฝาเดียวและหนอนแดงเป็นสัตว์กลุ่มที่พบมากในพื้นที่ชุ่มน้ำทั้งสอง เนื่องจากมีความสัมพันธ์กับพืชและเศษซากตะกอนในพื้นที่ชุ่มน้ำ กลุ่มดัชนีชี้วัดหน้าที่ของชุมชนพืชและดัชนีหอยวงศ์ Lymnaeidae ระบุความแตกต่างระหว่างพื้นที่ชุ่มน้ำทั้งสอง โดยทุ่งน้ำจืดได้รับผลกระทบจากการกระจายของธูปฤาษีและสภาวะสารอาหารมากเกินในระดับต่ำ ส่วนทุ่งหญ้าชื้นแฉะได้รับผลกระทบจากหญ้าขนซึ่งเป็นพืชต่างถิ่น บทปฏิบัติการนิเวศวิทยาที่ใช้พื้นที่ชุ่มน้ำเป็นแหล่งเรียนรู้ 60% สามารถพัฒนาทั้งความรู้ทางนิเวศวิทยาและทัศนคติของนักศึกษาต่อพื้นที่ชุ่มน้ำได้ ขณะที่โครงการปรับปรุงแผนแม่บทของวิทยาเขตจำเป็นต้องบูรณาการความรู้นิเวศวิทยาของพื้นที่ชุ่มน้ำด้วย

การอนุรักษ์พื้นที่ชุ่มน้ำในวิทยาเขตสามารถทำได้โดยผ่านโครงการเพิ่มเติมด้วยการปล่อยหิ่งห้อยซึ่งเป็นสัตว์พื้นถิ่นที่สาธารณชนสนใจคืนสู่ธรรมชาติ การจัดให้ทุ่งหญ้าชื้นแฉะบางส่วนทางด้านตะวันออกเฉียงเหนือของมหาวิทยาลัยเป็นพื้นที่อนุรักษ์ รวมทั้งการมีส่วนร่วมของชุมชนมหาวิทยาลัยในการจัดการ การให้การศึกษา และการวิจัยเกี่ยวกับนิเวศวิทยาของระบบนิเวศดั้งเดิมให้กลมกลืนกับระบบนิเวศที่กำลังเปลี่ยนไปเพราะการดำเนินการจัดการพื้นที่ของมหาวิทยาลัย

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LIST OF ABBREVIATIONS

Abbreviation	Term
AqF	Aquatic fern
AqH	Aquatic herb
ANOVA	Analysis of variance
C	Climber
°C	Degree Celsius
cm	centimeter
Cr	Creeper
DO	Dissolved oxygen
ETO	Ephemeroptera-Trichptera-Odonata
F	Fern
FAC	Facultative
FACU	Facultative upland
FACW	Facultative wetland
FQAI	Floristic Quality Assessment Index
g	gram
G	Grass
GIS	Geographic Information System
H	Herb
H'	Shannon Diversity Index
ha	hectare
km^2	square kilometer
m^2	square meter
mg/l	milligram per liter
MU	Mahidol University
n.d.	no date
OBL	Obligate wetland

LIST OF ABBREVIATIONS (Continued)

Abbreviation	Term
OEPP	The Office of Natural Resources and Environmental Policy and Planning
Pa	Palm
P	Phosphate
ppm	part per million
S	Shrub
sp.	species
SWAMPS	The Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity index
T	Tree
UPL	Upland

CHAPTER I
INTRODUCTION

1.1. Justification and Rationale

Although the Lower Central Plain is a wetland of national importance (OEPP, 1999a), this wetland is fragmented and mostly outside of protected areas. It has been impacted by rapid urbanization, particularly around Bangkok. Large areas of rice paddy have been changed in land-use to industrial estates, housing estates, and sites for government agencies and universities. Some parts of the Central Plain wetlands may still maintain direct and indirect ecological functions that benefit local communities. Since no ecological study has been done, knowledge-integrated management has never been implemented. Such loss in quantity and quality of freshwater wetlands reflect a lack of understanding on wetland ecology, and low profile of wetlands perceived by people other than rice farmers.

Universities located in wetland landscape are expected to be places that demonstrate wetland-friendly management as they are sources of knowledge and personnel. Unfortunately, gaps between wetland knowledge and education even occur in universities. Less wetland ecology has been taught in higher education while most campus landscapes are managed in a similar way as other urbanized areas. Unless wetlands are filled and converted to buildings, roads, and university facilities, they are just other types of wastelands in most people perception.

Finding practical ways for conservation and management of wetlands on campus is challenging. Because universities produce educated people for future society, this should be their role as leaders for sustainable development (Heinz Family Foundation, 1995; Keniry, 1995). At larger scales, ecological knowledge of wetland on campus could also benefit conservation and management of other wetlands in the Lower Central Plain as the country's knowledge on ecology of freshwater wetland is fulfilled.

1.2. Objectives

Representing wetland mesocosms of the Lower Central Plain, the wetlands of Salaya Campus, Mahidol University, were explored. Ecological research and environmental education approaches for wetlands on campus were adopted in order to reduce the gap between wetland knowledge and education mentioned above. This study is based on the following objectives:

1. To describe the general characters of wetland ecosystems of the Salaya Campus
2. To develop and implement multiple indices for Salaya Campus' freshwater wetland bioassessment
3. To do a pilot project using wetland ecology for developing ecological literacy especially at formal education at Mahidol University
4. To determine the proper roles of wetlands in campus ecology and management

1.2.1. To describe general characters of wetland ecosystem of Salaya Campus

Unlike riverine ecosystems, the biodiversity and ecology of freshwater wetlands of Thailand are little understood and appreciated. Natural wetlands existing on Salaya Campus were surveyed to investigate biodiversity and understand ecology of non-paddy field wetlands in the Lower Central Plain which have some degree of human disturbances. This study focused on plants and aquatic macroinvertebrates since their distributions are directly related to wetland hydrology. Types of plants found in wetland can help in wetland classification and its boundary determination (Keddy, 2004; Cronk and Fennessy, 2001). Attributes of plant communities determine habitats for wildlife, as well as aquatic macroinvertebrates. In addition, aquatic macroinvertebrate communities are related to wetland water quality. After this study, types of wetlands of Salaya Campus were classified. Boundaries of each wetland type were mapped. Species compositions, abundances, and distributions of plants and aquatic macroinvertebrates in the campus wetlands were analyzed.

1.2.2. To develop and implement multiple indices for Salaya Campus' freshwater wetland bioassessment

Many studies have indicated the practical uses of plant and aquatic macroinvertebrate communities as multiple biological indices for evaluating health and functions of freshwater wetlands (Gernes and Helgen, 2002; Andreas and Lichvar, 1995; Cronk and Fennessy, 2001; Mack, 2001; Haugerud, 2003; DWAF, 2004). These groups of organisms were used for evaluating health and functions of wetlands in this study. However, no biological index for freshwater wetlands of Thailand has been developed, despite the development of biological indices for river and stream monitoring (Sangpradub et al., 1996; Mustow, 2002; Sripongpun, 2003; Laowdee, 2008; Cheunbarn and Chantaramongkol, 2003; Rungruengwong and Kositpol, 2008). This study was a pilot project to demonstrate the potential use of plant and aquatic macroinvertebrate communities in wetland bioassessment. Results from the study were expected to indicate impairment of wetlands of Salaya Campus which benefits in planning for wetland management and restoration.

1.2.3. To do a pilot project using wetland ecology for developing ecological literacy especially at formal education at Mahidol University

Education for sustainability has been proposed for an overcrowded world (Tilbury and Wortman, 2004). Environmental education has been used as a tool to fulfill that approach (Hungerford and Volk, 1990; Monroe, 2003). Also, ecology is recognized as a core subject for environmental education (Stone and Barlow, 2005). In Thailand, however, very few courses in wetland ecology are given even in higher education. Moreover, the declinine in biological fieldwork, as in other regions (Barker et al., 2002), is resulting in education failure. Such a phenomenon has stimulated a renewal of education at the Salaya Campus. As many ecological concepts were developed from wetlands (Shelford, 1907, as cited in Elton, 1962; Cowles, 1899, as cited in Chapman, 1931; Lindeman, 1970; Hutchinson, 1975; Stiling, 1999; Beeby and Brennan, 2004; Odum and Barrett, 2005; Begon et al., 2006; Smith and Smith, 2006; Kevin et al., 2006), their educational values could not be underestimated. So, this study developed wetland-based exercises based on concepts of place-based education and experiential learning which will develop environmental awareness by connecting students to their local environment (Sobel, 2005; Beard and Wilson, 2006). The study was expected to build up ecological literacy among undergraduate biology students, and improve their attitudes toward the campus wetland.

1.2.4. To determine roles of wetlands in campus ecology and management

Recently after ecological study of the campus wetlands was finished, Mahidol University established an ambitious master plan for renovating Salaya Campus. The master plan aims to create Salaya Campus as *"A Promise Place to Live and Learn Together with Nature"* (Mahidol University, 2008a; Mahidol University, 2008b; Mahidol University, 2008c). Such motto expressed the campus intention to adopting campus ecology, or "*Green Campus*" (Heinz Family Foundation, 1995; Keniry, 1995). Therefore, wetlands on campus would be preserved and have sustainable management. By reviewing such master plan, roles of wetlands in campus ecology and management were explored and compared with international criteria (Heinz Family Foundation, 1995; Keniry, 1995). If this ambitious plan had really been followed the "*Green Campus*", no negative action would impact the wetlands on campus. Furthermore, such management would benefit to both university communities and biodiversity. Assumptions from this study were expected as a stepping stone for integrated-knowledge management and wetland conservation without boundary.

CHAPTER II
LITERATURE REVIEW

2.1. General Definition and Classification of Wetland

A wetland is an in-between upland and aquatic ecosystem located worldwide and contains diverse features in different parts of the world. Many definitions of wetlands exist (Mitsch and Gosselink, 2000; Cronk and Fennessy, 2001; Keddy, 2004). Dugan (2005) referred that more than 50 definitions of wetlands are in use throughout the world. Based on the objectives and the field of interest of the users, however, wetland is defined in 2 ways i.e., the scientific definitions for wetland scientists, and the legal definitions for wetland manager and regulators (Mitsch and Gosselink, 2000). Among these, the international legal definition that is widely adopted, even in Asian Wetland Inventory program (Finlayson et al., 2002), is defined by the International Treaty on wetlands, the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (or the Ramsar Convention) as follow (Ramsar, 2006, p. 7):

"Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Article 1.1). In addition Ramsar sites may *"incorporate riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands"* (Article 2.1).

In general, wetland definitions often include 3 main components (Mitsch and Gosselink, 2000, p. 26):

1. Wetlands are distinguished by the presence of water, either at the surface or within the root zone.

2. Wetlands often have unique soil conditions that differ from adjacent uplands.
3. Wetlands support vegetation adapted to the wet conditions (hydrophytes) and, conversely, are characterized by an absence of flooding-intolerant vegetation.

So a broad definition of wetland (Keddy, 2004, p. 3) can be:

An ecosystem that arises when inundation by water produces soils dominated by anaerobic processes and forces the biota, particularly rooted plants, to exhibit adaptations to tolerate flooding.

Despite complicated definition, terminology for describing wetlands also varies both among human societies, and among their scientific communities. Therefore, wetland classification system has been developed to divide and sort many kinds of wetlands into similar types for proper management and scientific study (Mitsch and Gosselink, 2000; Keddy, 2004). Cowardin and his colleagues (1979, as cited in van der Valk, 2006) developed a widely-used hierarchical system for American wetlands which recognizes five major wetland types (systems) based on their hydrology (Figure 2.1). This system is a basis for Ramsar classification system for wetland type (Ramsar, 2006).

Semeniuk and Semeniuk (1997) reconciled the Ramsar Classification system with a geomorphic approach that incorporating landform setting with types of hydroperiod. This approach not only describes the full variety of natural wetlands, but also reduces the number of primary wetland classes throughout the globe. Similar to Brinson (1993), a classification approach emphasizing hydrology and geomorphology of wetlands was introduced. Such features of wetlands are responsible for maintaining many of the functional aspects of the wetland ecosystems including the chemical characteristic of water, habitat maintenance, and water storage and transport. Consequently, the Asian Wetland Inventory (AWI) program adopted the approaches of Brinson (1993) and Semeniuk and Semeniuk (1997) by classifying Asian wetlands based on 5 landform attributes and 4 hydrological characteristics. As a result, 13 basic wetland categories as shown in Table 2.1 were classified. With this classification, the AWI protocol for the production of maps and analysis of standardized categories of Asian wetland data within a hierarchical and scalar framework was developed (Finlayson et al., 2002). However, the Ramsar definition and classification system of wetland type is still widely used for wetland inventory and management planning. Like the Asian wetlands compiled by Scott (1989), 22 wetland types, including constructed wetlands, were recognized (Table 2.2).

To simplify the classification system, Mitsch and Gosselink (2000) classified wetlands currently found in North America into 7 major types, but divided into 2 major groups: (1) coastal - salt marsh, tidal freshwater marsh, mangrove, and (2) inland – freshwater marsh, peatland, freshwater swamp, and riparian ecosystems. In addition, the simplified system proposed by Keddy (2004) classified wetlands into six types i.e., swamp, marsh, bog, fen, wet meadow, and shallow water. Table 2.3 shows the description of these wetland types.

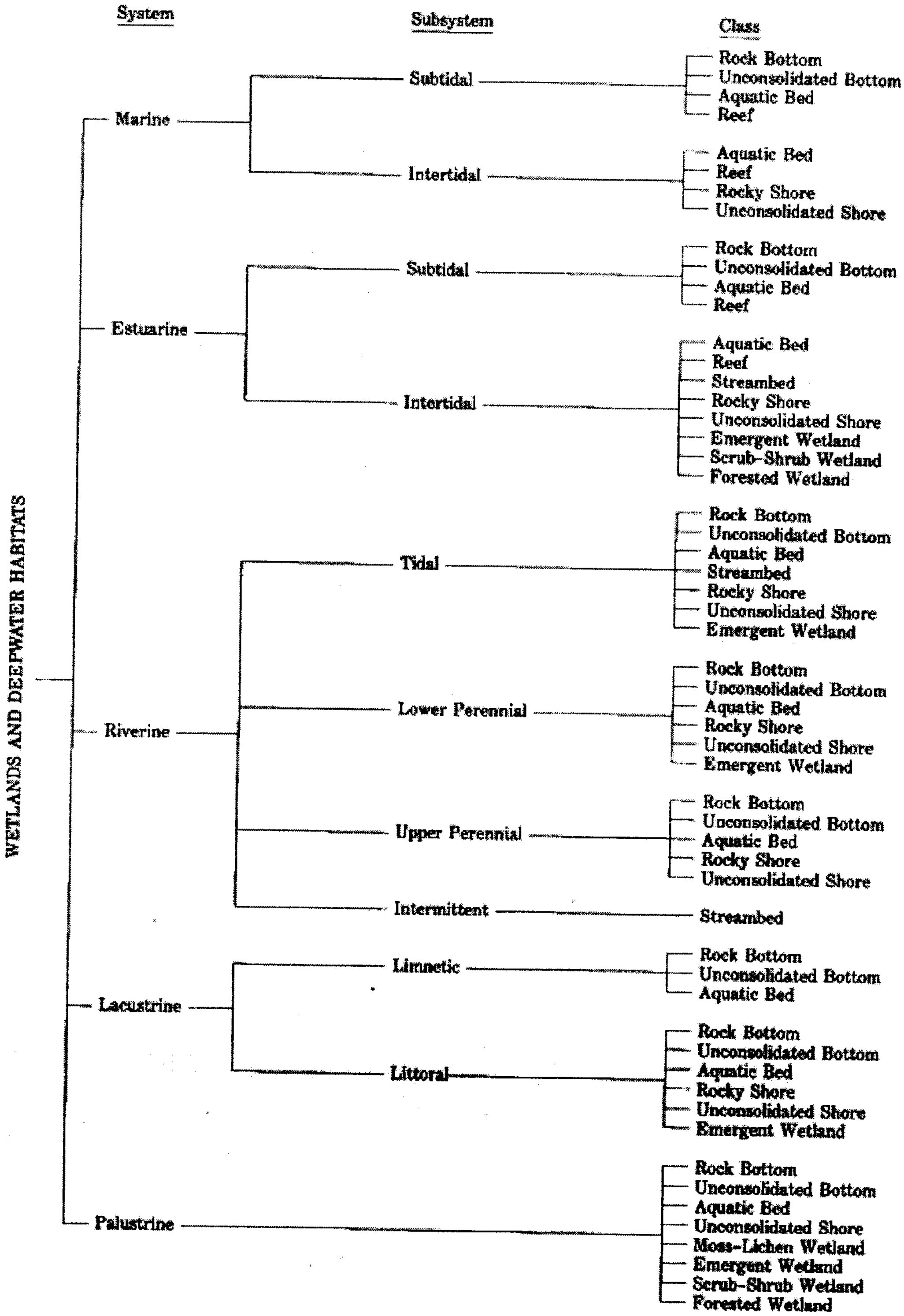


FIGURE 2.1 Classification of wetland types (systems) based on their hydrology (Cowardin et al., 1979, as cited in van der Valk, 2006, p. 7).

TABLE 2.1 Wetland categories of the Asian Wetland Inventory (AWI) program (Semeniuk and Semeniuk, 1995, as cited in Finlayson et al., 2002, p. 44)

Hydroperiod / landform
Permanently inundated basin
Seasonally inundated basin
Intermittently inundated basin
Seasonally waterlogged basin
Permanently inundated channel
Seasonally inundated channel
Intermittently inundated channel
Seasonally waterlogged channel
Permanently inundated flat
Seasonally inundated flat
Seasonally waterlogged flat
Seasonally waterlogged slope
Seasonally waterlogged highlands

TABLE 2.2 Classification of wetlands in a Directory of Asian Wetlands (Scott, 1989)
(* The reference number for the site as used in The Directory of Asian Wetlands)

No.*	Habitat Types
01	shallow sea bays and straits (under six metres at low tide)
02	estuaries, deltas
03	small offshore islands, islets
04	rocky sea coasts, sea cliffs
05	sea beaches (sand, pebbles)
06	inter-tidal mudflats, sand flats
07	mangrove swamps, mangrove forest
08	coastal brackish and saline lagoons and marshes
09	salt pans (artificial)
10	shrimp ponds, fish ponds
11	rivers, streams - slow-flowing (lower perennial)
12	rivers, streams - fast-flowing (upper perennial)
13	oxbow lakes, riverine marshes
14	freshwater lakes and associated marshes (lacustrine)
15	freshwater ponds (under 8 hectares), marshes, swamps (palustrine)
16	salt lakes, saline marshes (inland drainage systems)
17	water storage reservoirs, dams
18	seasonally flooded grassland, savanna, palm savanna
19	rice paddies
20	flooded arable land, irrigated land
21	swamp forest, temporarily flooded forest
22	peat bogs

TABLE 2.3 Simple wetland classification by Keddy (2004, p. 18)

Wetland Type	**Description**
Swamp	A wetland community that is dominated by trees that are rooted in hydric soils, but not in peat.
Marsh	A wetland community that is dominated by herbaceous plants that are usually emergent through water and rooted in hydric soils, but not in peat.
Bog	A wetland community dominated by *Sphagnum* moss, sedges, Ericaceous shrubs or evergreen trees rooted in deep peat.
Fen	A wetland community that is usually dominated by sedges and grasses rooted in shallow peat, often with considerable water movement through the peat.
Wet meadow	A wetland community dominated by herbaceous plants rooted in occasionally flooded soils. Temporary flooding excludes terrestrial plants and swamp plants, but drier growing seasons then produce plant communities typical of moist soils.
Shallow water	A wetland community dominated by truly aquatic plants growing in and covered by at least 25 cm of water.

2.2. Definition and Classification of Wetlands in Thailand

In general, the definition of wetlands in Thailand followed Ramsar Convention. However, wetlands of Thailand are referred in many Thai words which are varied in different parts of the country such as *Huay, Nhong, Klong, Bueng, Boh, Krabhang (Trabhang), Barai, Mae Nam, Lam Tharn, Kwae, Lahan, Chan Klong, Phang Nam, Sob Tharn, Sra, Thale Sab, Ang, Lum, Kud, Thung, Kwan, Mab, Bung, Tham, Pru, Sanun, Kang, Nam Tok, Had Hin, Had Kruad, Had Srai, Had Klone, Had Len, Chai Thale, Chai Phang Thale, Pued Hin Pakarang, Laeng Yah Thale, Laeng Sarai Thale, Khung, Aow, Din Don Sam Leam, Chong Khab, Chawag Thale, Takad, Nhong Nam Kroy, Pa Pru, Pa Len, Pa Chai Len, Pa Kongkang, Pa Jak, Pa Samae,* etc. (OEPP, 2003).

Moreover, various sub-categories can be classified from some ecosystems. For example, at the Mun River, the largest tributary of the Mekong River, 16 sub-ecosystems are classified by local fishermen. These include *Kaeng* (rapids), *Khum* (pool), *Wang* (longer pools), *Wuen* (eddy), *Don* (hump or island), *Kan* (rise), *Tham* (cave), *Hew* (waterfall), *Bung* (bodies of water that are at the end of a rise or island), *Bok Hin* or *Kra Bok Hin* (hole), *Taad* (flat), *Lhum Hin* (stone pocket), *Huu* (hole or tunnel), *Paew* or *Pong* (channel), *Kon* (shallow parts of rapids), and *Sarng* (drinking well) (Sretthachau and Deetes, 2004).

After the Ramsar Convention, information on wetlands of Thailand was compiled in 1989 by the Royal Forest Department and IUCN in order to develop a Directory of Asian Wetlands (Scott, 1989). This program classified 42 wetlands of the country with international importance. Then, during 1996-1999, the Office of Environmental Policy and Planning (OEPP) developed a national inventory of wetlands. Based on this program, wetland uses and management planning could be done properly following the Ramsar criteria (OEPP, 1999a). Table 2.4 shows classification system used in the national wetland inventory program simplified from the Ramsar Convention (OEPP, 1999b).

TABLE 2.4 Thailand's wetland classification system used in the national wetland inventory program simplified from the Ramsar Convention (OEPP, 1999b, p. 25) (Note: subsystems are classified by plant communities, substrate materials, flooding, and human involvement)

System	Subsystem
Marine/Coastal	Subtidal
	Intertidal
	Nontidal
Estuarine	Subtidal
	Intertidal
	Nontidal
Riverine	Riverine
	Riverine bank/beaches/bars
	Riverine floodplain
Lucustrine	Lake
	Pond
Palustrine	Permanent
	Seasonal

2.3. Functions and Values of Wetlands in General

After the definition of ecological function, '*the capacity of natural processes and components to provide goods and services that satisfy human needs*' (de Groot, 1992, as cited in Keddy, 2004, p. 56), wetlands maintain a lot of functions that natural environments perform for humans. In human perceptions, such ecological functions represent wetland values. Mitsch and Gosselink (2000) identified the wetland values from the perspective of three hierarchical levels – population, ecosystem, and global.

Wetland values at population level are the importance of wetlands as habitat for plant and animal survival. They provide animal harvested for pelts (fur-bearing mammals and the alligator), waterfowl and other birds, fish and shellfish, timber and other vegetation harvest, and habitats for endangered and threatened species (Mitsch and Gosselink, 2000). In Asian perspectives, wetland productivity is vital to local livelihoods, especially in rice fields (Bambaradeniya and Amerasinghe, 2003). Though wetlands function as refuges for biodiversity, particularly tropical wetlands (Coughanowr, 1998), their sensitivity to disturbances requires sustainable uses and practical conservation (Subramaniam, 1993). Therefore, this type of values becomes a major objective for the Ramsar Convention.

For the ecosystem values, wetlands function as flood mitigation, storm abasement, aquifer recharge, water quality, aesthetics, and subsistence use (Mitsch and Gosselink, 2000). Coughanowr (1998) emphasized an important role of wetlands in the tropical climate that has unique and frequently extreme meteorological conditions. Since, they help regulating the tropical hydrologic cycle, moderating river flows, and buffering tropical coastlines from storm damage. In case of water purification, freshwater marshes are among the well-known wetlands having such capacity (Weller, 1994). A study of Coon (2000) showed a capacity of cattail-dominated wetland in improving water quality of a creek flows through it. The process is primarily done via sedimentation and vegetative filtration. In United Kingdom, however, an idea of integrating wildlife value into treatment wetland management was issued (Peberdy et al., 1995). Many industries were encouraged for wetland creation and enhancement. With wildlife-related objectives, industry will in turn benefits from environmental image and enhancement of the working environment. In case of agricultural catchments, nutrient loading such as fertilizer applications below critical thresholds was not only able to maintain wetland function in water-quality improvement, but also minimize emission of the greenhouse gas like N_2O (Verhoeven et al., 2006).

As the regional and global levels, wetlands are significant factors in the global cycle of nitrogen, sulfur, methane, and carbon dioxide (Mitsch and Gosselink, 2000). Particularly, the development of mitigation wetlands to take up carbon is a currently challenging issue for minimizing impacts from global warming. Since, an estimated 0.076 PgC (Pg = 10^{15} g) of carbon is currently taken up annually in wetland peat. If the wetlands are drained and peat is burnt, approximately 45 to 89 percent of carbon being taken up will be released to the atmosphere (Gorham, 1991). In contrast, a long-lasting wetland has potential to balance greenhouse carbon between methane emission and carbon sequestration. Whiting and Chanton (2001) found that the wetlands are considered greenhouse gas sources over the short term (20 years). Over long-term changes (500-year time horizon), those wetlands can be regarded as greenhouse gas sinks because the net sink of longer-lived CO_2 molecule outweighs the release of the shorter-lived CH_4 molecule.

On an economic perspective, Power (2004) addressed two flows of valuable wetland services that can be modified by human activity i.e., the flow of goods and services directly from the natural wetland systems, and the flows of goods and services from human-controlled systems that rely on those natural wetland systems. He emphasized that environmental impacts and economic impacts are strongly related. People cannot evaluate environmental services unless they are aware of how changes in the availability of those services will affect them. Especially for impoverished communities in tropical region that the economic values of wetlands are absolutely vital to people's livelihoods (Coughanowr, 1998). Thus, economic analysis is crucial to wetland management. Presented by Power (2004, p. 133), Table 2.5 outlines the way in which scientific descriptions of the change in the ecological function of a wetland (column 1) can affect the flow of ecological goods and services (column 2) that in turn can have an impact on a broad range of human values that can be given economic expression (columns 3-5).

In spite of ecological and economic values, educational values of wetlands cannot be underestimated. After The UN Decade in Education for Sustainable

Development (Tilbury and Wortman, 2004), educating people to be environmentally responsible citizen has been promoted. Environmental education that changes awareness into action is proposed as a tool for conservation of natural resources. With this strategy, nature plays an important role as an outdoor classroom. Because wetlands are frequently the last remaining "wild" spaces in an urban and agricultural landscape (Dugan, 2005), wetland education potentially support the UN approach. However, educational values of wetlands will be addressed in details under the topic *Education as a tool for wetland conservation* at the latter part of this chapter.

TABLE 2.5 The transition of ecological functions to economic values in wetland management (Power, 2004, p. 133)

Ecological function ecosystem capabilities	**Ecological effect annual ecosystem goods & services**	**Societal economic values**		
		Intermediate goods & services	**Final goods & services**	**Future Goods & services**
Hydrological Short-term surface water storage; Long-term surface water storage; Maintenance of high water table	*Hydrological* Reduced downstream flood peaks; Maintenance of base flows & seasonal flow distribution; Maintenance of hydrophytic communities	Flood Control; Water Storage; Irrigation & Sub-Irrigation water for agriculture	Flood damage security; Reduced household utility costs; Maintain sport fishing habitat in dry periods	Unique species, landscapes & ecosystems; Bequest value; Option value; Undiscovered goods
Biogeochemical Transformation, cycling of elements; Retention, removal of dissolved substances; Accumulation of inorganic sediments	*Biogeochemical* Maintenance of nutrient stocks; Reduced transport of nutrients downstream; Retention of nutrients, metals, other; Retention of sediments and some nutrients	Assimilation of wastes; Pollution assimilation/water purification	Higher water quality as an amenity	Unique species, landscapes & ecosystems; Bequest value; Option value; Undiscovered goods
Habitat & Food Web Maintenance of characteristic plant communities; Maintenance of characteristic energy flow	*Habitat & Food Web* Food, nesting, cover for animals; Support for populations of vertebraes	Support for commercial fisheries and recreation; provision of commercially harvested natural resources (timber, fur-bearers, etc.)	Outdoor recreation; Fishing, hunting, camping, hiking, boating, bird watching, etc.; Scenic beauty, diversified landscapes; Educational value; Existence value	Unique species, landscapes & ecosystems; Bequest value; Option value; Undiscovered goods

2.4. Functions and Values of Wetlands in Thailand

From past to present, wetlands have influenced livelihood of Thai people in many ways. In particular the Lower Central Plain is well-watered throughout the year by receiving water from four major rivers: the Bang Pakong, Chao Phraya, Ta Chin, and Mae Klong (Scott, 1989; OEPP, 1999c). This area is a very productive freshwater wetland, especially for rice paddy. Back into the 16th century, the Chao Phraya River, the main river of the Lower Central Plain, was an important domestic and international commercial route to the Ayutthaya Kingdom (Nipatsukkij, 2007). As many tributaries are in the watershed of the Chao Phraya and Ta Chin Rivers, a lot of communities were settled in this region. Before roads were constructed, boating was the most important means of transportation.

During seasonal inundation, connections between terrestrial and aquatic systems of the Lower Central Plain provided various habitats influencing diversity of vegetation and wildlife (OEPP, 1999c). The architecture of traditional houses and markets is evidence of adaptation to the flooded landscape (Van Beek, 1995). Not only foods were provided, but in the past, the Lower Central Plain was also famous for recreation. Most festivals cerebrating the marsh's abundance begin in the flooding season. Traditional songs were played for entertaining during boating across large, inundated marshes. Even the royal family and city people whose livelihoods were far from marshs also preferred boating for sight-seeing (Navigamul, 1995). Furthermore, the seasonal inundated landscape of the Lower Central Plain also benefited the Kingdom in defending against its enemies in historic wars (Literature and History Division, 1999).

Use of the Lower Central Plain has been minimized since roads were introduced and modern development began. The function of wetlands in natural flood control is still maintained. Recently, this function was promoted by a royal project, Kaem Ling (Monkey Cheeks), which retains water by imitating the way monkeys store food in their mouths. The project helped relieve severe flooding by receiving water from the upper plain, before draining to the Gulf of Thailand (OEPP, 1999c; Chaipattana Foundation, 1996). Because the Lower Central Plain is located at an altitude range from 0-20 m above sea level, high level of water also prevents intrusion of salt water from the sea, especially in the dry season (OEPP, 1999c).

When water flows through wetlands, aquatic vegetation acts like a natural filter resulting in nutrient retention and sediment accumulation, which enriches soil in the areas. Furthermore, water quality is improved as toxic substances and waste is removed by this process (OEPP, 1999c). Thus, nutrient uptake by wetland plants such as cattail (*Typha* sp.) has been widely studied for water treatment (Koottatep et al, 2001; Nilratnisakorn et al., 2008) and soil contaminated by heavy metal (Panich-pat et al., 2005). A reputed use of wetland for water treatment is demonstrated by the Royally-initiated Laem Phak Bia Environmental Study, Research and Development Project (Chaipattana Foundation, 2001; Chankaew et al., 2008). Different systems for community's wastewater treatment have been developed including the Constructed-wetland System, the Aquatic Plants System, the Lagoon System, the Grass Filtration System, and the Mangrove Forest Filtration System. The latter one can be applied to use in shrimp farming areas next to the mangrove forest without having to create a mangrove plot. In addition, benefits derived from the treatment wetlands are additional to wastewater treatment. The cultivated plants from the treatment wetlands can be cut for use as animal fodder and other benefits. The wetlands also provide important habitats for birds such as large-billed reed warbler which was rediscovered at Laem Phak Bia after 139 years of disappearance (Round et al., 2007).

Another value of the wetlands of Thailand that is not only vital to building up environmentally responsible citizens, but also improving the country's wetland conservation, environmental education. As mentioned above, this issue will be addressed in detail under the topic *Education as a tool for wetland conservation in Thailand* at the latter part of this chapter.

2.5. Status of Wetlands in General

Based on Mitsch and Gosselink (2000), the extent of the world's wetlands has been variously estimated. In general, it is thought to be from 7 to 9 million km^2, or about 4 to 6 percent of the land surface of the Earth. Excluding rice paddies, the wetland area of subtropical/tropical zone is approximately 2 to 5 million km^2. This accounts for 30 to 50 percent of the world's wetland area. In Asia, about 1.2 million km^2 of the wetlands, excluding permanent rice paddies, are recognized. Although this comprises only 14 percent of the world's wetland area, wetlands in this region help support about 56% of the world's human population. Therefore, they have an average population density about eight times that of the rest of the world. However, only 15% of these wetlands has been afforded some legal protection (Scott and Poole, 1989).

Despite natural changes, anthropogenic impacts from overpopulation and rapid development are accelerating the loss and degradation of wetlands. Table 2.6 identified causes of wetland loss either by human direct and indirect actions, or by natural causes (Dugan, 2005). Much of wetland loss happened before the launch of the Ramsar Convention. However, there still a lack of information about loss and degradation of wetlands in most countries. Though some information exists, most of them cannot be compared (Moser et al., 1996). In general, draining wetlands for intensive agriculture was the major cause of the 26% loss of the available wetland worldwide by 1985. By region, the figure was about 56-65% for Europe and North America, 27% for Asia, 6% for South America, and 2% for Africa. Furthermore, 50% percent of the wetlands worldwide that existed in 1900 have been lost since much of the loss occurred in the northern countries during the first 50 years of the century. Then, the problem expanded to tropical and sub-tropical countries since the 1950s (OECD 1996, as cited in Moser et al., 1996). As in the tropical region, causes of wetland loss mainly came from the demand of rapidly growing populations for land and other natural resources, economic incentives for quick profit, and some involve the health and safety of vulnerable human populations. Moreover, the loss usually is a result of disapproving plans, short-sighted development policies, and financial disincentives (Coughanowr, 1998). Unfortunately, the loss and degradation of wetlands have severe economic impacts, also remove opportunities for sustainable development. Although restoration and rehabilitation of wetlands can be done, not only is investment very expensive, but the full natural functions of wetlands are unlikely to be restored (Moser et al., 1996).

However, many efforts have been made toward global wetland conservation. The Ramsar Convention now has 158 contracting parties. A total of 1,752 wetlands, covering about 1.6 million km^2, have been designated as having internationally importance, known as Ramsar sites (Wetlands International, 2008). Frazier (1999) analyzed human uses of the Ramsar sites and the factors of change in the ecological character of the sites due to unwise uses (Figure 2.2). He found that, at the end of 1998, Ramsar sites were mostly used for fishing (59% of all sites). Secondly, they were used for conservation (56% of all sites), and for recreation and tourism (56% of all sites). Agriculture was the most frequently recorded change factor inside or surroundings of Ramsar sites, while pollution and water regulation were in the second and the third rank, respectively.

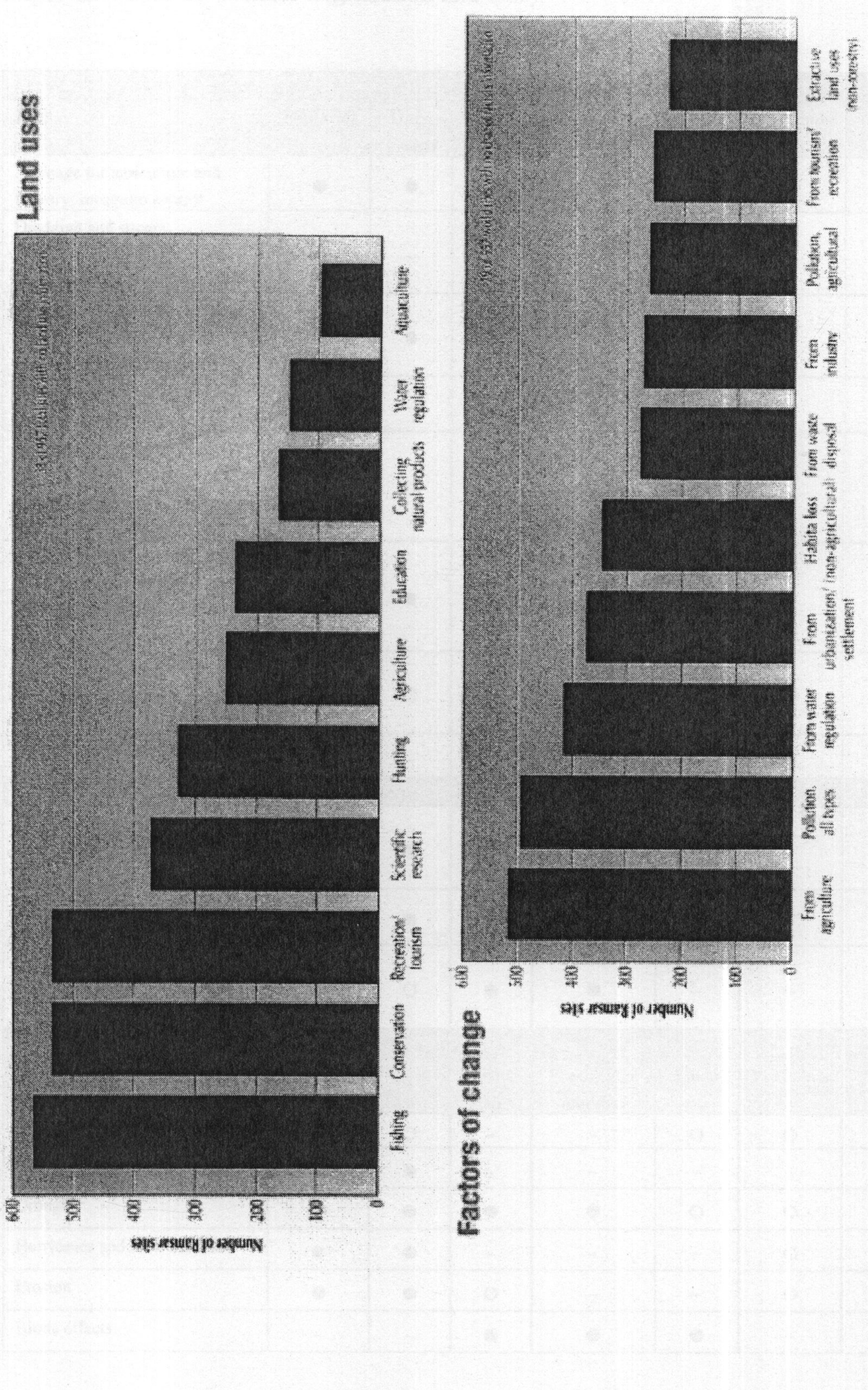


FIGURE 2.2 Human uses of Ramsar sites and the factors of change (Frazier, 1999, p. 5)

TABLE 2.6 Causes of wetland loss (Dugan, 2005, p. 52)

(– Absent or exceptional, ○ Present but not a major cause of loss, ● Common and important cause of wetland degradation and loss)

HUMAN ACTIONS							
Direct	**Estuaries**	**Open Coasts**	**Flood-plains**	**Freshwater marshes**	**Lakes**	**Peatlands**	**Swamp forest**
Drainage for agriculture and forestry; mosquito control	●	●	●	●	○	●	●
Dredging and stream channelization for navigation; flood protection	●	–	–	○	–	–	–
Filling for solid waste disposal; roads; commercial, residential and industrial development	●	●	●	●	○	–	–
Conversion for aquaculture/mariculture	●	–	–	–	–	–	–
Construction of dikes, dams and levees; seawalls for flood control, water supply, irrigation and storm protection	●	○	○	○	○	–	–
Discharges of pesticides, herbicides and nutrients from domestic sewage; agriculture runoff; sediment	●	●	●	●	●	–	–
Mining of wetland soils for peat, coal, gravel, phosphate and other materials	○	○	○		●	●	●
Groundwater abstraction	–	–	○	●	–	–	–
Indirect							
Sediment diversion by dams, deep channels and other structures	●	●	●	●	–	–	–
Hydrological alterations by canals, roads and other structures	●	●	●	●	●	–	–
Subsidence due to extraction of groundwater, oil, gas and other minerals	●	○	●	●	–	–	–
NATURAL CAUSES							
	Estuaries	**Open Coasts**	**Flood-plains**	**Freshwater marshes**	**Lakes**	**Peatlands**	**Swamp forest**
Subsidence	○	○	–	–	○	○	○
Sea-level rise	●	●					●
Drought	●	●	●	●	○	○	○
Hurricanes and other storms	●	●	–	–	–	○	○
Erosion	●	●	○	–	–	○	–
Biotic effects	–	–	●	●	●	–	–

2.6. Status of Wetlands in Thailand

Excluding rice paddies, there are at least 42,653 natural wetlands in Thailand (Table 2.7) which cover an area of 36,616 km^2, or 7.5% of total area of the country (OEPP, 1999a). Thailand joined as the 110^{th} contracting party of the Ramsar Convention in 1998 (OEPP, 1999b). A national inventory of wetlands were done during 1996-1999 (OEPP, 1999a). After the inventory, wetlands of Thailand were ranked into three levels of importance i.e., international importance (61 wetlands), national importance (208 wetlands), and local importance (42,396 wetlands). Among the wetlands of international importance, 11 have been designated as Ramsar sites (Wetlands International, 2008; ONEP, 2008). Among the wetlands of national importance, however, 107 wetlands are in national parks, 40 are in wildlife sanctuaries, 30 are in non-hunting areas, while another 31 wetlands, including those in the Lower Central Plain, are without any form of formal protection (OEPP, 1999a).

As part of the Lower Central Plain, Thung Luang Rangsit or Rangsit Great Plain, a wetland important in Thai history, was formerly defined as the Rangsit swamp forest (NSM, 2001). It contains trees, shrubs, climbers, herbs, aquatic plants, grasses, and sedges. At present, however, such forest condition and its dominant vegetation have been greatly altered by anthropogenic activities, resulting in remnants of the original swamp in temples and at the edges of cultivated grounds. The National Science Museum (NSM) recorded the diversity of existing fauna in Rangsit Great Plain: that there are 122 species of fishes, 11 species of amphibians, 58 species of reptiles, 214 species if birds (22.2% of total birds species of Thailand), 57 species of mammals (mostly are bats and rodents), and a large number of arthropods, especially dragonflies and damselflies including 86 species (31% of known species in Thailand). However, the drastic changes of the Lower Central Plain's habitats since 1890 caused many mammals like Asian elephant, Small-clawed Otter, Javan Rhino, Eld's Deer, Large Indian Civet, and Large-spotted Civet to be completely extirpated. An extinction of a beautiful, endemic species, the Schomburgk's Deer, became a lesson learned for biodiversity conservation in this region (NSM, 2001).

Nevertheless, the Lower Central Plain still contains important habitats for birds and is recognized as one of the most Important Bird Areas (BCST, 2004) of Thailand. Round (2008) listed 237 species found in the Lower Central Plain. Among these, at least 60 species are of conservation concern of which two-thirds are primarily associated with the coastal and mudflat zone and one-third with paddy land and freshwater marsh. Many bird watching areas were recommended, ranging from the city's parks to the areas surrounding Bangkok, including temples, universities, and natural and constructed wetlands. Salaya Campus, Mahidol University, was one of the riches areas around the city, containing over 130 species of birds, including some scarcer migrants (Brockelman et al., 1993; Round, 2008).

Though wetlands in Thai perception have been strongly related to their culture, society, and economy for a long time, gaps between scientific knowledge and normal education are very wide (Campbell and Parnrong, 2001). Increase in human population density, agricultural intensification, urban expansion, industrial development, and failure to fully mitigate the environmental impacts of development, particularly in the Lower Central Plain, are still the major threats to wetland biodiversity (Van Beek, 1995; Molle and Srijantr, 2003; Hara et al., 2005). Within seven years (1987 to 1994), 16% of rice fields in central and eastern Thailand have been lost, and rice area has declined from 19,537 to 16,354 km^2, while total irrigated agricultural area has been increased 9% from 19,476 to 21,243 km^2 during 1985-1993 (OEPP, 1999c). Moreover, industrialized areas have rapidly expanded in the Lower Central Plain. Pollution from agricultural chemicals, industrial and domestic wastes (Sripongpun, 2003; Patarasiriwong, 2004,), invasion of exotic species (Kangwan, 2002), spread of emerging disease like bird flu (Tiensin et al., 2005; Srikosamata and Milne, 2007), and unsustainable development all impact biodiversity of the wetlands.

To better conserve wetlands in the Lower Central Plain, Scott and Poole (1989) suggested that the existing reserves should be upgraded or expanded, and that improvement in the enforcement of existing legislation be improved. Some form of management is required to maintain or enhance the nature conservation values of the site. Furthermore, watershed management that incorporates more biodiversity elements rather than just forest cover is needed (Srikosamatara et al., 2004). Since the Lower Central Plain has an exceptional potential for conservation education and nature-oriented outdoor recreation, such potential should be developed to improve awareness of local people to the need for wetland conservation (Scott and Poole, 1989).

TABLE 2.7 Types and number of wetlands in Thailand (OEPP, 1999a) (Note: Rice paddies were excluded)

System	Number (sites)
Canals, Streams, and Rivers	25,008
Lakes	14,128
Marshes and Inundated plains	1,993
Seas, Coastal areas, and Estuaries	1,256
Yet to be classified	268
Total	**42,653**

2.7. Measuring the Condition of Wetlands in General

There are many approaches for evaluating the health and functions of wetland, either by physical, chemical, or biological measurement. Among these, the measurement of biological integrity is widely applied (Adamus et al., 2001) due to its lower financial investment and professionalism required, and attractive characteristics of flora and fauna. Karr and Dudley (1981, as cited in Karr, 1991, p. 69) defined biological integrity as *the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region.*

In different region, different groups of wetland biota have been selected as wetland indicators depending on wetland characteristics, expertise, and management goals. However, most wetland biomonitoring studies have been done in the temperate zone. Karr (1991) developed the index of biotic integrity (IBI) using a set of ecosystem attributes (e.g., species richness, changing abundance of an indicator species, production/respiration ratio) to measure organization and structure of fish communities in running waters. Galatowitsch et al. (1999) evaluated the recovery of Minnesota's wetlands by developing indices for plant, bird, fish, invertebrate, and amphibian communities. Mitsch and his colleagues (2004) used 16 abiotic (e.g. biogeochemistry, nutrient dynamics) and biotic (e.g. macrophyte, algal, avian communities) indicators to estimate wetland divergence and convergence between planted and natural colonizing wetland in a whole ecosystem experiment. Balcombe et al. (2005) evaluated mitigation wetlands in West Virginia through vegetation, avian, anuran, and invertebrate communities. In South Africa, a framework developed for the wetland assessment of ecological integrity considered the advantages and disadvantages of variables including soil, plants, aquatic macroinvertebrates, fish, amphibian, and waterbirds as wetland indicators. In addition, international approaches to wetland assessment in USA, Australia, Asia, and Mediterranean have been reviewed (DWAF, 2004). Goodrich et al. (2004) determined that all 50 states of the USA currently have biological assessment programs in place. Fish, macroinvertebrates, and periphyton comprise the major aquatic assemblages utilized by state biological monitoring programs. The most common assemblage used is macroinvertebrates. However, many states are benefiting from assessing more than one assemblage.

In Minnesota, for example, the invertebrate index developed by Helgen (Gernes and Helgen, 2002) contain 10 indicators i.e., total invertebrate taxa, Odonata taxa, Chironomid genera, Leech taxa, Snail taxa, ETSD (mayflies, caddisflies, fingernail clams, dragonflies), intolerant taxa, tolerant taxa, dominant three taxa, and Corixidae proportion. In contrast, the index evaluating the effects of disturbances in seasonal floodplain wetlands in the Upper Missouri River developed by Haugerud (2003) included 7 indicators i.e., proportional abundance of Chironomidae, proportional abundance of Lymnaeidae, proportional abundance of predators, proportional abundance of dominant taxa, proportional biomass of Hydraenidae, proportional biomass of univoltine taxa, and number of Odonata taxa. Furthermore, he found differences in macroinvertebrate community structure between forested and emergent wetlands which indicated that biomonitoring criteria for these two types of wetlands would be developed separately. On the other hand, the SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution) score is an example of a macroinvertebrate index developed for evaluating wetlands in Australia. This index uses numerical values between 1 and 100 (1 = most tolerant, 100 = most sensitive) assigned to wetland macroinvertebrate families to reflect their sensitivities to nutrient enrichment (Chessman et al., 2002, cited in Ling, 2006; Davis et al., n.d.).

Apart from macroinvertebrates, a plant-based index for evaluation of large depressional wetlands in Minnesota was developed by Gernes (Gernes and Helgen, 2002). The index contains 10 indicators, i.e., vascular genera, nonvascular taxa, Carex cover, sensitive species, tolerant taxa, grasslike, perennials, aquatic guild, dominant three taxa, and persistent litter. Another example of applying wetland plant assemblages as biological indicators reviewed by Cronk and Fennessy (2001) was the Floristic Quality Assessment Index (FQAI). This index accounts for both the presence of exotic species and the degree of fidelity of each native species to specific environmental conditions. Therefore, it can be used to assess an area based on the balance between ecologically conservative and highly tolerant species. The effectiveness of the FQAI was tested by Lopez and Fennessy (2002) and interpreted as a measure of environmental factors that maintain and control plant communities. It was recommended for the assessment and monitoring of wetland ecosystems and for tracking wetland restoration projects over time such as that applied in the monitoring of Ohio's wetlands (Mack, 2001). In addition, Miller and his colleagues (2006) developed a plant-based index of biological integrity to evaluate headwater wetland condition in response to anthropogenic disturbances. The indicator included adjusted FQAI, percent cover of tolerant plant species, percent annual species, percent non-native species, percent invasive species, percent trees, percent vascular cryptogams, and percent cover of *Phalaris arundinacea* (Family: Gramineae).

2.8. Measuring the Condition of Wetlands in Thailand

In Thailand, most wetland bioassessment approaches have focused on the macroinvertebrate fauna in riverine systems. Sangpradub and her colleagues (1996) found some inconsistency of BMWP/ASPT scores (Biological Monitoring Working Party score/the average score per taxon) (Armitage et al., 1983, as cited in Sangpradub et al., 1996) which were not fitted to benthic macroinvertebrates of Thailand. Therefore, they developed two local indices. The first one was the Pong index, based on family-level benthic taxon distribution and water quality at each sampling site. The second one was the Q index, based on general patterns of organism tolerance and the ratio of presence/absence of organisms in benthic communities at sampling sites. Mustow (2002) modified the BMWP score of the British Department of the Environment (National Water Council, 1981 as cited in Mustow, 2002), naming it as the $BMWP^{THAI}$ score, and applied it for monitoring rivers in northern Thailand. The BMWP score was also used for monitoring water quality in the Lower Thachin River of the Lower Central Plain by Sripongpun (2003). The study related the poor quality of the river during the study period. An Oligochaete (*Ophidonais* sp.) was the most abundant species found. Similarly, the index was used for environmental monitoring in the Tapee watershed, Surat-Thani Province, in southern Thailand (Laowdee, 2008).

Based on a multivariate approach, Cheunbarn and Chantaramongkol (2003) used Trichoptera communities as indicators in monitoring environmental degradation in the upper Ping watershed, northern Thailand. Rungruengwong and Kositpol (2008) used macroinvertebrate assemblages for stream ecological monitoring at Mae Wang Stream, Chiang Mai Province. Such multivariate analysis assess human impact using comparisons between patterns observed at test sites and patterns expected in the absence of human impacts revealed by statistical analysis. However, Bonada et al. (2006) identified some disadvantages of this approach, since no ecological functions were assessed, it had no large-scale applicability, and its indications of changes in different types of human impact were of unproven reliability.

In contrast, Srinoparatwatana (2001) and Patarasiriwong (2004) are examples *of the studies that evaluate wetlands* based only on diversity indices of benthic invertebrates. Though their results indicate the positive responses of the diversity index to water quality, these studies did not characterize the benthic invertebrate habitats and the degree of human disturbance of the environments studied, therefore, the indices used in these studies only reflect the community structure of the aquatic invertebrates but not their ecological functions.

At present, Thailand has no practical biotic indices for evaluating wetlands such as freshwater marshes. Davis et al. (2006) determined that methods for river bioassessment and monitoring would be applied to wetland bioassessment. However, specific models need to be developed for specific geographic regions and climatic conditions for determining the composition and richness of invertebrate communities since wetland habitats, particularly plant communities, differ among the regions. Unlike streams and rivers, organisms in freshwater marshes require adaptation to low-oxygenated environments. Some invertebrate taxa such as Chironomids which are used as indicators of low water quality in riverine systems, are common in this type of wetland (Weller, 1994). In order to develop an index of biological integrity of freshwater marshes, biological indicators for river and stream assessment should be revised. Some studies mentioned above (e.g. Gernes and Helgen, 2002; Haugerud, 2003; Miller et al., *2006; Davis et al., n.d.; Mack, 2001) are based on a multimetric* approach (multiple indices system) which at least partially meets 10 of 12 criteria for defining an ideal biomonitoring tool, including the potential to assess ecological functions (Bonada et al., 2006). Consequently, they can be a basis for developing biological indices evaluating the health and functioning of freshwater marshes of Thailand.

2.9. Education as A Tool for Wetland Conservation

Many ecological concepts taught in textbooks were developed from wetlands. The wetland plant communities are used to demonstrate interspecific competition, niche separation, and community concepts (Smith and Smith, 2006). A model of plant succession was developed by the study of plant communities on sand dunes (Cowles, 1899, as cited in Chapman, 1931). Shelford (1907, as cited in Elton, 1962) demonstrated relationships between successional pattern of the tiger beetles *Cicindela* sp. and succession of plant communities on the shores of Lake Michigan. Distribution and zonation of plants in lakes were described by Hutchinson (1975). He addressed that exposure to wind and waves, water depth and turbidity, and sediments were external forces on plant zonation. Plant zonation along environmental gradient of wetlands was also studied for testing hypotheses on community concepts (Shipley and Keddy, 1987; Hoagland and Collins, 1997). Three characteristics of plant community structure along gradients, i.e. pattern of boundaries of species distribution, pattern of modes of species response curves, and appearance of hierarchical structure in species distribution, were statistically analyzed by Hoagland and Collins (1997). Figure 2.3 show four models of community structure supported by their study.

Lakes and ponds are also a classic example for demonstrating eutrophication or the enrichment of bodies of freshwater by inorganic plant nutrients such as nitrate and phosphate (Stiling, 1999; Beeby and Brennan, 2004). Occupying the interface between terrestrial and aquatic habitats, swamps and marshes were referred as the ecosystems that produce as much biomass annually as tropical forests (Ricklefs, 1993). With long food chains, wetlands provide knowledge on how trophic structure and energy flow is processed (Stiling, 1999; Odum and Barrett, 2005; Begon et al., 2006). Lindeman (1970) developed the trophic-dynamic principles from the study of aquatic food-cycle relationships. He emphasized trophic relationships within a lake to the process of succession. Moreover, basic ecological knowledge on wetlands is used in other disciplines such as disease ecology (Kevin et al., 2006).

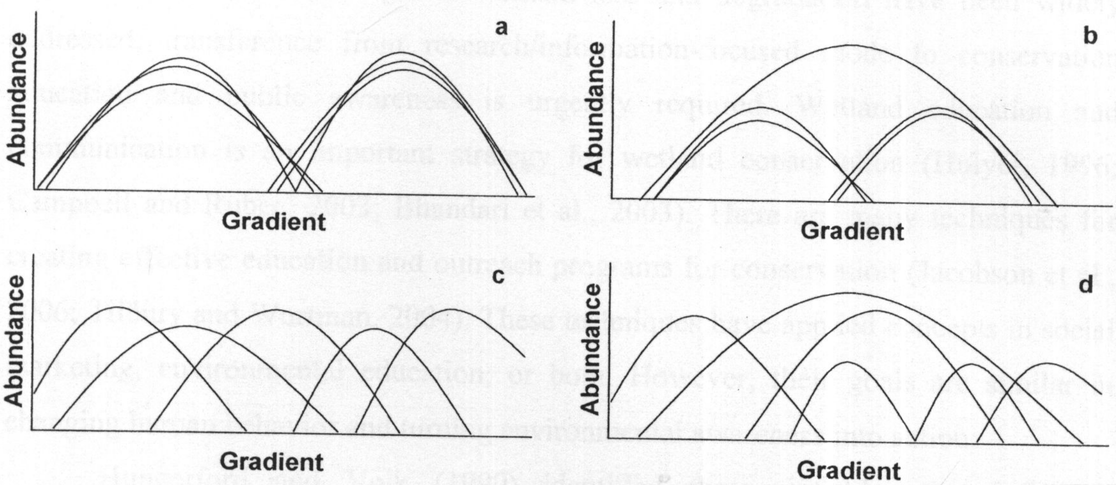


FIGURE 2.3 Models of species distribution along gradients presented by Hoagland and Collins (1997): a) community-unit, b) hierarchical community-unit, c) continuum concept, d) hierarchical continuum

Since the issues of global wetland loss and degradation have been widely addressed, transference from research/information-focused mode to conservation education and public awareness is urgently required. Wetland education and communication is an important strategy for wetland conservation (Hulyer, 1996; Campbell and Rubec, 2003; Bhandari et al., 2003). There are many techniques for creating effective education and outreach programs for conservation (Jacobson et al., 2006; Tilbury and Wortman, 2004). These techniques have applied concepts in social marketing, environmental education, or both. However, their goals are similar in changing human behavior and turning environmental awareness into action.

Hungerford and Volk (1990) identified three variables that influence environmental citizenship behavior. They are entry-level, ownership, and empowerment. The entry-level variables are variables that would enhance a person's decision-making, once an action is undertaken. They include environmental sensitivity, androgyny, ecological knowledge, and attitudes toward pollution/technology/economics. Secondly, the ownership variable can make environmental issues extremely important at a personal level. These include in-depth knowledge about issues, personal investment in issues and the environment, knowledge of the consequences of behavior (both positive and negative), and a personal commitment to issue resolution. Finally, the empowerment variables will give human beings a sense that they can make changes and help resolve important environmental issues. These variables are knowledge of and skill in using environmental action strategies, locus of control (expectancy of reinforcement), intention to act, and in-depth knowledge about issues.

Since cognition is a fundamental domain developed in education, ecology seems to be a core subject to provide scientific knowledge, helping people to understand nature, the human-environment relationship, the concepts of sustainability, and how to solve problems (Hale, 1993). Beyond knowledge, Iozzi (1989) emphasized environmental attitudes and values as important elements to turn environmental awareness into action. However, Ballantyne and Packer (1996) argued that balance between the attitudes/values-education approach and the environmental knowledge-education approach is required in environmental education. While environmental knowledge alone cannot bring learners to awareness, values-oriented education can bring learners to misconceptions (Munson, 1994). As an alternative conception in environmental education, constructivism, or a constructive integration of knowledge, was proposed to link an individual learner's conception of a phenomenon with his or her knowledge, attitudes/values, and behavior in relation to that phenomenon (Ballantyne and Packer, 1996). This process can overcome the imbalance problem mentioned above.

In the process of education, Monroe (2003) proposed two examples of strategies that may be useful in building environmental literacy. The first strategy is significant life experiences (Chawla, 1998). It is the experiences, especially in childhood, that people remember as significant in motivating their care and concern for the natural world. Such experiences can be developed from a learning process called experiential learning which is *the sense-making process of active engagement between the inner world of the person and the outer world of the environment* (Beard and Wilson, 2006, p. 19). Another strategy proposed by Monroe (2003) is environmental-based education (NEETF, 2001) which is an education that engages students in the real world, allowing them to explore problems and taking actions. These two strategies influence students in step by step learning from developing cognition to emulation learning i.e. learning from environmental events they are involved with (Tomasello, 2004). Consequently, critical thinking (Chiras, 1992) and a sense of place (Knapp, 2003) among students will be developed.

Place-based education can provide both significant life experiences and environmental-based education (Monroe, 2003). Sobel (2005, p. 9) referred to place-based education as a desirable environmental education that "*teaches about both the natural and built environments. The history, folk culture, social problems, economics, and aesthetics of the community and its environment are all on the agenda. In fact, one of the core objectives is to look at how landscape, community infrastructure, watershed, and cultural traditions all interact and shape each other*. So, the study of place focuses to examine the interrelationship between disciplines which link learners to their livelihoods (Calhoun et al., 2003; Orr, 2005).

By adopting the conceptual frameworks mentioned above, some examples of environmental education projects and materials for wetland conservation are available e.g. the Water Drop Patch Project (USEPA and GSCNC, 2001), Project WILD

Aquatic (Project WILD, 2003), Project WET (Water Education for Teachers) (http://www.projectwet.org), Florida's Water Resource Activity Pack (Jones, n.d.), WOW! The Wonders of Wetlands (Slattery and Kesselheim, 1995), WWF Hong Kong's Mai Po Marshes Wildlife Education Centre and Nature Reserve (Young, 1994), A Guide to Freshwater Life in Singapore (Ng, 2000), A guide to pond life (Bhathal and Shiew, 2004), etc.

2.10. Education as A Tool for Wetland Conservation in Thailand

In Thailand, a successful environmental education program which later became a model for river and stream biomonitoring among various schools and communities is the Stream Detectives Program developed by the Green World Foundation (Kanjanavanit, 2002, Kanjanavanit and Moonchinda, 2002). The project's method for biomonitoring was simplified from a product of the Field Studies Council (FSC), *A Freshwater Name Trail* (Orton et al., n.d., as cited in Kanjanavanit, 2002), and research of Mustow (1997, as cited in Mustow, 2002). Evaluation of the project showed that students were not only equipped with skill and knowledge, but their awareness and self-esteem for stream conservation were also built up. In addition to biomonitoring, a learning material for physical and chemical monitoring of water quality of wetlands in the northeastern Thailand was developed by Kijtivejakul et al. (2007). This manual was based on a pilot project carried out by 10 schools in the Lower Songkram River Basin in order to monitor water quality of the Songkram River. The project was coordinated by the Mekhong Wetland Biodiversity Conservation and Sustainable Use Programme, Lower Songkram River Basin Demo Site (MWBP) and Walai Rukhavej Botanical Research Institute, Maha Sarakam University.

Three nature education centers at wetlands were established by WWF Thailand (WWF Thailand, 2008) similar to those established by WWF Hong Kong. Two centers based on coastal ecosystems are Bang Pu Nature Education Center and Sirindhorn International Environmental Park-Sustainable Development Education Center. The former, located close to Bangkok, aims to engage city people and youth in mangrove forest conservation, while the latter aims to demonstrate biodiversity of the restored mangrove and beach forest. Another WWF Thailand nature education center is located in the Lower Central Plain. It is the Nature and Agricultural Ecosystem Education Center. Through experiential learning, this center aims to engage students in an ecosystem in which nature and agriculture of the Lower Central Plain can coexist, so that sustainable development will be achieved.

In addition, some of wetland education projects in Thailand are distinctively characterized by community-based environmental education (CBEE) which is a commitment strategy for conserving local natural resources developed by local communities in order to solve conflicts in resource use (Andrews et al., 2002). As part of environmental management processes, the CBEE emphasized qualities of equity, empowerment, and sustainability (Andrews et al., 2002). Examples of these projects are *Rao Rak Mae Nam Ta Chin* (We Love Ta Chin River) club (TEI, 2005), Sam Roi Yod wetland conservation (Sam Roi Yod Wetland Conservation and Development Group, unpublished document), Krabi Estuary Wetland Management and Protection Project (Nualcharoen et al., 2006), and Bung Khong Long Non-Hunting Area Ramsar Site biodiversity monitoring project (Klinhom et al., 2008).

However, some environmental education programs involving wetlands may not be primarily proposed for the purpose of wetland conservation. For example, some Local Science Projects use local wetlands as outdoor classrooms (Local Science Project, 2004; Rajabhat University Research Network, 2004). Based on inquiry learning in science education, school children participating in such projects explore their local wetlands mainly through the scientific process. Another example is a project on an environmental education center launched by the Department of Environmental Quality Promotion (DEQP) and the Biodiversity Research and Training Program (BRT) (DEQP, 2006). This project encouraged nature and biodiversity study on different ecosystems in four regions of Thailand. Though each center's ecosystem contained specific wetland habitat, the conservation approach was unclear. The project's results provided massive data of species lists and biodiversity details but less linkage to the structure and function of biological communities.

Most environmental education projects done in Thailand still have imbalance between knowledge and values addressed by Ballantyne and Packer (1996). In addition, essential knowledge and skills, which is a minimum requirement of environmental education in Thailand, particularly education for wetlands in the Lower Central Plain, is needed (OEPP, 2000). Very little education on wetland ecology is given, even in higher institutions. At the same time, Thailand faces a situation in which biological fieldwork in courses is declining, as has occurred in other regions (Barker et al., 2002). Without such literacy, it is difficult to develop wetland values in an overcrowded world. Consequently, integrated management cannot be effectively practiced. To solve such problems, not only wetland ecology of the Lower Central Plain has to be studied. But a strategy to transfer such knowledge into environmental management has to be explored.

2.11. Wetlands and Sustainable Campus Landscape Management

Under the idea that "*colleges and universities educate most of the people who run society's institutions and train the teachers who educate children* (Heinz Family Foundation, 1995, p. 2)", making campuses green, as catalysts for environmental sustainability, became an approach for many colleges and universities over the world. In 1994, 450 college and university delegates from 22 countries participated in The Campus Earth Summit at Yale University, USA. *The Blueprint for a Green Campus* (Heinz Family Foundation, 1995) was produced from this meeting. *The Blueprint* proposed 10 recommendations for campus ecology and management i.e.:

I. Integrate environmental knowledge into all relevant disciplines
II. Improve undergraduate environmental studies course offerings
III. Improve opportunities for students to study campus and local environmental issues
IV. Conduct a campus environmental audit
V. Institute environmentally responsible purchasing policies
VI. Reduce campus waste
VII. Maximize energy efficiency
VIII. Make environmental sustainability as top priority in campus land-use, transportation, and building planning
IX. Establish a student environmental center

X. Support students who seek environmentally responsible careers

In land-use planning of recommendation VIII, campus development without "*a negative impact on parks, forests, wetlands, wildlife habitats, agricultural land, watersheds, historic buildings, traffic congestion, or noise and air pollution*" was concerned (Heinz Family Foundation, 1995, p. 31). Lack of ecological knowledge and definition of campus beauty can cause negative impacts to campus nature such as bulldozing weeds, applying pesticides, herbicides, and fertilizers, and introducing exotic species (Hocking, 2000; Simpson, n.d.). Such controversy often occurs when university developers are more concerned with display of the campus's appearance rather than ecological, educational, and social values of natural areas (Hocking, 2000; Harris et al., 2001).

The campus landscape not only plays a role as a recreational area of the university, but it also functions as a teaching tool about environmental change, in both negative and positive terms (Franklin et al., 2003; Uhl and Anderson, 2001). In the case of wetlands, for example, students and the university community can learn about impacts from a polluted, eroded stream bank, storm water regulation by a natural wetland, and functions of constructed wetland in processing the university's wastewater. Franklin and her colleagues (2003) emphasized the need of Environmental Master Plan (EMP) in designing sustainable campus landscape. EMPs are best developed by 1) using democratic, or participatory planning process; 2) considering each site's unique essential environmental resources ; 3) working in the regulatory environment such as a campus storm water management program; and 4) education and outreach either students, faculties, staffs, or larger communities.

In addition, sustainable landscaping involves protecting native organisms, preserving natural habitats, reducing the use of resources and viewing the landscaped campus as part of the local or original ecosystem (Keniry, 1995; Harris et al., 2001; Macquire University, 2007). Uhl and Anderson (2001) proposed this as a land ethic. They emphasized that universities which mostly own large amounts of land have to demonstrate responsible land stewardship to their students and community members. Landscaping also requires understanding on campus context includes its natural settings, site history, current infrastructure, and population and development pressures

(Harris et al., 2001). Such concept is consistent with campus landscape design determinants proposed by Dober (2000).

Under uniqueness of harmonious man-made and natural areas, sustainable campus landscape provides various benefits to university community. University's academic performance can increase as its landscape supports education and research (Sobel, 2005; Hocking, 2000; NATL, n.d.), even a chance to discover new species on campus (Taylor et al., 2007). With recreational values, the natural landscape can improve personnel's mental health (Knapp, 2003). Furthermore, university can minimize costs in campus management such as wastewater treatment, storm water management, and flood control by deriving ecological services from natural ecosystems on campus (Keniry, 1995; Hocking, 2000; Harris et al., 2001; Franklin et al., 2003; NATL, n.d.). On the other hand, maintaining native, natural landscape help conserving habitats for wildlife, as well as, promoting biodiversity on campus (Keniry, 1995; Hocking, 2000; Harris et al., 2001; Macquire University, 2007).

CHAPTER III
STUDY AREA AND METHODS

3.1. Study Area

Salaya Campus, Mahidol University is located in Tha Chin River Basin in Nakhon Pathom Province, Thailand. It is about 20 km west of Bangkok. With area coverage of approximately 200 ha (2 km^2), the campus has mixed natural and man-made habitats. As part of the Lower Central Plain, this area is young delta flat composed of alluvial soil (Takaya and Thiramongkol, 1982). Original land uses were mainly rice paddies, orchards, and casuarina plantations harvested for poles. The rice paddies begin to be inundated in July, with peak of water depth of almost 25 cm in November to December. Then, water level decreases and dries up in February (Takaya and Thiramongkol, 1982). In addition, the campus and its surrounding areas were originally characterized by numerous man-made ponds. These ponds were usually about 5 x 6 m^2. They were used for various purposes from securing drinking water to raising fish. *Combretum quadrangulare* Kurz and bamboos were usually found along the edges of the ponds. These trees served as windbreaks and supplied firewood (Takaya and Thiramongkol, 1982). Later in 1975, such original land uses were abandoned and changed for establishment of the university campus (Mahidol University, 1983). In 1990, buildings and surrounding lawns occupied about 10% of the campus area (Brockelman et al., 1993). During 1993, five natural areas, mainly wetlands in the north, east, west, and south of the campus, were proposed to be nature reserves (Center for Conservation Biology, Faculty of Science, Mahidol University, unpublished document) and approved by the administration and university council. Unfortunately, the initiative failed due to changes in the university administration and policies. After 25 years of establishment, Salaya campus has progressively been developed by filling of wetlands. A large area of marshy field was converted into buildings, roads, lawns, and other facilities, leading to increase in area coverage of buildings and surrounding lawns to approximately 80%. Recently in 2008, an ambitious master plan of Salaya Campus was revised (Mahidol University, 2008a; Mahidol University, 2008b; Mahidol University, 2008c). Drastic changes on the campus landscape have occurred in 2008. However, patches of natural wetland still exist due to their location in undeveloped zones. This study explored two existing wetlands of Salaya Campus once proposed as nature reserves. These wetlands are located in the northern and the southern part of the campus. They cover areas of 6 ha and 2 ha, respectively. These are small wetlands that totally cover only 4% of the campus area. Figure 3.1 shows a map of Salaya Campus and the wetlands used in this study.

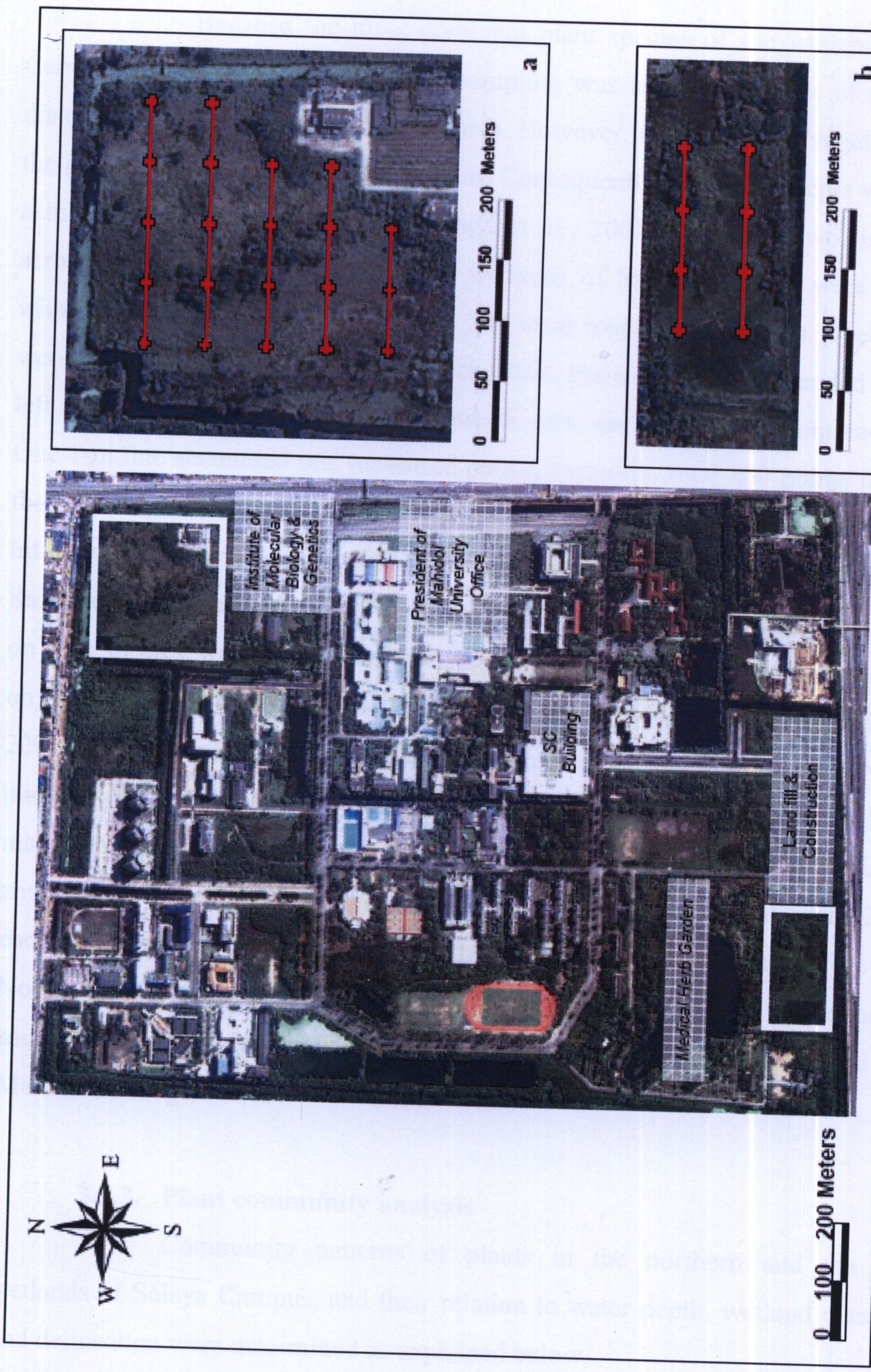


FIGURE 3.1 IKONOS satellite image of Salaya Campus, Mahidol University (1 m resolution, collection date: 15/02/2004), showing wetland study areas and line transects with sampling station at every 50 m (a = the northern wetland, b = the southern wetland)

3.2. The Study on Wetland Plant Communities

3.2.1. Vegetation survey

Because the most dominant plant species of the wetlands of Salaya Campus appear in zone, if the plot sampling was applied, number of plots had to distribute to cover all of the wetland area. However, dense and tall vegetation causes the plot sampling method to be difficult. Consequently, point intercepts were used as a method for measuring cover (Elzinga et al., 2001). Five and two line transects across the northern and the southern wetlands of Salaya Campus were established with ranged distances from 100 m to 200 m in length (Figure 3.1). These transects were located at 50 m interval from each other. Horizontal lines extended 1 m on the left and 1 m on the right sides of transects were set every 2 m along each transect. One 1-m line accounted one measured points, therefore, total 800 points measured in the northern wetland and 300 points measured in the southern wetland. Plant species hit by each 1 m line were identified (Department of Biology, 2002; Nanakorn, 2002; Smitinand, 2001) and recorded. Sampling points were determined by number of "hits" on each species. Relative percent coverage was calculated to each plant species based on the number of "hits" out of the total number of points measured (Elzinga et al., 2001). In addition, Global Positioning System (GPS) equipment and IKONOS aerial photograph (1 m resolution, collection date: 15/02/2004) were used for vegetation mapping while walking along each transect when different visually-dominant plant zones were observed. Above-ground water level was measured at every 2 m along each transect. The survey of the northern wetland was repeated in October and November 2006, and January, February, March, and August 2007, while those of the southern wetland was repeated in November and December 2006, and January, March, and August 2007.

3.2.2. Plant community analysis

Community patterns of plants in the northern and the southern wetlands of Salaya Campus, and their relation to water depth, wetland classification and delineation were determined as explained below.

3.2.2.1. Relative percent coverage of plant species

Vegetation data from the survey were used to calculate relative percent cover of each plant species by using the following formula (Elzinga et al., 2001):

$$\% \text{ Cover} = \frac{\text{Number of sampling points species hit} \times 100}{\text{Total number of points measured}}$$

Where total number of points measured in the northern wetland = 800 points
total number of points measured in the southern wetland = 300 points

3.2.2.2. Shannon Diversity Index (H′)

Values from the percent coverage of plant species were calculated for Shannon Diversity Index (H′) to take into account both species richness and evenness of the plant communities (Stiling, 1999):

$$H' = -\Sigma\, p_i \ln p_i$$

Where p_i is the proportion of percent coverage of plant found in the i^{th} species within each wetland

3.2.2.3. Morisita-Horn measure (C_{MH})

In order to compare species similarity between the northern and the southern wetlands, a similarity coefficient using Morisita-Horn measure (C_{MH}) which takes into account the quantitative data on abundance of species (Stiling, 1999) was also calculated from the percent coverage of plant species:

$$C_{MH} = \frac{2 \sum (an_i \times bn_i)}{(da + db)\, aN \times bN}$$

Where aN is total percent cover of plants in the northern wetland bN is total percent cover of plants in the southern wetland

an_i is the percent cover of the ith species in the northern mash

bn_i is the percent cover of the ith species in the southern mash

$$da = \frac{\sum an_i^2}{aN^2} \quad \text{and} \quad db = \frac{\sum bn_i^2}{bN^2}$$

3.2.3. Transition zone

After Cronk and Fennessy (2001), hydrophytic vegetation is basically used for delineating the boundary of a wetland. Transects established for vegetation survey were divided into 50 m sub-transects. Each plant species found along those sub-transects were assigned one of five wetland indicator status categories (Table 3.1) based on the probability that species will be found in a wetland. Then, average scores of wetland indicator status categories for each sub-transect were calculated. The values were mapped in the middle of those sub-transects using the ArcView GIS 3.2a. By computing spatial interpolation based on locations of the mapped scores, gradients of the scores of wetland indicator status categories were created. On the gradient map, areas containing cores of more than 3.5 were determined as upland areas. The central wetland area where wetland plant species were abundant was determined by scores of below 2.5. However, in the score range 2.5-3.5, the area was determined as a transition zone between wetland and upland since it was commonly covered by facultative species. To identify whether such areas are parts of the wetland or upland, it was confirmed with a hydrology indicator (Cronk and Fennessy, 2001). The area and width of the transition zone were determined from the map.

TABLE 3.1 Wetland indicator status categories for plant species (Cronk and Fennessy, 2001)

Wetland Indicator Status	Probability of Occurrence in Wetlands (%)	Probability of Occurrence in Non-Wetlands (%)	Weighed Score
Obligate wetland (OBL)	> 99	< 1	1
Facultative wetland (FACW)	67 – 99	1 – 33	2
Facultative (FAC)	34 – 66	34 – 66	3
Facultative upland (FACU)	1 – 33	67 -99	4
Upland (UPL)	< 1	> 99	5

3.2.4. Plant zonation

3.2.4.1. Zonation mapping and plant distribution

Different plant zones in the northern and the southern wetlands were identified from direct observation and vegetation mapping. For each zone, abundances of dominant species in each sampling plot were mapped in ArcView GIS 3.2a. As for the transition zone, spatial interpolation based on locations of abundance values of dominant species in each wetland zone was computed for plant zonation mapping. In general, a coenocline, or a series of plant communities found along an environmental gradient (van der Valk, 2006), of Salaya Campus wetland was also demonstrated through a diagram showing a cross-section of the major vegetation zones distributed against water depth.

3.2.4.2. Statistical properties of zonation

Three attributes of zonation patterns of wetlands of Salaya Campus were measured in order to determine the plant community structure of the wetlands along the environmental gradient of water depth (Hoagland and Collins, 1997; Keddy, 2004). Because slopes of the studied wetlands are not continuous, average water depth measured at every 2 m along transects of each wetland were sorted ranking from the lowest to the highest water level. Then, they were divided into classes (<0.5, 0.5-5.4, ..., 30.5-35.4, respectively). At average water depth lower than 0.5 cm and the highest range of depths were excluded from the calculation to minimize bias of abundance at the extreme end of the environmental gradient. Then, the data were calculated for statistical properties of zonation as described below.

3.2.4.2.1. Pattern of boundaries of species distribution

To determine whether or not species boundaries of wetland plants were clustered, the number of starting and stopping boundaries was calculated per plot. Like Hoagland and Collins (1997, p. 26), "breaks in species distribution did not mean that the species was physiologically unable to occur in these intervals at each site". So, the analysis used only the initial lower and upper boundaries of species distribution. Morisita's index (Hurlbert, 1990; Hoagland and Collins, 1997) was used to evaluate degree of boundary clustering of species response curves.

$$I = Q \sum_{i=1}^{Q} (n_i/N)\,(n_i\text{-}1/N\text{-}1)$$

Where Q is the number of quadrats (or water depth classes in this case), n_i is the number of starting and stopping boundaries in the *i*th quadrat (class), and N is the total number of boundaries. If I = 1, boundaries are random; if I < 1 boundaries are regularly distributed, and if I > 1 boundaries are clustered. A chi-square test was used to determine significance.

3.2.4.2.2. Pattern of modes of species response curves

The degree of aggregation (P) of species modes was determined using the sample variance of distance between modes (Pool and Rathcke, 1979). After Hoagland and Collins (1997), modes of species response curves along a transect were considered to occur in the quadrat with the highest cover value.

$$P = \frac{\sum_{i=0}^{k}\{y_{i+1} - y_i - [1/(k+1)]\}^2}{k+1}$$

Where k is the number of species, $y_{i+1} - y_i$ is the distance between modes, and $1/(k+1)$ is the mean of $y_{i+1} - y_i$. If $P = 1$ modes are randomly distributed, if $P < 1$ modes are regularly distributed, if $P > 1$ modes are aggregated. A chi-square test was used to determine significance.

3.2.4.2.3. Hierarchical structure in species distribution

The relative nestedness index (C) was calculated to determine the hierarchical structure of species distributions (Wright and Reeves, 1992; Hoagland and Collins, 1997). The value of C ranges from 0 for complete independence of species distributions to 1 for perfect nestedness.

$$C = \frac{N_c - E\{N_c\}}{\max\{N_c\} - E\{N_c\}}$$

Where N_c is the nestedness index (Wright and Reeves, 1992):

$$N_c = \sum_{i=1}^{K-1} \sum_{m=i-1}^{K} \sum_{j=1}^{S} X_{ij}X_{mj}$$

Where S is the total number of species, K is the number of quadrats (or water depth classes in this case), and $X_{ij} = 1$ if species *j* is present at quadrat (class) *i* and 0 if it is absent.

$E\{N_c\}$ is the expected value of the nestedness index (Wright and Reeves, 1992):

$$E\{N_c\} = 1/2S\,(G^2 - \sum_{i=1}^{K} R_i^2)$$

Where G is the grand total of occurrences in the matrix, and R_i is the species richness value at quadrat (class) *i*

In addition, $\max\{N_c\}$ is the maximum possible value of the nestedness index when the matrix is perfectly nested (Wright and Reeves, 1992):

$$\max\{N_c\} = \sum_{i=1}^{K} (i - 1)\,R_i$$

After Wright and Reeves (1992), Cochran's *Q* was used to test for significance of nested species distributions.

3.3. The Study on Aquatic Macroinvertebrate Communities

For convenience in sampling aquatic macroinvertebrates and water quality measurement in densely vegetated wetlands, non-professional standardized methods that can be applied as simple tools were used in this study.

3.3.1. Aquatic macroinvertebrate sampling

3.3.1.1. Field work

The flagging at every 50 m along the line transects marked stations for macroinvertebrate sampling; 21 stations were located in the northern wetland, and 8 stations in the southern wetland. An 8"x11" pond net was used to sample aquatic invertebrates. Ten-second scoop sampling was done at the inundated sampling stations and the invertebrates were preserved with 95% ethyl alcohol. Habitat characteristics at each station were also recorded. The sampling of the northern wetland was repeated in October and November 2006, and January, February, March, August, and September 2007 while that of the southern wetland was repeated in October and November 2006, and January, March, April, June, August, and September 2007.

3.3.1.2. Laboratory work

In the laboratory, a sample was put in a Newark sieve (18 Mesh, opening size 980 microns), cleaned through running water, and flooded in a 44 x 29 cm white tray for sorting out aquatic macroinvertebrates. Separated aquatic macroinvertebrates were identified at least to family level (McCafferty, 1998; Ng, 2000; Chitramvong, 1992; Kanjanavanit and Tilling, 2000; Lekprayoon, 2006; MRC, 2006; CSIRO, 1991; Cheng et al., 2001) using a 40x stereo microscope and 100x light microscope. After identification, the samples were preserved in 70% ethyl alcohol.

3.3.2. Aquatic macroinvertebrate community analysis

3.3.2.1. Shannon Diversity Index (H′)

The Shannon Diversity Index (H′) (Stiling, 1999) were used to calculate the diversity of aquatic macroinvertebrate as for the plant community.

$$H' = -\Sigma\, p_i \ln p_i$$

Where p_i is the proportion of individuals found in the i^{th} species

3.3.2.2. Morisita-Horn measure (C_{MH})

Similarity coefficient was calculated by using Morisita-Horn measure (C_{MH}) (Stiling, 1999).

$$C_{MH} = \frac{2 \sum (an_i \times bn_i)}{(da + db)\, aN \times bN}$$

Where aN is the number of individuals in the northern wetland

bN is the number of individuals in the southern wetland

an_i is the number of individuals in the ith species in the northern wetland

bn_i is the number of individuals in the ith species in the southern wetland

$$da = \frac{\sum an_i^2}{aN^2} \quad \text{and} \quad db = \frac{\sum bn_i^2}{bN^2}$$

In addition, feeding guilds and habits of the aquatic macroinvertebrates were also classified (McCafferty, 1998; Merritt and Cummins, 1996, as cited in NCTC, 2006).

3.3.2.3. Temporal and spatial distribution

The seasonal distribution of aquatic macroinvertebrates in the northern and the southern wetlands of Salaya Campus, and the distribution in different vegetation zones, were analyzed. The Kruskal-Wallis test in SPSS 10.0 for Windows software was used to find differences between average numbers of aquatic macroinvertebrate families both among plant zones and months based on following hypotheses:

H_0 = numbers of aquatic macroinvertebrate families among plant zones/months are equal

H_1 = numbers of aquatic macroinvertebrate families among plant zones/months are not equal

In addition, impacts of seasonality, water depth, and vegetation zones to the aquatic macroinvertebrate communities were determined.

3.3.3. Sediment analysis

During sorting out aquatic macroinvertebrates in laboratory, sediments in each sample were separated and classified as decayed Cattail, decayed Phragmites, grass, leaves, sticks, and clay. Then, the substrates were dried in an oven at 80°C for 12 hours before weighed on digital balance to find dry mass of sediment composition, for ten-second scoop sampling with 8"x11" pond net at the bottom of each wetland.

Proportions of sediments in each plant zone relating to water depth were also analyzed. However, this semi-quantitative method has a limitation in making valid estimates of absolute abundance of substrates which plot sampler technique can provide. But, plot sampler also has disadvantage in very time consuming to sort organisms in lab as so much substrate is included (NCTC, 2006). Therefore, the pond net was selected.

3.3.4. Water quality measurement

At the aquatic macroinvertebrate sampling station, water quality including, water temperature, turbidity, pH, Dissolved Oxygen (DO), and Phosphate (P) were measured.

3.3.4.1. Temperature

A pond thermometer (Figure 3.2a) was put in the bottom of water for 3 minutes to measure water temperature.

3.3.4.2. Turbidity

The method to measure turbidity of water followed the Stream Detectives Project (Kanjanavanit and Moonchinda, 2002) which used a turbidity plate (Figure 3.2b, c). Water were poured into a 500 ml beaker, then put over the turbidity plate. From the top of the beaker, numbers seen on the turbidity plate were read. The numbers on the plate vary in darkness from 2-5, number 2 being the darkest indicating very turbid water, while number 5, the lightest, indicates clean water. If none of the number could be seen, number 1 is recorded which means water is extremely turbid, or opaque.

3.3.4.3. pH, Dissolved Oxygen (DO), and Phosphate (P)

pH, Dissolved Oxygen (DO), and Phosphate (P) of water were measured with the MU Field Test Kits (Figure 3.2d) which developed by the Technology Innovation Unit and Department of Chemistry, Faculty of Science, Mahidol University. Since the kit was obtained after 6 months of field work, these parameters were measured from April 2007 to September 2007.

FIGURE 3.2 Materials for water quality measurement: a) pond thermometer b) and c) turbidity plate d) MU Test Kits for pH, Dissolved Oxygen (DO), and Phosphate (P)

3.4. Wetland Bioassessment

3.4.1. Developing multiple indices for wetland bioassessment

The multiple indices for wetland bioassessment were developed from the data of wetland plant and aquatic macroinvertebrate communities mentioned above (Gernes and Helgen, 2002; Andreas and Lichvar, 1995; Cronk and Fennessy, 2001; Mack, 2001; Haugerud, 2003; DWAF, 2004). Table 3.2 showed the description of each index.

3.4.1.1. Developing vegetation indices

To find which index is sensitive to distinguish differences between the northern and the southern wetlands of Salaya Campus, values of each index were plotted against sampling months. Index that trend lines of the two wetlands do not intercept will be accounted the sensitive one. Furthermore, plant communities of Salaya Campus were compared with the plant community of a low-disturbed freshwater marsh at Khao Sam Roi Yot National Park, Prachuap Khiri Khan Province (Chareonsiri and Parr, 1994).

3.4.1.2. Developing aquatic macroinvertebrate indices

By plotting index values against sampling months, as in vegetation indices, index that trend lines of the two wetlands do not intercept will be accounted the sensitive aquatic macroinvertebrate index which can distinguish differences between the northern and the southern campus wetlands.

3.4.2. Human disturbance evaluation

Human disturbance of both the northern and the southern wetland was scored following Gernes and Helgen (2002) (See Appendix A).

TABLE 3.2 Description of the index measurement systems (or metrics) for wetland bioassessment

VEGETATION INDEX			
Index name	**Description of the index**	**Expected response to human disturbances**	**Reference**
Shannon-Weiner Diversity Index (H')	$H' = -\Sigma p_i \ln p_i$ Where p_i is the proportion of individuals found in the i^{th} species	Decrease	Stiling, 1999
FQAI	$FQAI = R/N^{1/2}$ Where R = the sum of all the coeffients of conservatism (c-value) for the community (Appendix B), N = the number of native species	Decrease	Cronk & Fennessy, 2001
Exotic species	Proportion of non-native taxa to total taxa	Increase	Gernes & Helgen, 2002
Sensitive species	Number of intolerant species (c-value 6-10, Appendix B)	Decrease	Gernes & Helgen, 2002
Tolerant Taxa	Proportion of tolerant taxa (c-value 0-2, Appendix B) to total taxa	Increase	Gernes & Helgen, 2002

TABLE 3.2 Description of the index measurement systems (Continued)

VEGETATION INDEX			
Index name	**Description of the index**	**Expected response to human disturbances**	**Reference**
Monocarpic species	The sum of the number of native monocarpic species and their percent coverage values and dividing by the total cover of native monocarpic species	Increase	Gernes & Helgen, 2002
Grass-like	Number of grass, sedge and rush species	Decrease	Gernes & Helgen, 2002
Aquatic guild	Number of aquatic guild species (FACW + OBL)	Decrease	Gernes & Helgen, 2002
Dominance taxa	$D = \Sigma(n_i/N)^2$ Where n_i = the percent cover for each taxa N = the sum of all cover values for all taxa within the sampling plot	Increase (0 = most biologically diverse, 1 = most monotypic)	Cronk & Fennessy, 2001
Persistent litter taxa	Relative cover class (sum of individual cc/total sample cc) taxa with persistent litter (including *Phragmites* sp. and *Typha* sp.)	Increase	Gernes & Helgen, 2002

TABLE 3.2 Description of the index measurement systems (Continued)

AQUATIC MACROINVERTEBRATE INDEX			
Index name	**Description of the index**	**Expected response to human disturbances**	**Reference**
Shannon-Weiner Diversity Index (H')	$H' = -\Sigma p_i \ln p_i$ Where p_i is the proportion of individuals found in the i^{th} species	Decrease	Stiling, 1999
Chironomidae	Proportional abundance of Chironomidae	Decrease	Haugerud, 2003
Lymnaeidae	Proportional abundance of Lymnaeidae	Decrease	Haugerud, 2003
Exotic *Pomacea* (Ampullaridae)	Proportional abundance of an exotic snail, *Pomacea* sp.	Increase	
Predators	Proportional abundance of predators	Decrease	Haugerud, 2003
3-dominance taxa	Proportional abundance of 3 dominant taxa	Increase	Gernes & Helgen, 2002
Odonata	Number of Odonata taxa	Decrease	Haugerud, 2003

TABLE 3.2 Description of the index measurement systems (Continued)

Index name	Description of the index	Expected response to human disturbances	Reference
AQUATIC MACROINVERTEBRATE INDEX			
ETO	Total number of Ephemeroptera, Trichoptera and Odonata families per wetland	Decrease	DWAF, 2004
Total invertebrate taxa	Total number of invertebrate taxa	Decrease	Gernes & Helgen, 2002
SWAMPS	Average of total score assigned from 1 to 100 to invertebrate families	Decrease (1 = most tolerant, 100 = most sensitive)	Chessman, et al., 2002, cited in DWAF, 2004

3.5. Wetlands of Salaya Campus as An Outdoor Ecology Classroom

3.5.1. Review of campus-based ecological exercises

Exercise development, and learning process provided by campus-based ecological exercises in General Ecology course for 3rd year biology students of Mahidol University were reviewed as researcher participated in voluntary teaching assistant during 2002-2007. This information was used as a basis for developing additional ecological exercises based on campus wetlands mentioned below.

3.5.2. Connecting students to the campus wetlands

Participating as voluntary teaching assistant, researcher worked with teachers of the Ecology course for 3rd year biology students of Mahidol University in 2006 and 2007 to design the ecological exercises connecting students to the natural campus wetlands, in addition to previous campus-based exercises. The exercises were developed by integrating place-based education (Sobel, 2005) and experiential learning approaches (Beard and Wilson, 2006) (Table 3.3). Different patterns of wetland exercises were conducted in different years (Table 3.4). In 2006, 50 students participated in the course, in which two short wetland exercises addressing wetland biodiversity and its community ecology were conducted. Such exercises occupied 9 of 30 hours of total ecological exercises, or 30% of the total exercises. In 2007, there were 64 participating students, and three intensive wetland exercises engaged students in empowerment process. These exercises occupied 18 of 33 hours of total ecological exercises (approximately 60% of the total exercises).

TABLE 3.3 Conceptual framework of ecological exercises conducted at wetlands of Salaya Campus, Mahidol University

Year	Exercises	Duration	Conceptual framework
2006	1. Rapid Biodiversity Inventory	6 hrs (x 1 day)	Students learn diversity and richness of organisms in their local environment.
	2. Environmental Gradients, Species Distribution and Community	3 hrs (x 1 day)	Students explore distribution of wetland plants against water depth at the edge of the freshwater marsh, to understand 2 contrasting community concepts, individualistic (or continuum) versus organismic.
	Total	*9 hrs*	
2007	1. Interspecific Competition and the Niche of a Species	3 hrs (x 1 day) and 1 hr (x 3 days)	Students explore influence of interspecific competition on the niche of a species between two emergent plants, cattail (*Typha angustifolia* L.) and exotic paragrass (*Brachiaria mutica* (Forssk.) Stapf) by setting field experiment at the edge of the freshwater marsh
	2. Mini EcoBlitz	6 hrs (x 1 day)	Adapted from BioBlitz (Lundmark, 2003), students learn diversity and richness of organisms in their local environment based on landscape ecology in one day's observation
	3. Individual Projects	6 hrs (x 1 day)	Students develop one-day individual projects from observational phenomena at Salaya Campus ecosystems that attract their interest.
	Total	*18 hrs*	

TABLE 3.4 Schedules of ecological exercises at Salaya Campus, Mahidol University, during 2006 and 2007. The exercise was organized one day per week (shaded cells referred to wetland exercises)

	November			December				January			February	
	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 1	Week 3
2006	Orientation to Salaya Campus ecosystems	Rapid Biodiversity Inventory		Trade-off between predation risk and feeding time in butterflies	Environ-mental gradient, species distribution and community	Species richness of birds at Salaya Campus	Niche separation in birds at Salaya Campus		Plants as habitat	Interactions among sap-sucking mealy bugs and associated arthropods	Population growth and life table	
Duration 30 hrs	*3 hrs*	*6 hrs*		*3 hrs*	*3 hrs*	*3 hrs*	*3 hrs*		*3 hrs*	*3 hrs*	*3 hrs*	
2007	The physical environ-ment	Adaptation, life history and Selection	Population growth and life table		Interspecific competition and the niche of species				Species richness of birds at Salaya Campus	Niche separation in birds at Salaya Campus	Mini EcoBlitz	Individual projects
Duration 33 hrs	*3 hrs*	*3 hrs*	*3 hrs*		*3 hrs*	*1 hr*	*1 hr*	*1 hr*	*3 hrs*	*3 hrs*	*6 hrs*	*6 hrs*

3.5.2.1. Rapid Biodiversity Inventory

As an orientation of the beginning of the semester, students practiced a rapid biodiversity inventory exercise to learn diversity and richness of organisms in their local environment. Five groups of 10 students were divided to survey different habitats of Salaya Campus including building & roadsides, grassland, woodland, gardens & tree plantation, and wetland (the wet meadow). After 3 hours of the observation in the morning, students met in the classroom in the afternoon, prepared a small exhibition of plants and animals they found, and gave a presentation on each group's survey.

Objectives:

1. Students will learn about biodiversity of various habitats on Salaya Campus
2. Students will learn how to use simple techniques and mapping for a rapid biodiversity survey

3.5.2.2. Environmental Gradients, Species Distribution and Community

This three-hour exercise established in one week of December 2006 allowed students to explore the distribution of wetland plants against water depth at the edge of the freshwater marsh, in order to understand 2 community concepts, individualistic (or continuum) versus organismic (Smith and Smith, 2006). After the observations, data was analyzed from a pattern of normal distribution curves of individual plant species found along water depth gradients.

Objectives:

1. Students will learn relationship between environmental gradient (water level in this case) and wetland plant community
2. Students will learn about community concepts i.e. individualistic (or continuum) and organismic concepts

3.5.2.3. Interspecific Competition and the Niche of a Species

In this exercise, students explored the influence of interspecific competition on the realized niche of a species using two emergent plants, Cattail (*Typha angustifolia* L.) and exotic Paragrass (*Brachiaria mutica* (Forssk.) Stapf). By setting a field experiment at the edge of the freshwater marsh, three experimental plots (50 cm x 200 cm) were established: plot one, remove all other plants except Cattail; plot two, remove all other plants except Paragrass; and plot three, remove all other plants except and Paragrass. Then, percent coverage of each plant species and water depth were measured to compare the distribution of the two species along water depth gradients when growing separately versus growing together. This exercise was a long-term observation in which the measurement was repeated after one week and one month. A three-hour session was taken in the first week. Then, one-hour sessions were taken in the others.

Objectives:

1. Students will learn interaction between two wetland plant species, *Typha angustifolia* L. and *Brachiaria mutica* (Forssk.) Stapf in the Salaya Campus wetland

2. Students will learn how to conduct a field experiment in ecological study

3.5.2.4. Mini EcoBlitz

As in the rapid biodiversity inventory, in the Mini EcoBlitz the students were divided into groups (9-10 students per group) and each group surveyed plants and animals found in one particular area. However, the Mini EcoBlitz is based more on landscape ecology. The different areas that each group was responsible for included natural wetland (the wet meadow), low human-dominated landscape (botanical herb garden and wasted-water treatment pond areas), and high human-dominated landscape (lawns around the various faculties). After the survey, the students in each group exchanged their experiences with other groups. All data were compiled and mapped in ArcView GIS 3.2a. This exercise was finished within one day after a three-hour observation lab in the morning (8.00-11.00 am), and three-hour discussion in the afternoon (13.00-16.00 pm).

Objectives:

1. Students will learn about biodiversity of various habitats on Salaya Campus
2. Students will learn about impacts of human activities to biodiversity and natural ecosystems
3. Students will learn how to use both simple techniques and high technological equipments in mapping for a rapid biodiversity survey

3.5.2.5. Individual Projects

At the end of the semester, after experiences learned from Mini EcoBlitz and the previous exercises, students were encouraged to develop one-day individual projects from phenomena observed in Salaya Campus ecosystems that attracted their interests. Hypothesis setting, data collection, and analysis were included in the processes before writing up a report and giving an oral presentation in the coming week. In this exercise, the teacher and teaching assistants acted as mentors, empowering students to use their knowledge and skills as much as they can.

Objectives:

1. Students will learn how to converting observations in real ecological settings to scientific process
2. Students will practice writing scientific report and giving scientific oral presentation

3.5.3. Evaluation of students' attitudes towards wetlands and university's ecosystems

Apart from ecological knowledge and skills, students are expected to have appreciation and awareness on the campus ecosystems, particularly the wetlands, they experienced. Their environmental attitudes are expected to be improved. Evaluation was done from students' field notes and attitude assessment survey.

3.5.3.1. Field Notes Evaluation

Students taking the General Ecology course had to hand in their field notes after each exercise. The student's ecological literacy was evaluated from these materials. In addition, discussion and reflections written by each student at the end of each exercise represented the students' self-reports which were qualitatively used for evaluating their attitudes toward wetlands and ecosystems of the Salaya Campus.

3.5.3.2. Attitude Assessment Survey

For quantitative measurement, the students' attitudes toward wetlands and ecosystems of Salaya Campus were evaluated before and after the course each year with a questionaire. As an attitude assessment survey, ten emotion-evoking statements were presented (Table 3.5), and respondents reported their feelings about each statement on a five-point Likert Scale (strongly agree, agree, not sure, disagree, and strongly disagree). The scale in each statement was scored differently (-2,-1, 0, 1, 2) depending on the degree that the statement focused on the environment (Schindler, 1999). These statements were specific to the Salaya Campus which has large human modified areas, as well as, wetland wilderness on its backyard. Under progressive campus development, some conflicting attitudes toward pros and cons of wetlands and biodiversity on campus may occur.

Nonparametric Mann-Whitney U test, with 95% confidence intervals was calculated by SPSS 10.0 for Windows in order to compare average score of the students' attitudes before and after taking the course. In the academic year 2006, 50 students participated in pre-attitude assessment whereas only 36 participated in the post-attitude assessment. In the academic year 2007, 64 students participated in pre-attitude assessment and 48 participated in post-attitude assessment 48. The hypotheses of this test are as follow;

H_0: the scores before and after taking the course are equal

H_1: the scores before and after taking the course are not equal

The Mann-Whitney U test (SPSS 10.0) was also used for comparing the results of attitude assessment survey between two academic years. The hypotheses of this test are;

H_0: before taking the course, the scores of students' attitudes in different years are equal

H_1: before taking the course, the scores of students' attitudes in different years are not equal

3.6. Wetlands as A Part of Campus Ecology and Management

To explore the role of wetlands on the Salaya Campus in ecology and management, the most recent ambitious master plan of the Salaya Campus was reviewed (Mahidol University, 2008a; Mahidol University, 2008b; Mahidol University, 2008c). Specifically, the review focused on landscape management policy. The following issues were considered (Keniry, 1995; Harris et al., 2001):

1. Did the master plan reflect concern about the campus context (natural settings, site history, current infrastructure, and population and development pressures)?
2. Did the master plan provide for protection of native organisms?
3. Did the master plan preserve natural habitats, i.e. wetlands?
4. Did the master plan involve reducing the use of resources?
5. Did the master plan view the landscaped campus as part of the local or original ecosystem?
6. Did the master plan recognize the function of the landscaped campus as a tool for teaching ecology and environment?

TABLE 3.5 A questionnaire for attitude assessment survey towards wetlands and ecosystems on Salaya Campus, Mahidol University

Statement	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1. Animals like birds, frogs, and insects are not really important to me.	a	b	c	d	e
2. I do not enjoy walking through dense vegetation and marshy fields.	a	b	c	d	e
3. Nothing is interesting in grasslands and marshy fields.	a	b	c	d	e
4. Marshy fields are sources of diseases such as Leptospirosis and Dengue Haemorrhagic Fever.	a	b	c	d	e
5. When the university decides what to do with its land, it should only think about what people need. (no concern of birds, rats, trees)	a	b	c	d	e
6. We need more nature areas on campus.	a	b	c	d	e
7. We should allow weeds to grow on campus.	a	b	c	d	e
8. I prefer ponds and canals of the campus that have no weeds on the banks and water surface.	a	b	c	d	e
9. All water monitors living on campus have to be removed.	a	b	c	d	e
10. We need to protect wetlands on campus as much as trees.	a	b	c	d	e

CHAPTER IV
RESULTS

4.1. The Study on Wetland Plant Communities

4.1.1. Classification of wetlands of Salaya Campus

By considering hydric soil, hydrology, and dominant vegetation, the types of wetlands in this study were classified. The wetland in the north of Salaya Campus is seasonally inundated. Its hydroperiod or time of inundation was about 8 months from July to February. During this period, water level was average 6 cm depth. Then, water dried up in the dry season during March to June, although soil remained saturated. In general, this wetland was dominated by sedges and grasses. In contrast, the wetland in the south of the campus is permanently flooded. Its water level was average 16 cm in wet season. However, water level slightly decreased to an average depth of 13 cm in dry season. Cattails (*Typha angustifolia* L.) were observed to be dominant in this site. Since vegetation in both wetlands was rooted in hydic soil which is not peat, they were distinguished by differences in hydrology and dominant vegetation. After Keddy (2004), the northern wetland was classified as a wet meadow. On the other hand, the southern wetland was classified as a freshwater marsh. Figure 4.1 shows the hydrology of both wetlands during October 2006 to September 2007.

4.1.2. Wetland plant communities

4.1.2.1. Plant diversity

Plant communities of the wet meadow and the freshwater marsh of Salaya Campus were similar in species richness and diversity. The plant species richness of both wetlands was equal to 52 species (among these, 4 species are unidentified), while both wetlands had the Shannon diversity index (H′) similar to 2.7. But, the Morisita-Horn measure (C_{MH}) of similarity coefficient was 0.46 which indicated approximately 46% similarity in species composition between wetland plant communities of the wet meadow and the freshwater marsh. Figure 4.2 showed composition of plant communities comparing between the two wetlands. *Cayratia trifolia* (L.) Domin, a climber species of Vitaceae is the highest abundant species of the wet meadow. Many grass species such as *Brachiaria mutica* (Forssk.) Stapf, *Panicum repens* L., *Imperata cylindrica* (L.) P.Beauv., and *Phragmites vallatoria* (Pluk. ex L.) Veldkamp cover large areas of the wet meadow. *Phyllanthus reticulatus* Poir. and *Pluchea indica* (L.) Less. are the two highly abundant shrubs found in this wetland. On the other hand, a floating plant species, *Lemna perpusilla* Torr. is the highest abundant species of the freshwater marsh, while *Typha angustifolia* L. and *Brachiaria mutica* (Forssk.) Stapf are the second and the third most highly abundant, respectively.

Considering wetland indicator of status categories (Cronk and Fennessy, 2001), both wet meadow and the freshwater marsh had highest number of plant species that are obligate to wetland (Figure 4.3). In comparison, the freshwater marsh contained more obligate species (21 species) than the wet meadow (16 species). Figure 4.4 showed higher proportion of wetland plant species (OBL, FACW, and FAC) covering the freshwater marsh than the wet meadow. Most plants in both wetlands are native, other 9 species in the wet meadow and 5 species in the freshwater marsh are exotic. Among these exotic plants, *B. mutica* or Paragrass, was the species that were highly abundant in both wetlands. Appendix C showed a list of plant species and their attributes found in the Salaya Campus wetlands.

Relating to water depth, number of plant species on both wet meadow (Figure 4.5) and freshwater marsh (Figure 4.6) tended to decrease when water level increase. In comparison, most plant species of the wet meadow were distributed in shallower water level (mean of depth = 5.6 ± 6.38 cm) than those of the freshwater marsh (mean of depth = 15.0 ± 6.96 cm). Very few trees and shrubs were found at the depth higher than 25 cm. Since the freshwater marsh has higher water level, many aquatic species were found including 2 species of aquatic ferns, *Ceratopteris thalictroides* (L.) Brongn and *Acrostichum aureum* L. Besides the exotic *B. mutica, P. vallatoria* was a grass species that can grow in deep water. Additionally, *T. angustifolia* was the only emergent, herbaceous plant growing well in high water level.

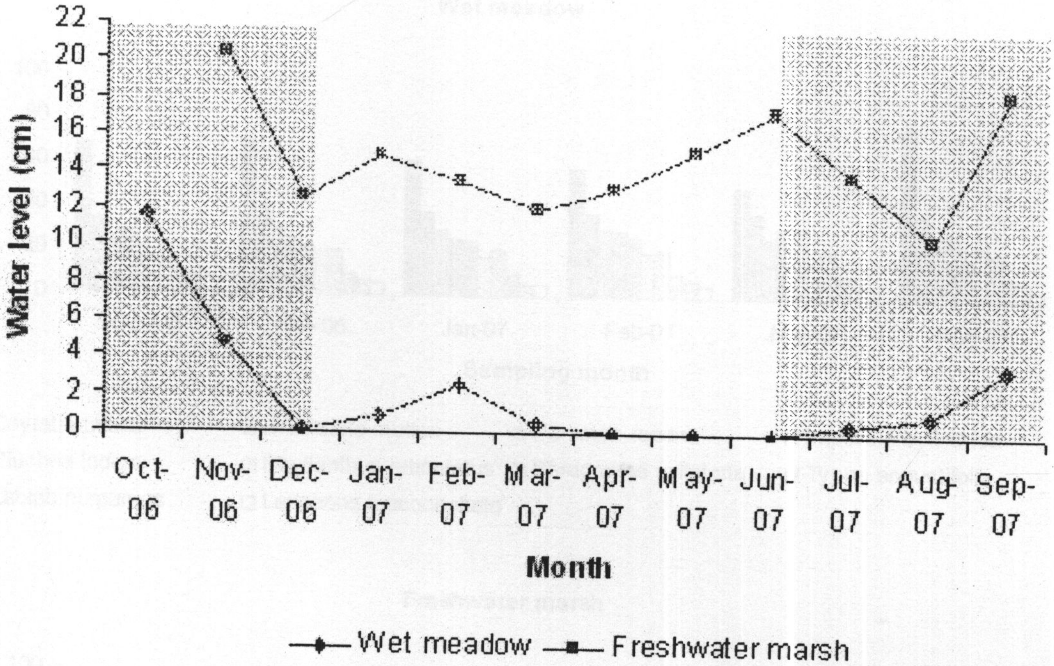
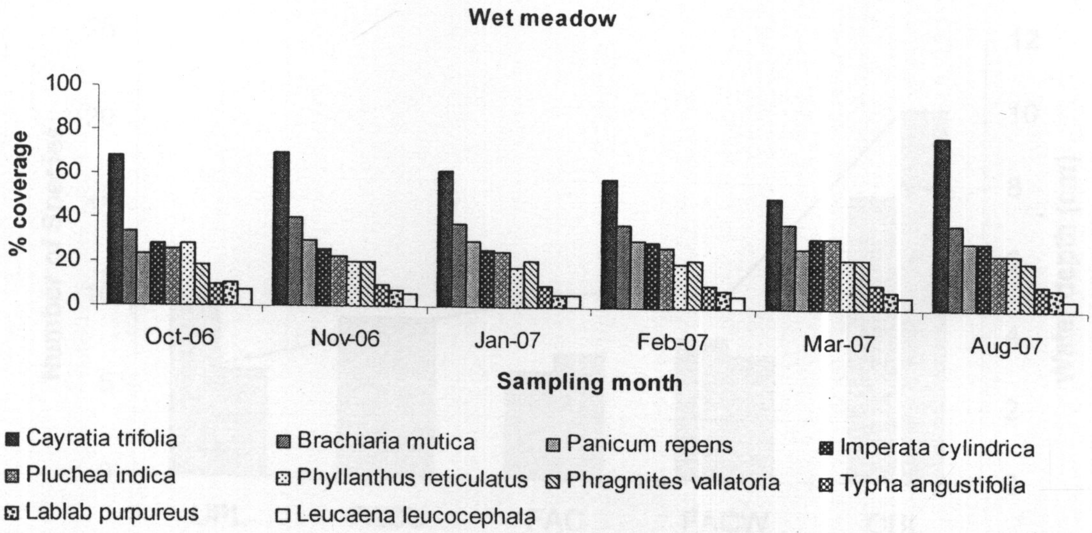


FIGURE 4.1 Hydrology of the wetlands of Salaya Campus (wet season is in dark shade, while dry season is in light shade)



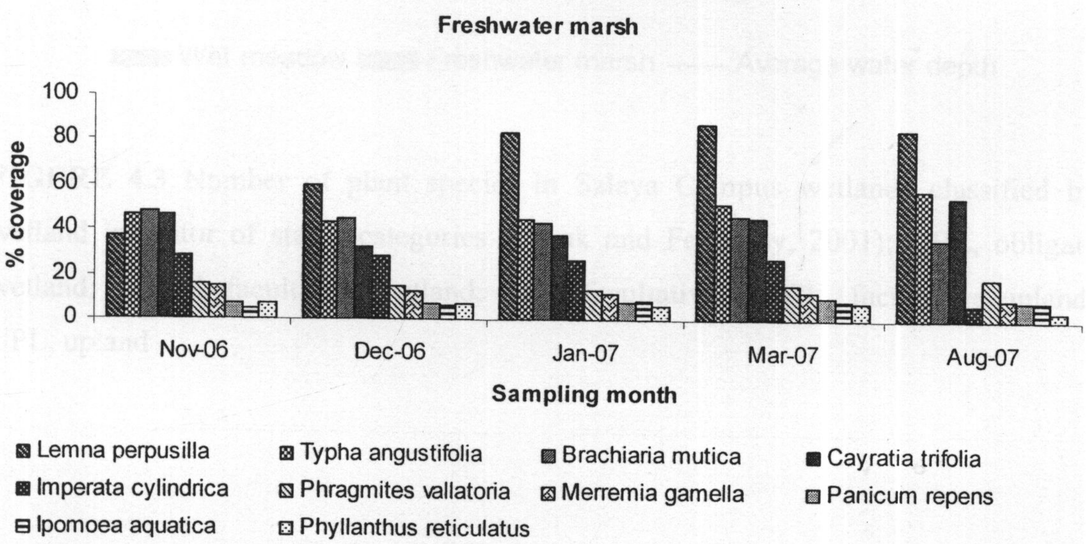


FIGURE 4.2 Composition of plant communities showing the ten most abundant species found in each wetland of Salaya Campus (total sampling point, wet meadow, 800; freshwater marsh, 300) (Note that low abundance of *Lemna perpusilla* in the freshwater marsh during the first two sampling months resulted from underestimation of this floating species)

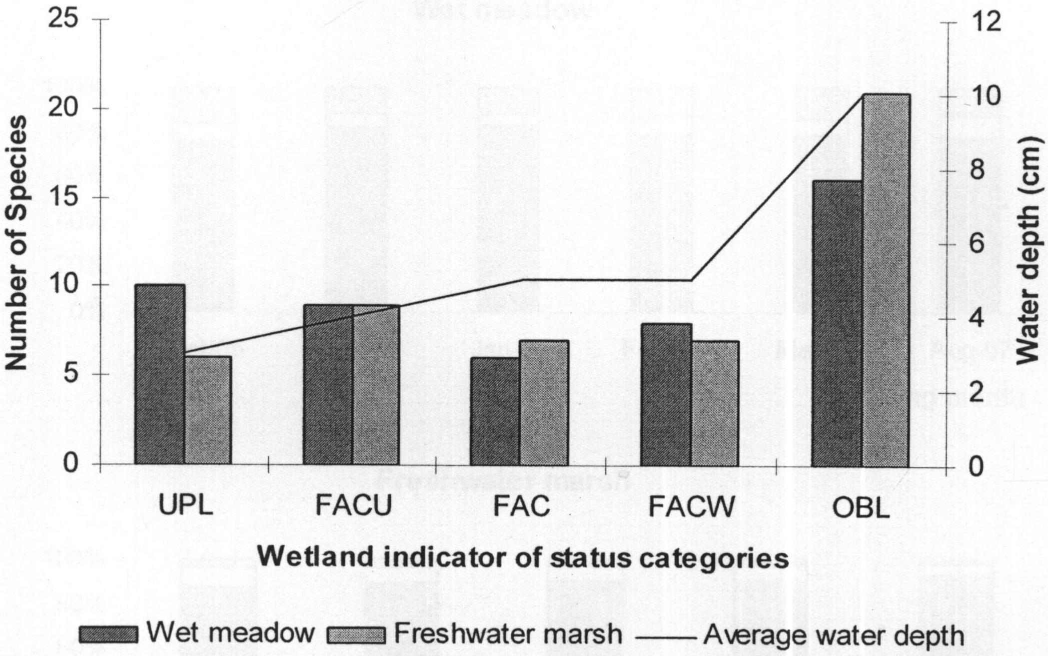


FIGURE 4.3 Number of plant species in Salaya Campus wetlands classified by wetland indicator of status categories (Cronk and Fennessy, 2001); OBL, obligate wetland; FACW, facultative wetland; FAC, facultative; FACU, facultative upland; UPL, upland

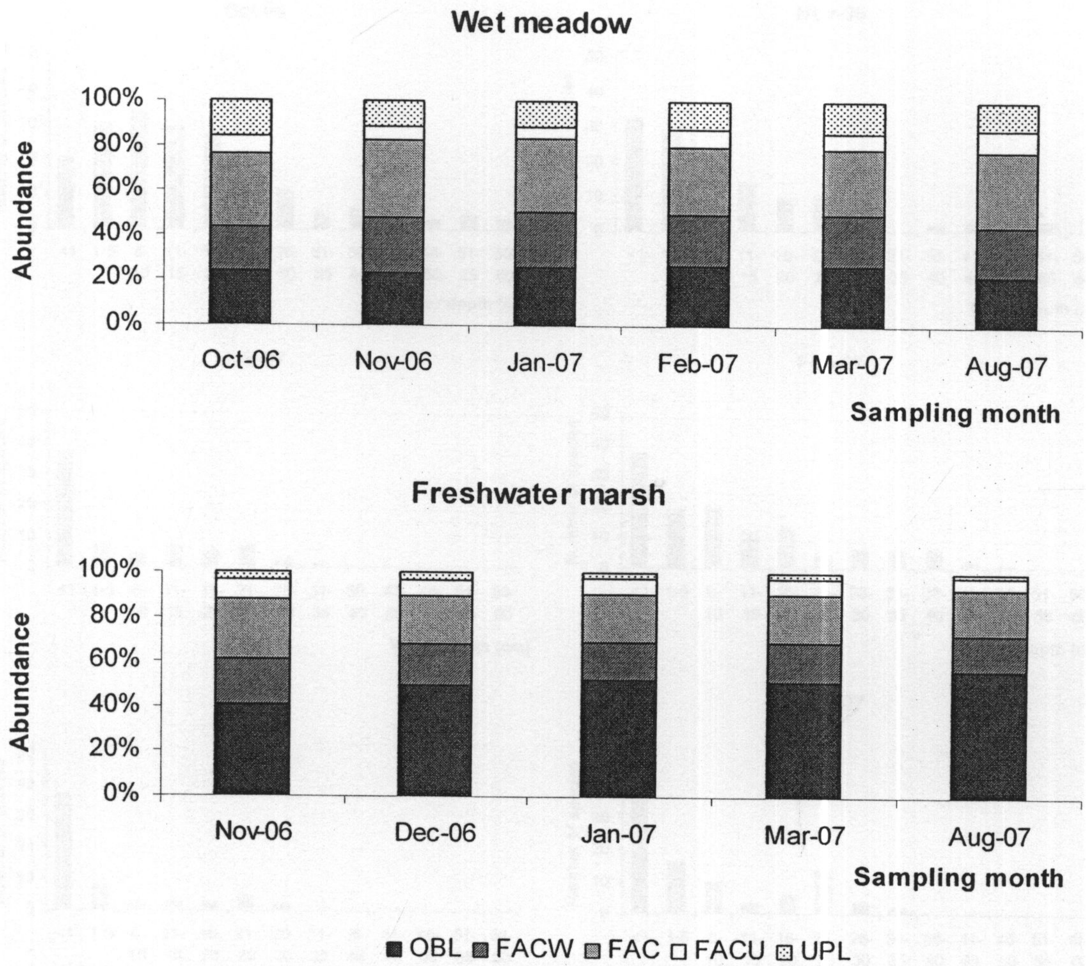


FIGURE 4.4 Proportion abundances of wetland indicator of status categories (Cronk and Fennessy, 2001) of Salaya Campus wetland plants (total sampling point, wet meadow, 800; freshwater marsh, 300). OBL, obligate wetland; FACW, facultative wetland; FAC, facultative; FACU, facultative upland; UPL, upland

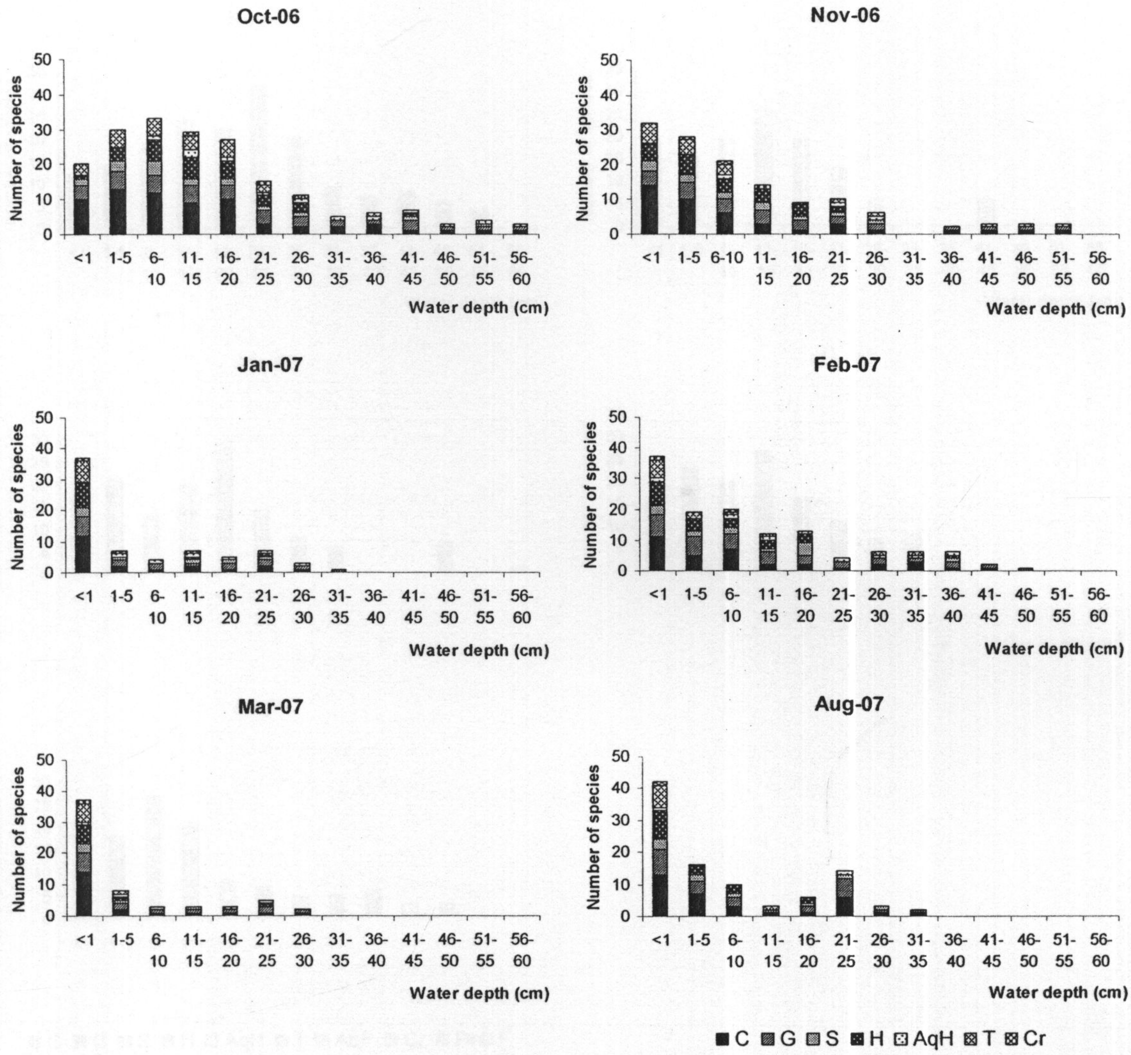


FIGURE 4.5 Relationship between water level and number of plant species on the wet meadow of Salaya Campus (C, climber; G, grass; S, shrub; H, herb; AqH, aquatic herb; T, tree; Cr, creeper; F, fern)

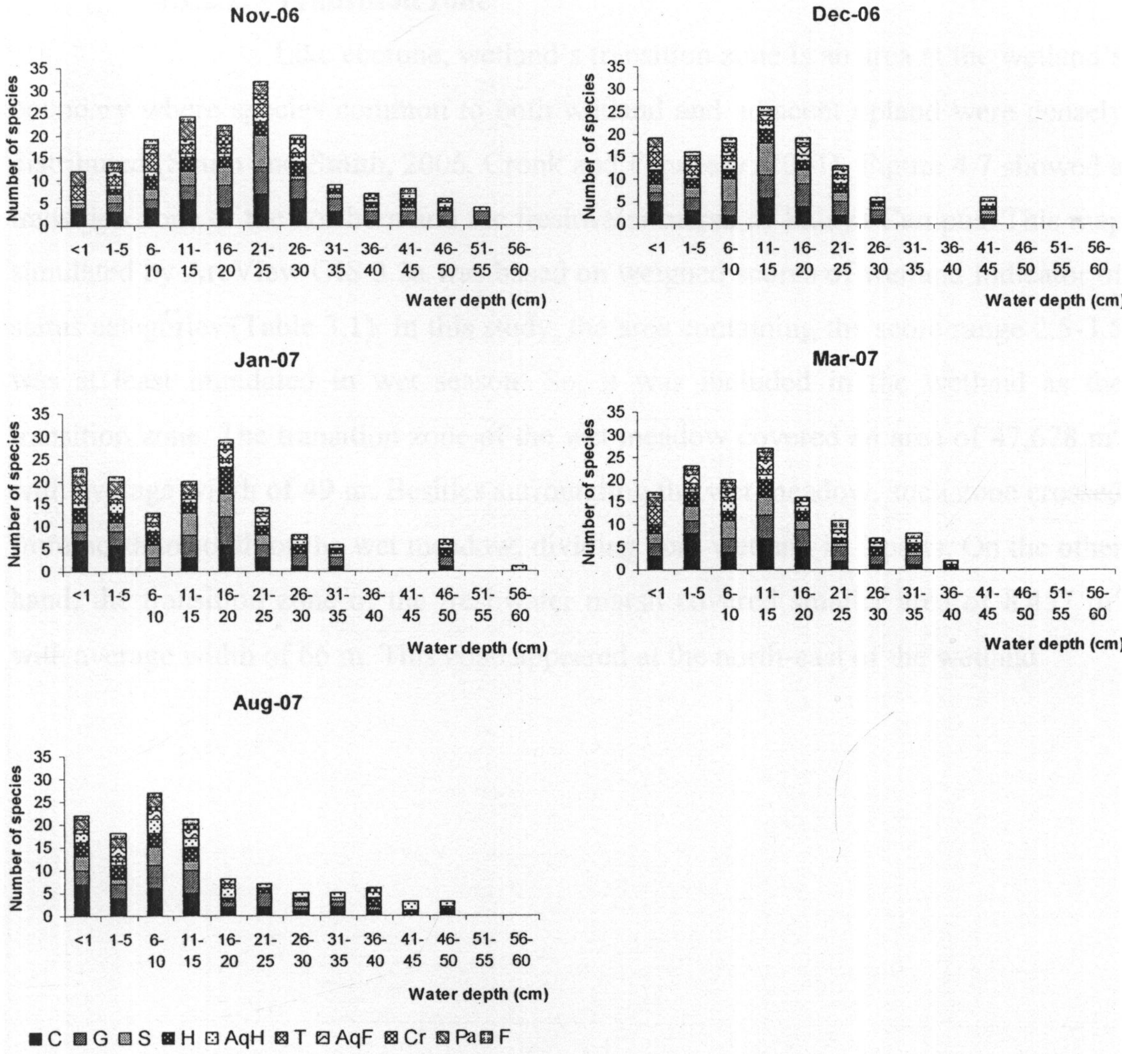


FIGURE 4.6 Relationship between water level and number of plant species on the freshwater marsh of Salaya Campus (C, climber; S, shrub; G, grass; H, herb; AqH, aquatic herb; T, tree; Pa, Palm; AqF, aquatic fern; Cr, creeper; F, fern)

4.1.2.2. Transition zone

Like ecotone, wetland's transition zone is an area at the wetland's boundary where species common to both wetland and adjacent upland were densely distributed (Smith and Smith, 2006, Cronk and Fennessy, 2001). Figure 4.7 showed a transition zone of the northern and the freshwater marsh of Salaya Campus. This map simulated by ArcView GIS 3.2a was based on weighed scores of wetland indicator of status categories (Table 3.1). In this study, the area containing the score range 2.5-3.5 was at least inundated in wet season. So, it was included in the wetland as the transition zone. The transition zone of the wet meadow covered an area of 47,678 m^2 with average width of 49 m. Besides surrounding the wet meadow, such zone crossed from north to south of the wet meadow, dividing core wetland in 2 parts. On the other hand, the transition zone of the freshwater marsh covered smaller area of 8,457 m^2 with average width of 66 m. This zone appeared at the north-east of the wetland.

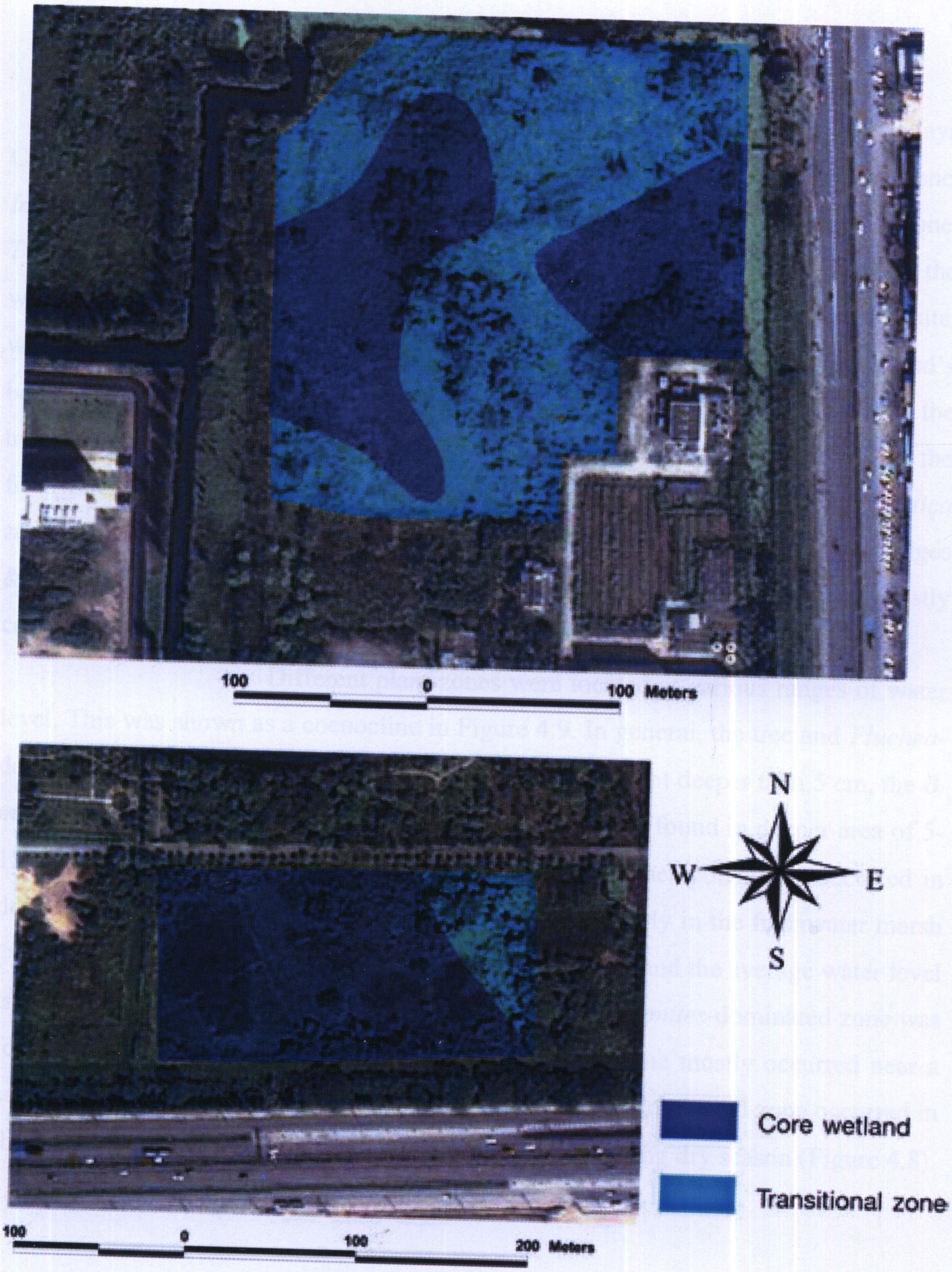


FIGURE 4.7 Core wetlands and transitional zones of Salaya Campus wetlands (a, wet meadow; b, freshwater marsh; modified from IKONOS satellite image, 1 m resolution, collection date: 15/02/2004)

4.1.2.3. Plant zonation

4.1.2.3.1. Zonation mapping and coenocline

Plant zonation was apparent in the wetlands of Salaya Campus (Figure 4.8). Seven visually dominant zones including *B. mutica* zone, *Imperata*-dominated zone, *Phragmites*-dominated zone, *Pluchea*-dominated zone, *Typha*-dominated zone, trees zone, and mixed sedges & grasses zone appeared at the wet meadow. The mixed sedges & grasses zone cover the largest area at this site, whereas *B. mutica* which is an exotic grass was dominant around the wetland's boundary. At the middle of the wet meadow where the transition zone crossed, the trees zone appeared. In contrast, the *Typha*-dominated zone was the largest zone at the freshwater marsh. This wetland proportionately had smaller patch of the *B. mutica* zone at its edges comparing to the wet meadow. But, it had no obvious mixed sedges & grasses, and *Pluchea*-dominated zone. As in the wet meadow, the tree zone mostly covered the area at the north-east of the wetland where was a transition zone.

Different plant zones were located at various ranges of water level. This was shown as a coenocline in Figure 4.9. In general, the tree and *Pluchea*-dominated zones were commonly found at shallow depth not deeper than 5 cm, the *B. mutica*, *Imperata*, and mixed sedges & grasses zones were found in deeper area of 5-15 cm, whereas the *Phragmites* and *Typha*-dominated zones potentially occurred in deepest area comparing to other emergent zones, particularly in the freshwater marsh (>15 cm). In the wet meadow, where it is occasionally dry and the average water level is lower than the freshwater marsh, nevertheless, the *Phragmites*-dominated zone was found in deeper area than the *Typha*. This *Phragmites* zone mostly occurred near a canal in the north of the wetland. In contrast, small *Typha*-dominated zone occurred in the inner part of the wet meadow where water dried up during dry season (Figure 4.8).

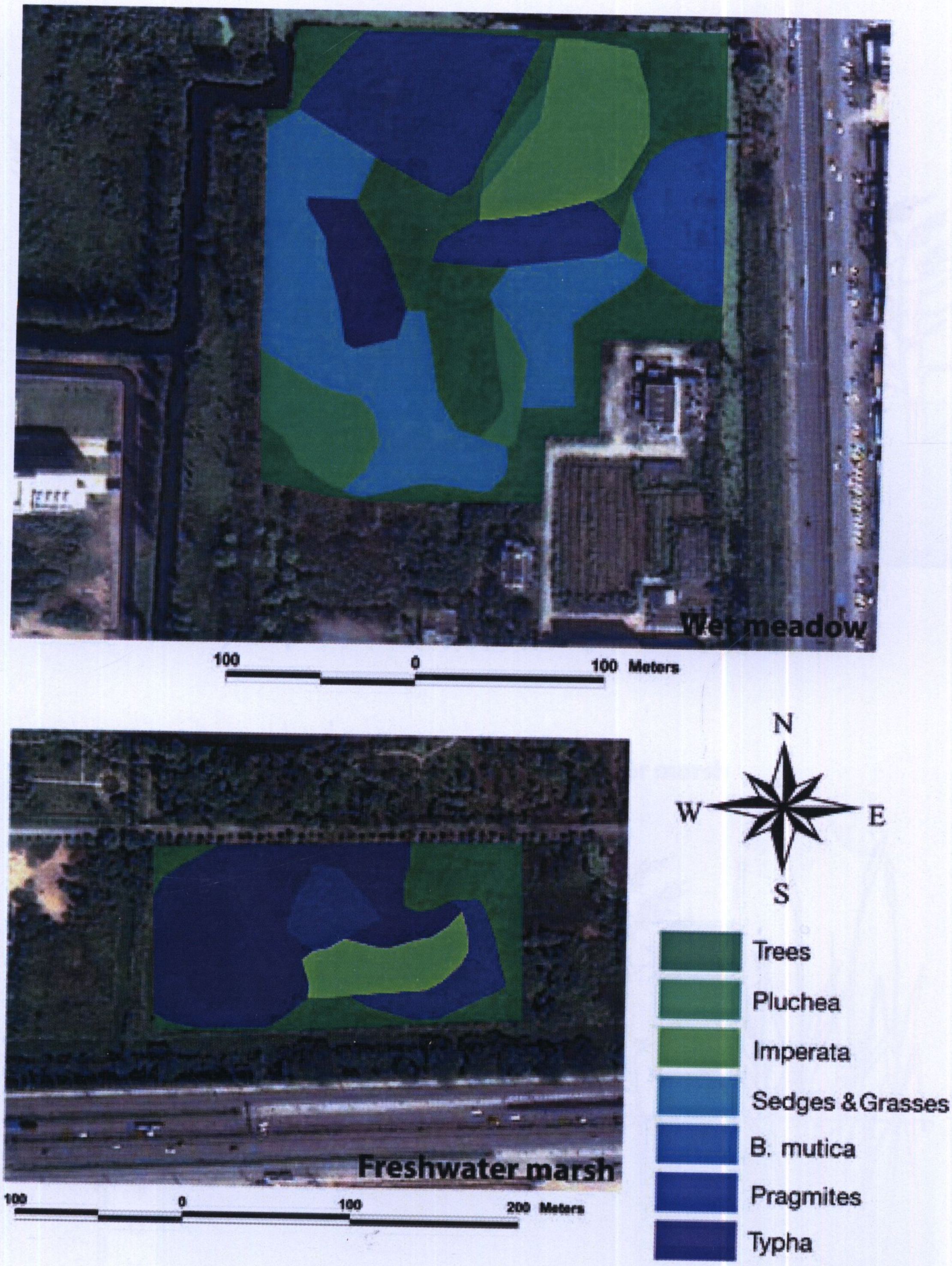


FIGURE 4.8 Map of plant zonation of Salaya Campus wetlands (a, wet meadow; b, freshwater marsh; modified from IKONOS satellite image, 1 m resolution, collection date: 15/02/2004)

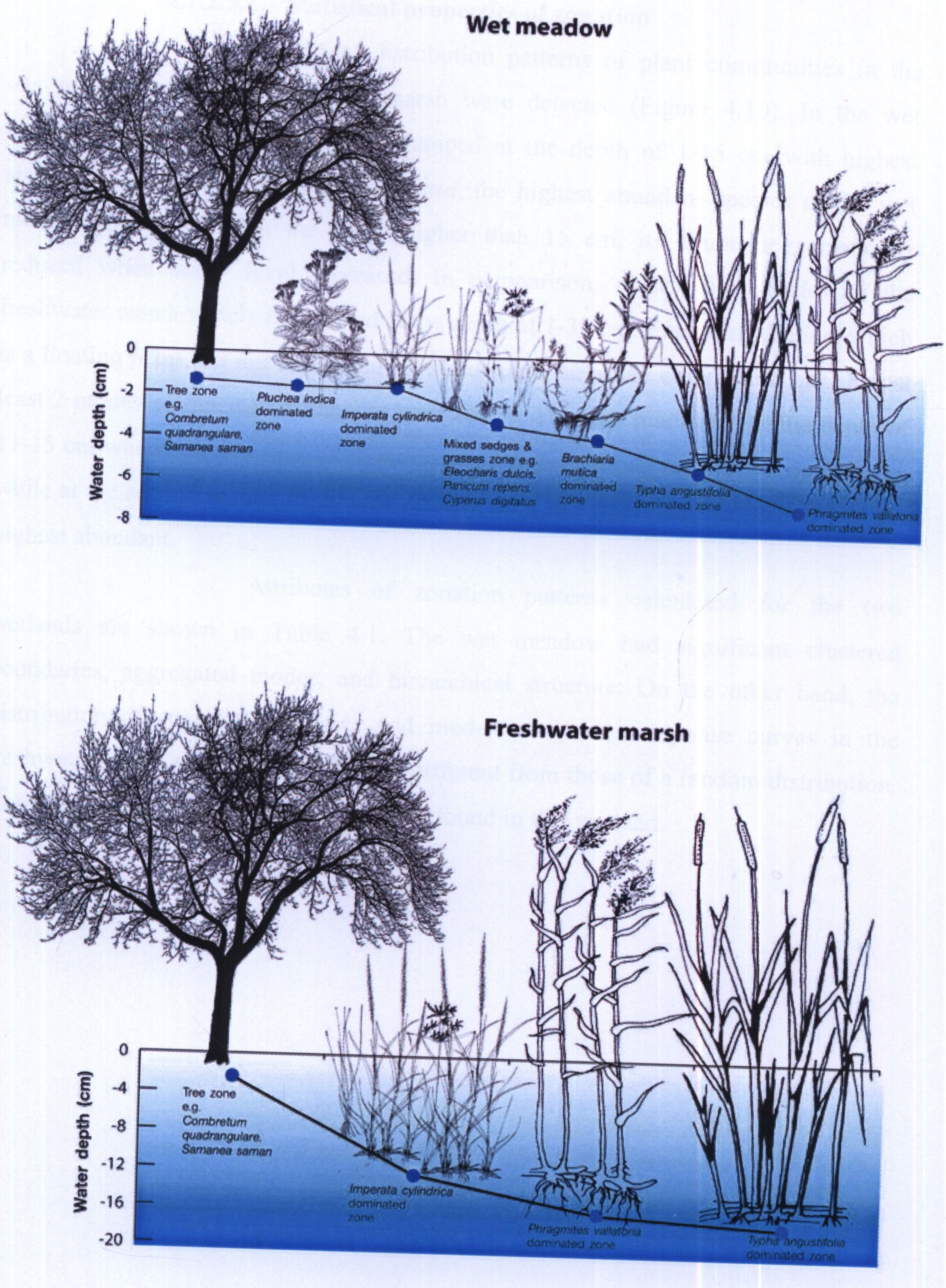
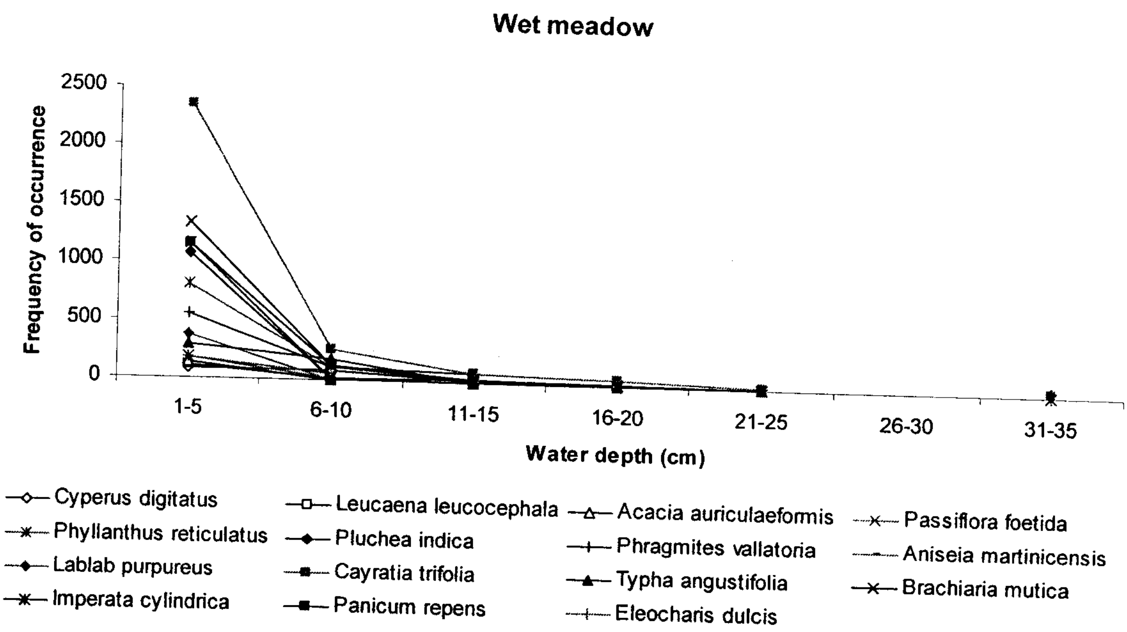


FIGURE 4.9 A coenocline of wetland plant communities of Salaya Campus, Mahidol University along gradients of water depth

4.1.2.3.2. Statistical properties of zonation

Different distribution patterns of plant communities in the wet meadow and the freshwater marsh were detected (Figure 4.10). In the wet meadow, most plant species were clumped at the depth of 1-15 cm with highest abundance at 1-5 cm. Although *Cayratia*, the highest abundant species of the wet meadow, were found at the depth higher than 15 cm, its abundance drastically reduced when water level increased. In comparison, most plant species of the freshwater marsh widely distributed at the depth of 1-30 cm. Excluding *Lemna*, which is a floating plant and not dependent on a soil substrate as the other plants are, then at least 2 modes of species abundances were found. The first mode was at the depth of 11-15 cm where species such as *B. mutica*, and *Imperata* had the highest abundance, while at the second mode (16-20 cm), species such as *Typha* and *Phragmites* had the highest abundant.

Attributes of zonation patterns calculated for the two wetlands are shown in Table 4.1. The wet meadow had significant clustered boundaries, aggregated modes, and hierarchical structure. On the other hand, the distribution of species boundaries and modes of species response curves in the freshwater marsh were not significantly different from those of a random distribution. However, a hierarchical structure was also found in this wetland.



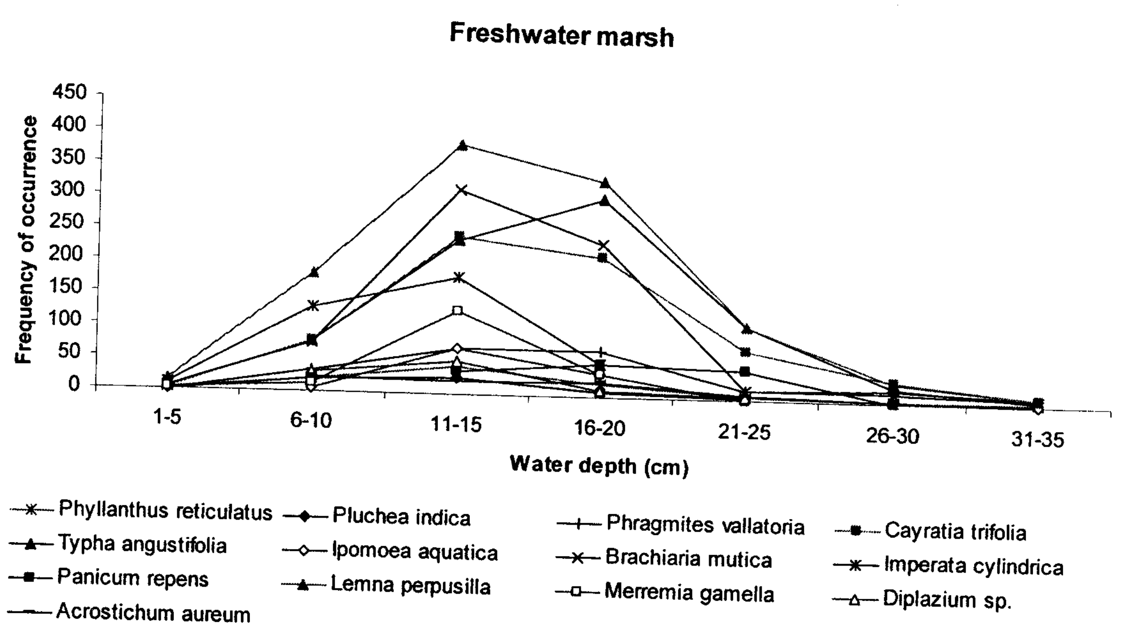


FIGURE 4.10 Distribution of plant communities of Salaya Campus wetlands along gradient of water depth

TABLE 4.1 Statistical properties of zonations of Salaya Campus wetlands

	Wet meadow	Freshwater marsh
Degree of boundary clustering (I)	2.08	1.06
Chi-square test	$\chi^2_{(5)} = 46.67$ $p < 0.05$, n = 54	$\chi^2_{(6)} = 10.48$ $p > 0.05$, n = 80
Degree of aggregation (P)	1.41	2.15
Chi-square test	$\chi^2_{(2)} = 28.67$ $p < 0.05$, n = 27	$\chi^2_{(4)} = 15.75$ $p > 0.05$, n = 40
Degree of hierarchical structure (C)	1.3	0.1
Cochran's Q test	$Q_{(47)} = 136.74$ $p < 0.05$, n = 7	$Q_{(50)} = 117.16$ $p < 0.05$, n = 7

4.1.2.4. Seasonal dynamics

In the wet meadow when water dried up during dry season at the *Typha*-dominated zone, most *Typha* turned brown and were covered with a vine, *C. trifolia* (Figure 4.11). However, young leaves of *Typha* emerged in wet season when water was rising. Then, the *Typha* increased in abundance resulting in decrease in density of *C. trifolia*. Also *Eleocharis dulcis* (Burm.f.) Hensch (Family Cyperaceae) in the mixed sedges and grasses zone, after turned brown in dry season, new young plants with inflorescences emerged in the wet season (Figure 4.12). On the other hand, boundaries of *Typha*-dominated zone which covered most area of the freshwater marsh tended to expand in dry season when water decreased but did not dry up. *Imperata*-dominated zone which found adjacent to the *Typha*-dominated zone was highly affected by *Typha* succession. Not only *Typha*, but the *Imperata*-dominated zone was also succeeded by *Phragmites* from another zone nearby. In addition, some buried seeds of sedges and grasses germinated at the *Imperata*-dominated zone in dry season. Since lower water level in dry season caused gradual changes in plant community structure (Figure 4.13), the *Imperata*-dominated zone of the freshwater marsh tended to be replaced by different plant zone that had higher competitive efficiency.

FIGURE 4.11 Seasonal changes of Salaya Campus wetland a) Wet meadow in dry season. b) cattails (*Typha angustifolia* L.) covered with a vine, *Cayratia trifolia* (L.) Domin (Family Vitaceae), at the beginning of dry season

FIGURE 4.12 Some sedges and grasses of the wet meadow turned brown in dry season (a), but in wet season, new young plants with inflorescences emerged (b) such as *Eleocharis dulcis* (Burm.f.) Hensch. (Family Cyperaceae) (c)

FIGURE 4.13 Succession of cattails, *Phragmites*, and other sedges and grasses in *Imperata*-dominated zone of the freshwater marsh (a and b, wet season; c and d, dry season)

4.2. The Study on Aquatic Macroinvertebrate Communities

4.2.1. Aquatic macroinvertebrate communities

4.2.1.1. Diversity

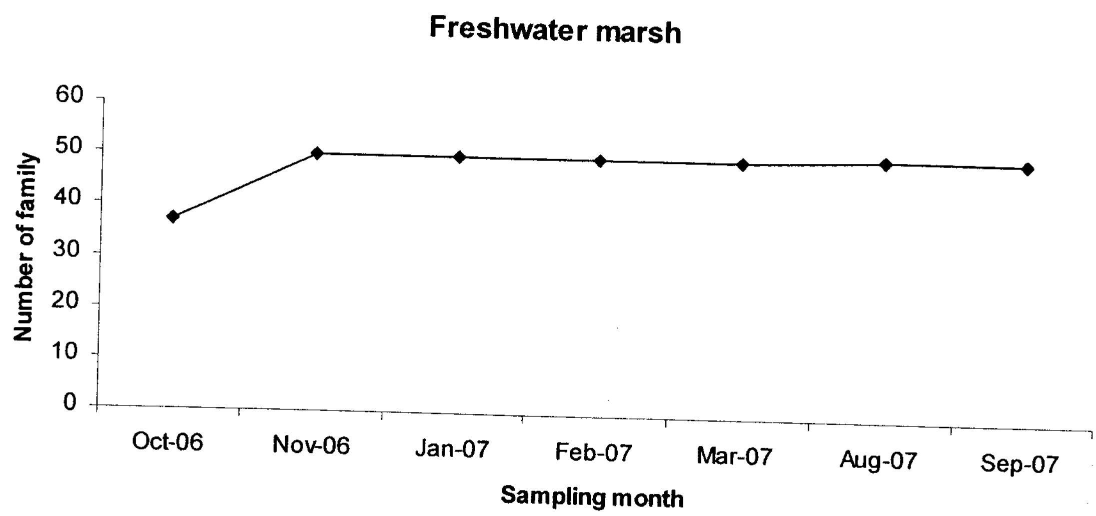
Abundances of aquatic macroinvertebrates found in this study were shown in Table 4.2. Cumulative family curves of both wet meadow and freshwater marsh (Figure 4.14) indicated potential of the aquatic macroinvertebrates sampled in this study as representatives of the whole community structure in the Salaya Campus wetlands. The freshwater marsh contained lower number of families, but higher total number of aquatic macroinvertebrate individuals. Its Shannon diversity index is 1.91, lower than that of the wet meadow which is 2.20. In general, composition of aquatic macroinvertebrate families between the two wetlands was strongly similar. Since The Morisita-Horn measure (C_{MH}) of similarity coefficient was equal to 0.92, it indicated 92% similarity in family composition between the two wetlands. About 50% of total number of aquatic macroinvertebrates found in the freshwater marsh was dominated by Planorbid snails (Planorbidae). Midge larvae (Chironomidae) were the second most abundant family comprising about 20% (Figure 4.15a). In the wet meadow, Planorbid snails, midge larvae, and marsh beetles (Helodidae) were the three most abundant families comprising almost 70% of total number of aquatic macroinvertebrates (Figure 4.15a). Appendix D showed a list of aquatic macroinvertebrates sampled from this study.

Different proportion of feeding groups of aquatic macroinvertebrates (McCafferty, 1998; Merritt and Cummins, 1996, as cited in NCTC, 2006) also found in the campus wetlands (Figure 4.15b). The three most abundant feeding groups of the wet meadow were shredder-herbivores (31%), collector-gatherers (28%), and shredder-detritivores (21%), respectively. Shredder-herbivores refer to macroinvetebrates that chew on living plant such as some snails including *Camptoceras* sp. and *Pomacea* sp., and Lepidoptera larvae (Pyralidae). Unlike herbivores, shredder-detritivores chew on large piece of decaying plant materials such as freshwater isopods and marsh beetle larvae (Helodidae). Collector-gatherers refer to the groups that acquire and ingest deposited fine detritus such as midge larvae (Chironomidae), small minnow mayfly larvae (Baetidae), and aquatic earthworm (Oligochaeta). In addition, predators such as aquatic bugs, dragonfly larvae, and predaceous diving beetles (Dytiscidae) comprised 10% of total individuals classified by feeding guilds. On the other hand, the freshwater marsh was approximately 50% dominated by scrapers, or grazers, which most of them are snails e.g. *Gyraulus* sp., *Helicorbis* sp., and *Wattebledia* sp. Like the wet meadow, collector-gatherers were the second most abundant feeding guild comprising 26% of total macroinvertebrate individuals. Additionally, predators were in the third rank comprising 15%.

With classification by habit (McCafferty, 1998; Merritt and Cummins, 1996, as cited in NCTC, 2006), the top three abundances of aquatic macroinvertebrates in both wet meadow and freshwater marsh were sprawlers, burrowers, and climbers, respectively (Figure 4.15c). Sprawlers are benthic macroinvertebrates which crawl on surfaces of substrates e.g. common skimmer larvae (Libellulidae), isopods, and some snails. The sprawlers strongly dominated the freshwater marsh with 61% of total macroinvertebrate individuals. Their proportion was higher than those of the wet meadow which comprising 48% of total macroinvertebrate individuals. In contrast, proportions of the burrowers, benthic macroinvertebrates that usually live within fine sediments, of both wetlands were similar to about 20%. These groups of macroinvertebrates include midge larvae, aquatic earthworms, and burrowing water beetles (Noteridae). However, climbers which live on vascular plants or debris e.g. water scorpions (Nepidae), giant water bugs (Belostomatidae), firefly larvae (Lampyridae), and narrowwinged damselfly larvae (Coenagrionidae) were proportionately higher in the wet meadow (18%) than in the freshwater marsh (9%).

TABLE 4.2 Abundances of aquatic marcoinvertebrates of Salaya Campus wetlands

	Wet meadow	**Freshwater Marsh**	**Both wetlands**
No. of individuals	2,847	5,114	7,961
No. of order	19	16	19
No. of families	51	44	55



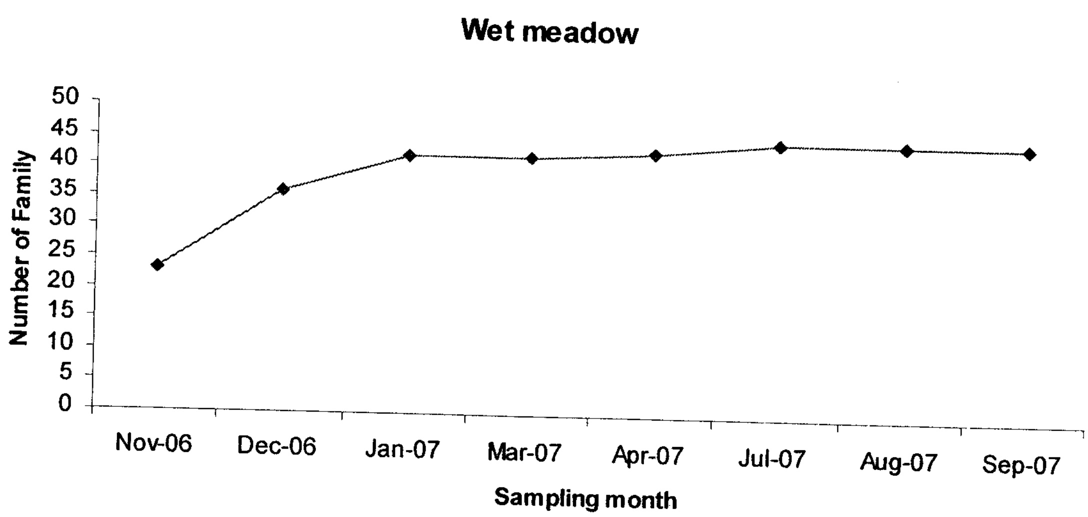


FIGURE 4.14 Cumulative family curves of aquatic macroinvertebrates sampled in this study

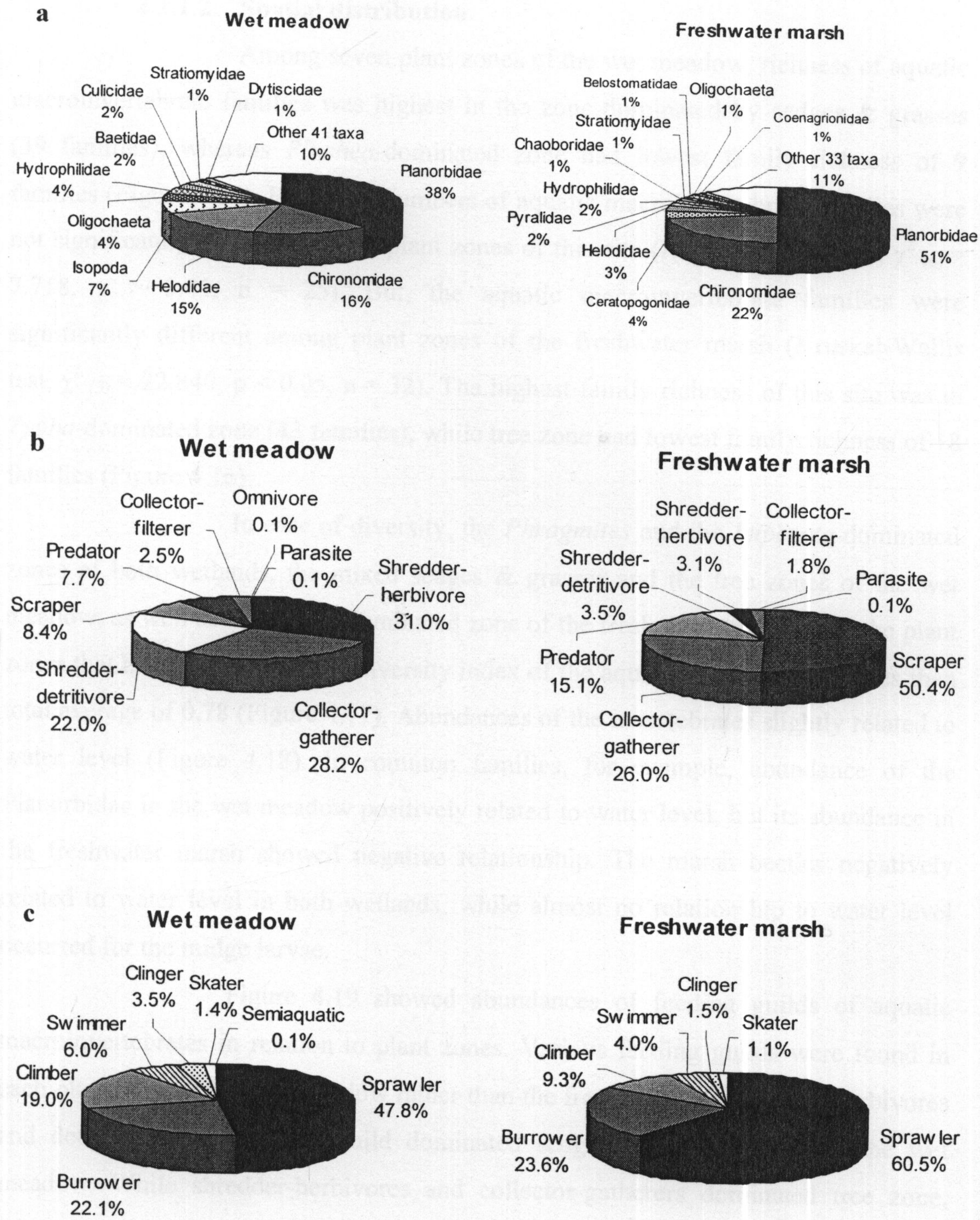


FIGURE 4.15 a) Compositions of aquatic macroinvertebrate families of Salaya Campus wetlands; b) classified by feeding guilds; c) classified by habitats (total samples of the wet meadow, 53; the freshwater marsh, 64)

4.2.1.2. Spatial distribution

Among seven plant zones of the wet meadow, richness of aquatic macroinvertebrate families was highest in the zone dominated by sedges & grasses (39 families), whereas *Pluchea*-dominated zone had lowest family richness of 9 families (Figure 4.16). However, numbers of aquatic macroinvertebrate families were not significantly different among plant zones of this site (Kruskal-Wallis test, $\chi^2_{(6)} = 7.718$, $p > 0.05$, $n = 25$). But, the aquatic macroinvertebrate families were significantly different among plant zones of the freshwater marsh (Kruskal-Wallis test, $\chi^2_{(3)} = 22.840$, $p < 0.05$, $n = 32$). The highest family richness of this site was in *Typha*-dominated zone (43 families), while tree zone had lowest family richness of 18 families (Figure 4.16).

In case of diversity, the *Phragmites* and the *Imperata*-dominated zones of both wetlands, the mixed sedges & grasses and the tree zones of the wet meadow, as well as the *Typha*-dominated zone of the freshwater marsh were the plant zones that had higher values of diversity index of the aquatic macroinvertebrates than total average of 0.78 (Figure 4.17). Abundances of the invertebrates slightly related to water level (Figure 4.18). In common families, for example, abundance of the Planorbidae in the wet meadow positively related to water level, but its abundance in the freshwater marsh showed negative relationship. The marsh beetles negatively related to water level in both wetlands, while almost no relationship to water level occurred for the midge larvae.

Figure 4.19 showed abundances of feeding guilds of aquatic macroinvertebrates in relation to plant zones. Various feeding guilds were found in each plant zone of the wet meadow rather than the freshwater marsh. Both herbivores and detritivores of shredder guild dominated sedges & grasses zone of the wet meadow. While shredder-herbivores and collector-gatherers dominated tree zone, *Phragmites*-dominated zone was only dominated by the collector-gatherers, and *B. mutica* zone was only dominated by the shredder-herbivores. Despite few occurrences of the shredder-herbivores, most plant zones of the freshwater marsh tended to be dominated by scrapers, particularly in the *Typha*-dominated zone causing it to have highest total abundances of aquatic macroinvertebrates.

Considering distribution of habit guilds (Figure 4.20), sprawlers were highly abundant in most plant zones of both wetlands. Besides the *Typha*-dominated zone that contained similar number of individuals between burrowers and climbers, the *Pluchea*, mixed sedges & grasses, and *B. mutica* zones were the plant zones that had proportions of climbers higher than burrowers.

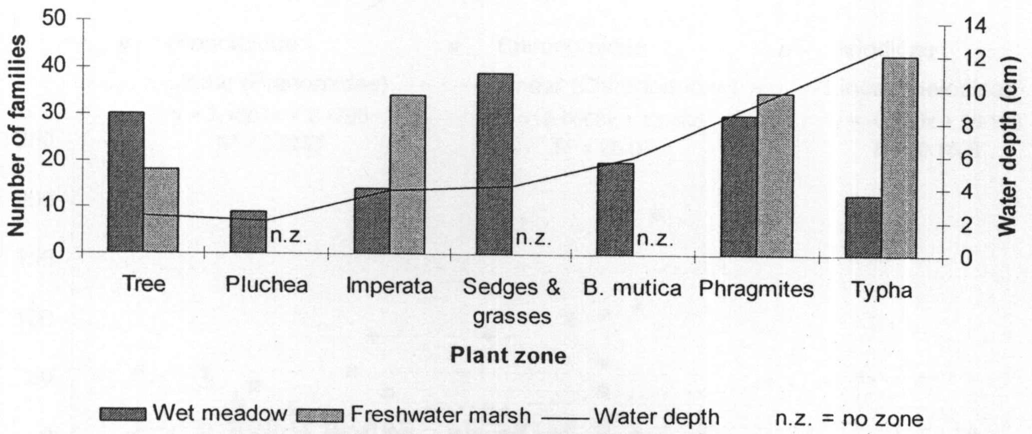


FIGURE 4.16 Family richness of aquatic macroinvertebrates in relation to plant zones of Salaya Campus wetlands

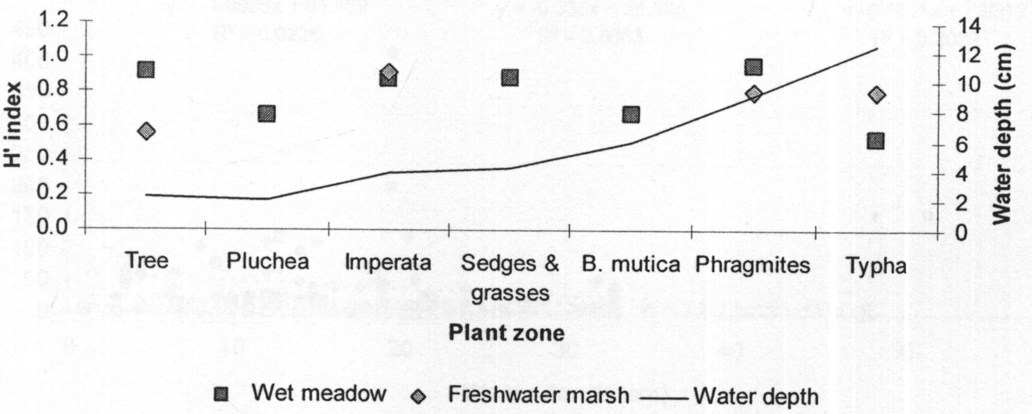
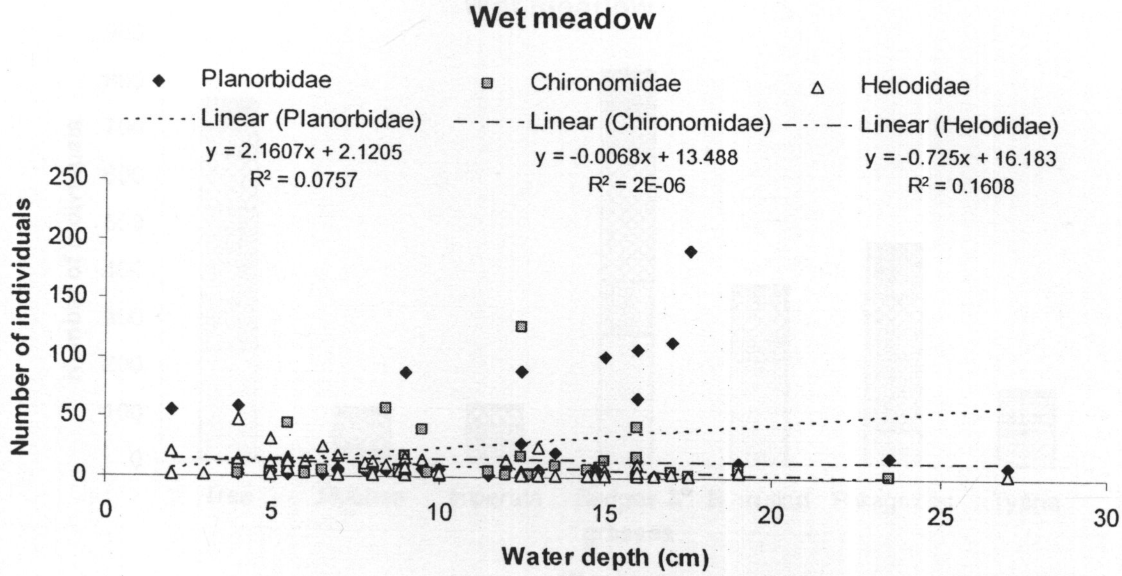


FIGURE 4.17 Values of Shannon diversity index (H') of aquatic macroinvertebrates compared among plant zones.



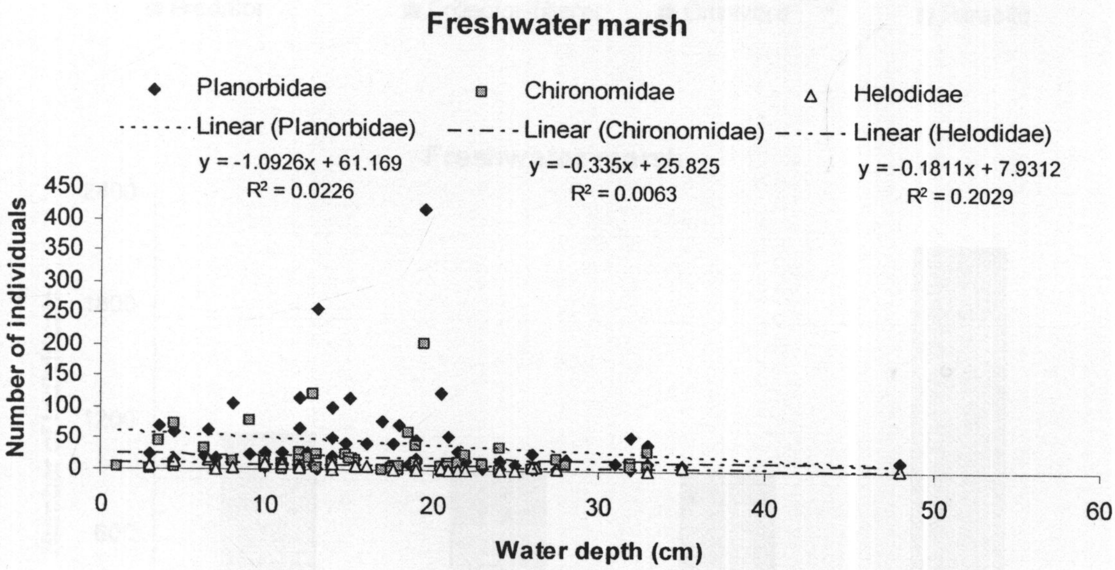


FIGURE 4.18 Abundances of common aquatic macroinvertebrate families against water level.

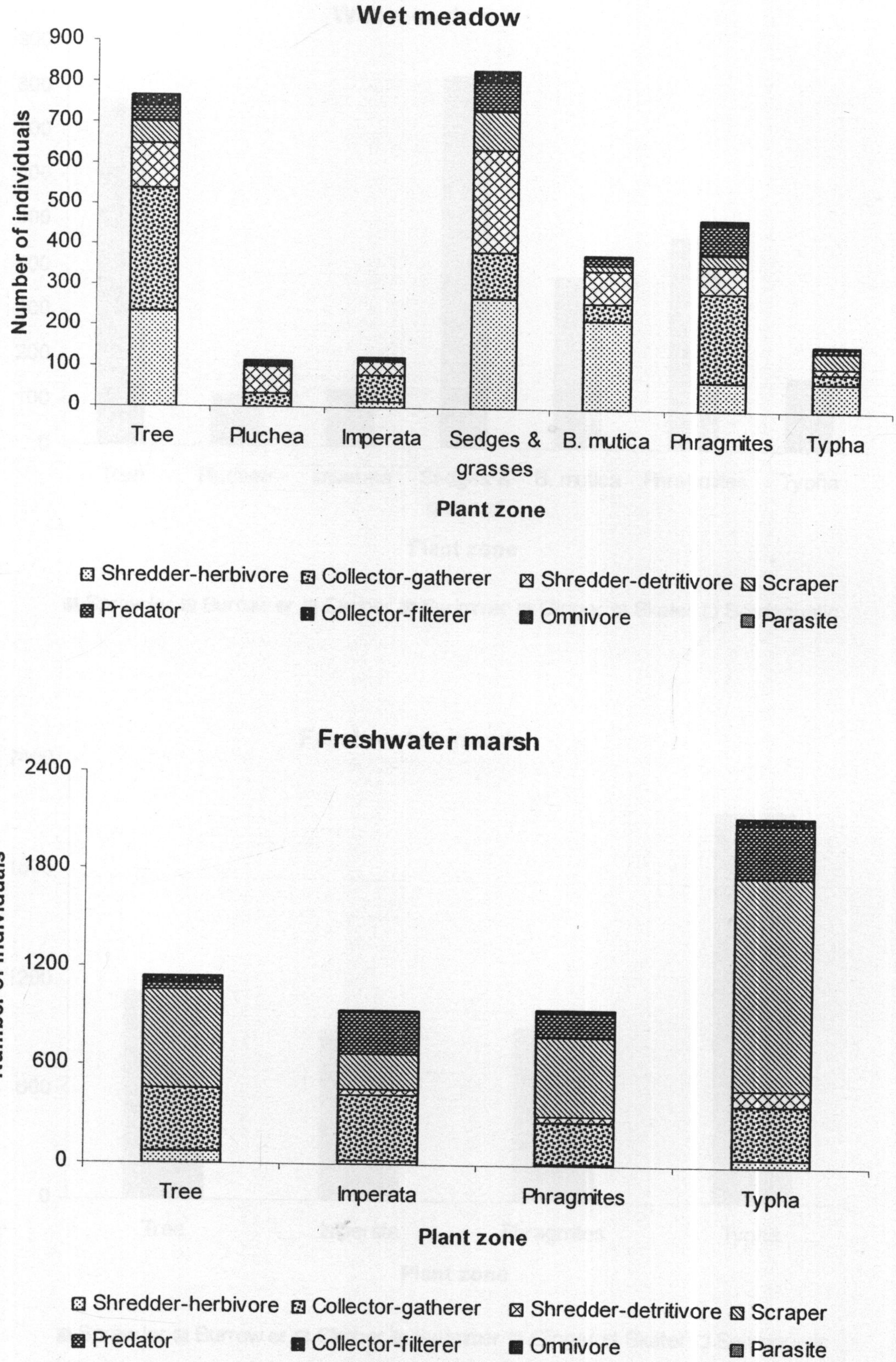
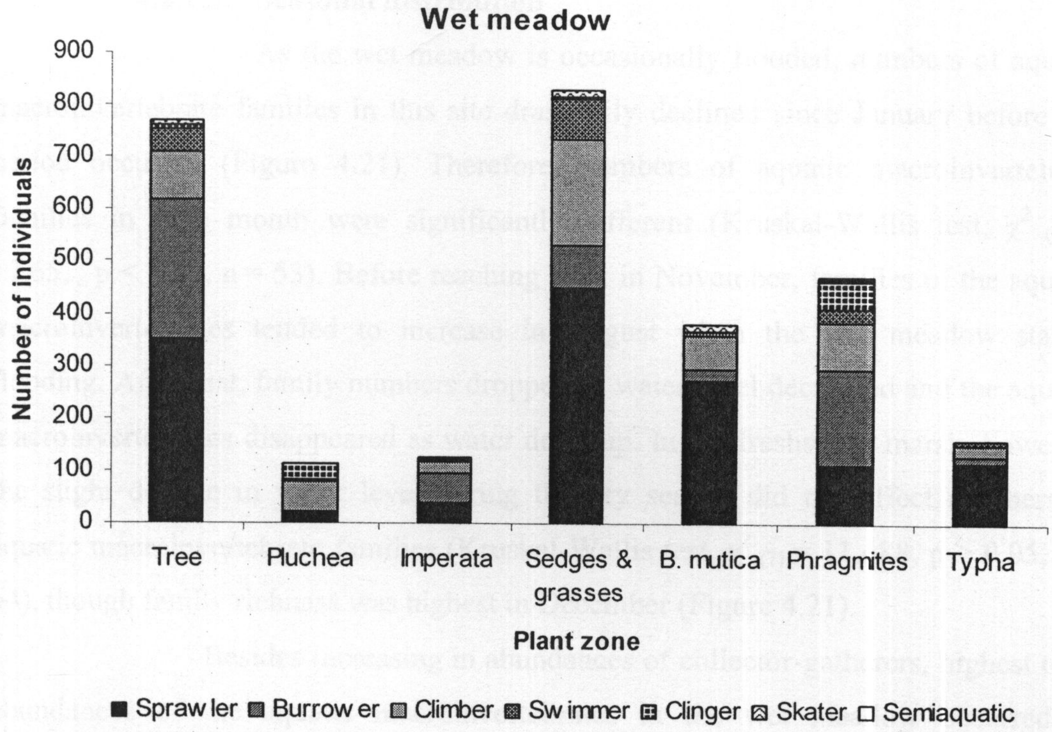


FIGURE 4.19 Abundances of feeding guilds of aquatic macroinvertebrates in relation to plant zones



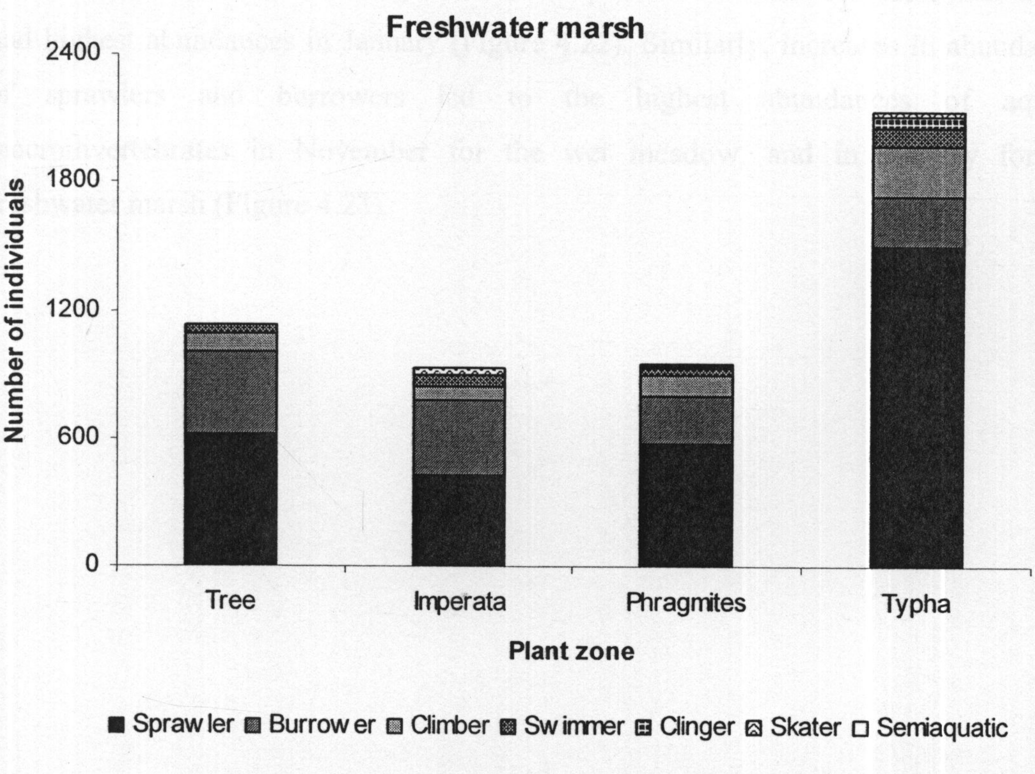
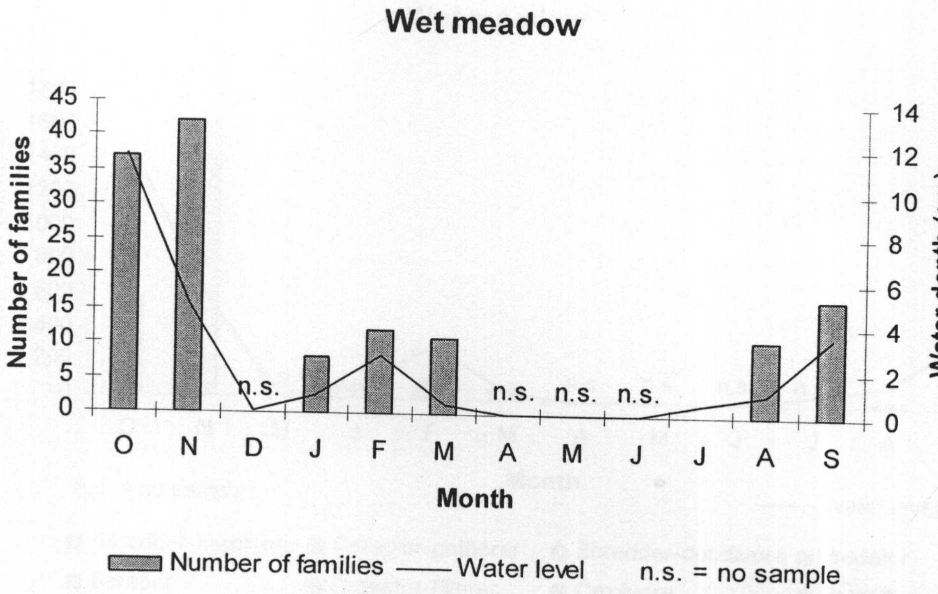


FIGURE 4.20 Abundances of habit guilds of aquatic macroinvertebrates in relation to plant zones

4.2.1.3. Seasonal distribution

As the wet meadow is occasionally flooded, numbers of aquatic macroinvertebrate families in this site drastically declined since January before dry period occurred (Figure 4.21). Therefore, numbers of aquatic macroinvertebrate families in each month were significantly different (Kruskal-Wallis test, $\chi^2_{(6)} = 19.651$, $p < 0.05$, $n = 53$). Before reaching peak in November, families of the aquatic macroinvertebrates tended to increase in August when the wet meadow started flooding. After that, family numbers dropped as water level decreased and the aquatic macroinvertebrates disappeared as water dried up. In the freshwater marsh, however, the slight decline in water level during the dry season did not affect numbers of aquatic macroinvertebrate families (Kruskal-Wallis test, $\chi^2_{(7)} = 11.488$, $p > 0.05$, $n = 64$), though family richness was highest in December (Figure 4.21).

Besides increasing in abundances of collector-gatherers, highest total abundances of the aquatic macroinvertebrates in the wet meadow occurred in November when shredder-herbivores were distinctively high. In contrast, increases in number of scrapers, collectors-gatherers, and predators caused the freshwater marsh had highest abundances in January (Figure 4.22). Similarly, increases in abundances of sprawlers and burrowers led to the highest abundances of aquatic macroinvertebrates in November for the wet meadow, and in January for the freshwater marsh (Figure 4.23).



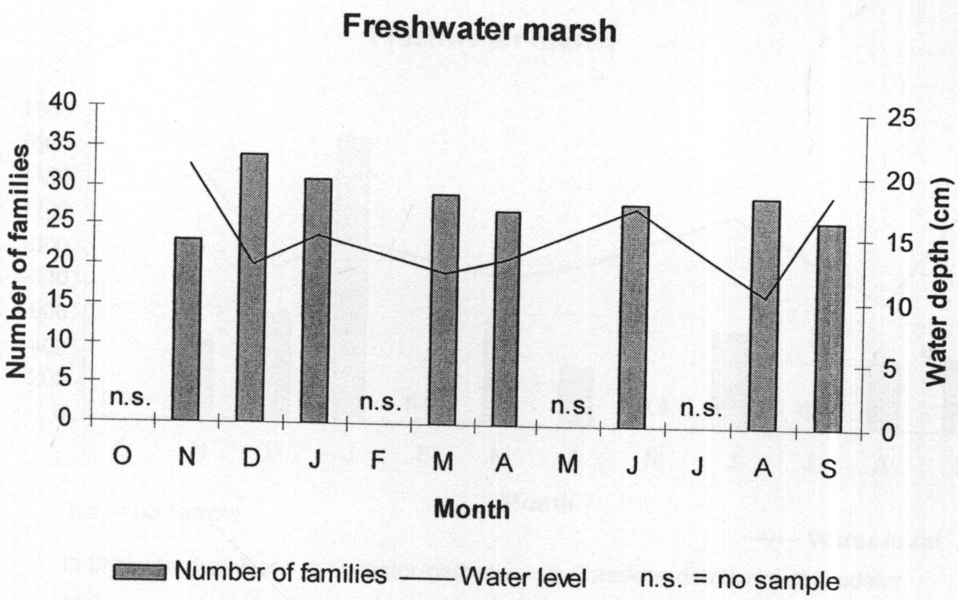
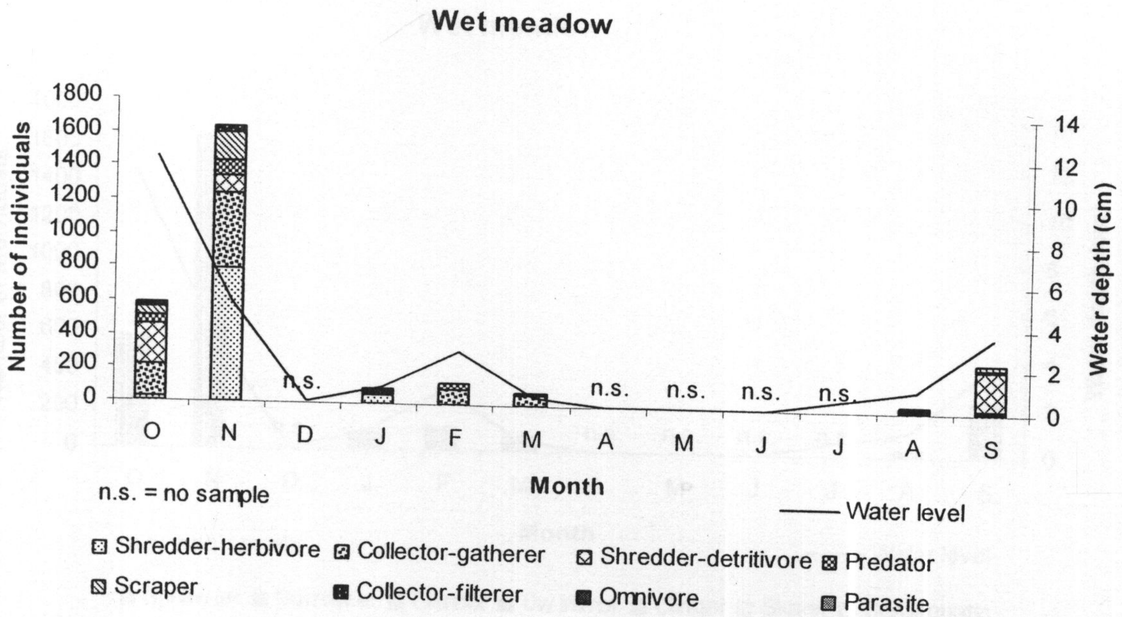


FIGURE 4.21 Seasonal distribution of aquatic macroinvertebrate families found on Salaya Campus wetlands



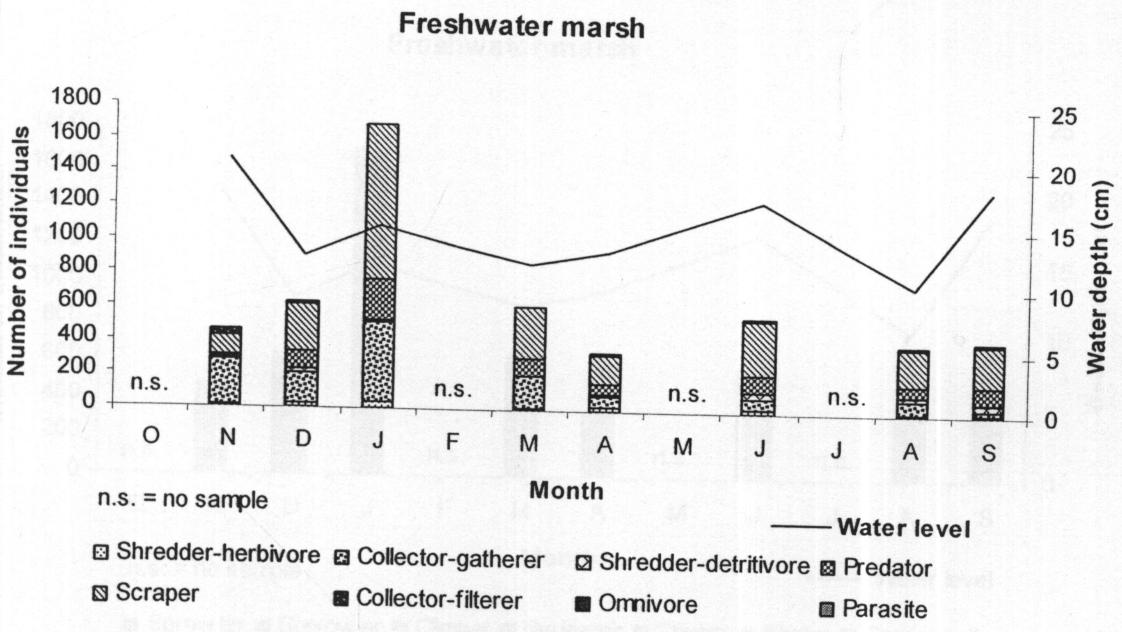
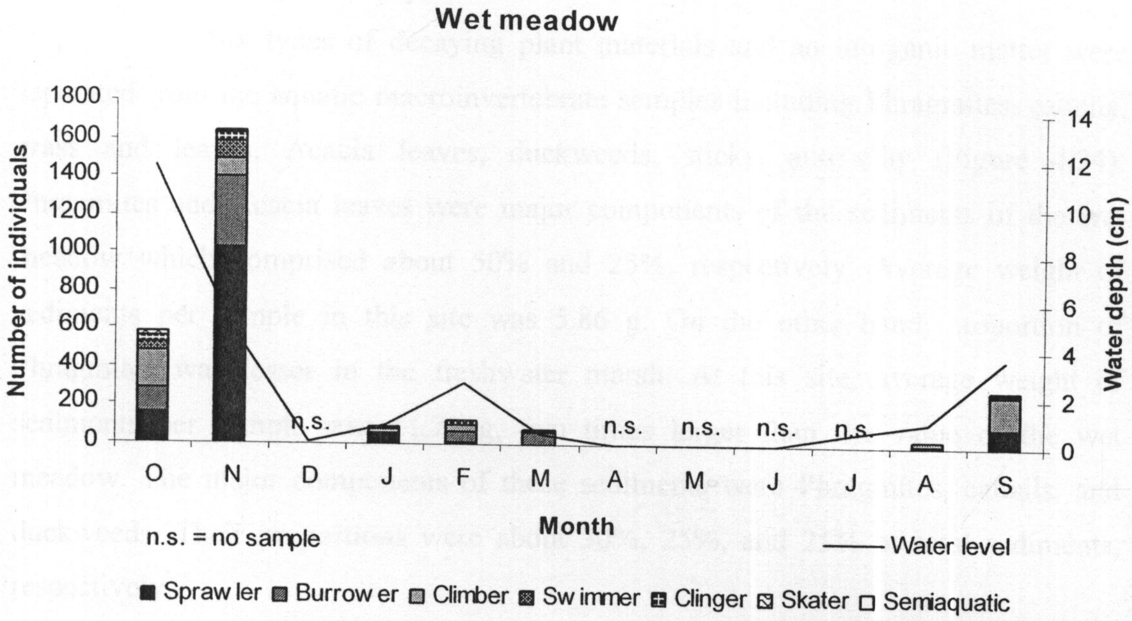


FIGURE 4.22 Seasonal abundances of feeding guilds of aquatic macroinvertebrates



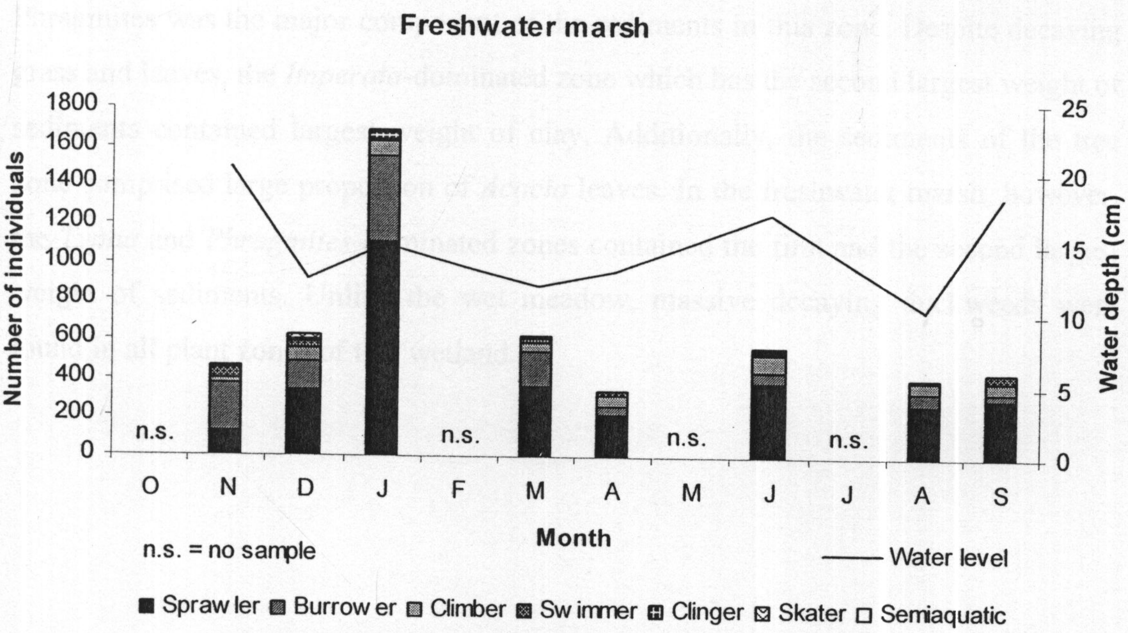


FIGURE 4.23 Seasonal abundances of habit guilds of aquatic macroinvertebrates

4.2.2. Sediment analysis

Six types of decaying plant materials and an inorganic matter were separated from the aquatic macroinvertebrate samples including Phragmites, cattails, grass and leaves, Acacia leaves, duckweeds, sticks, and clay (Figure 4.24). Phragmites and Acacia leaves were major components of the sediments of the wet meadow which comprised about 50% and 25%, respectively. Average weight of sediments per sample in this site was 5.86 g. On the other hand, proportion of Phragmites was lesser in the freshwater marsh. At this site, average weight of sediments per sample was 11.71 g, two times larger than the value of the wet meadow. The major components of these sediments were Phragmites, cattails, and duckweeds. Their proportions were about 30%, 25%, and 25% of total sediments, respectively.

As shown in Figure 4.25, total sediment weights of the *Phragmites*-dominated zone was largest among the plant zones of the wet meadow. And, decaying Phragmites was the major component of the sediments in this zone. Despite decaying grass and leaves, the *Imperata*-dominated zone which has the second largest weight of sediments contained largest weight of clay. Additionally, the sediments of the tree zone comprised large proportion of *Acacia* leaves. In the freshwater marsh, however, the *Typha* and *Phragmites*-dominated zones contained the first and the second largest weight of sediments. Unlike the wet meadow, massive decaying duckweeds were found in all plant zones of this wetland.

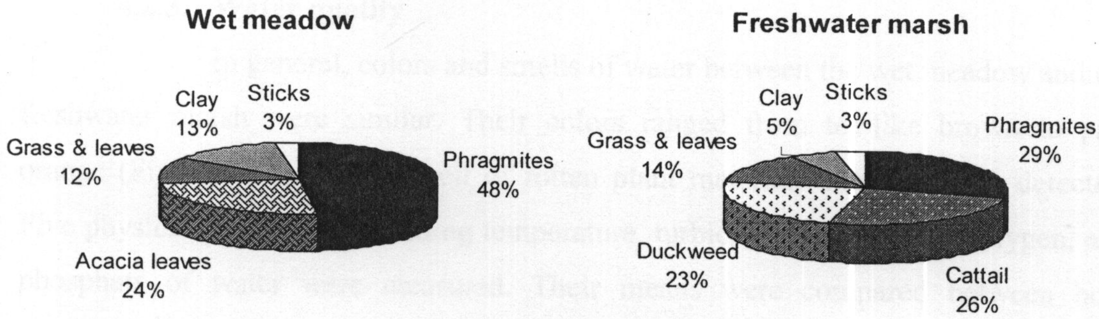
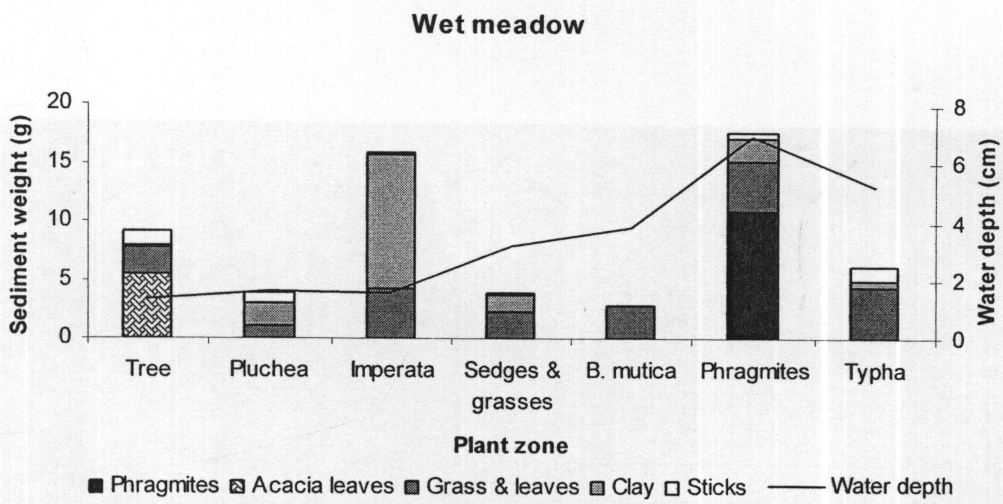


FIGURE 4.24 Sediment composition of Salaya Campus wetlands ($n_{\text{wet meadow}} = 53$, $n_{\text{freshwater marsh}} = 64$)



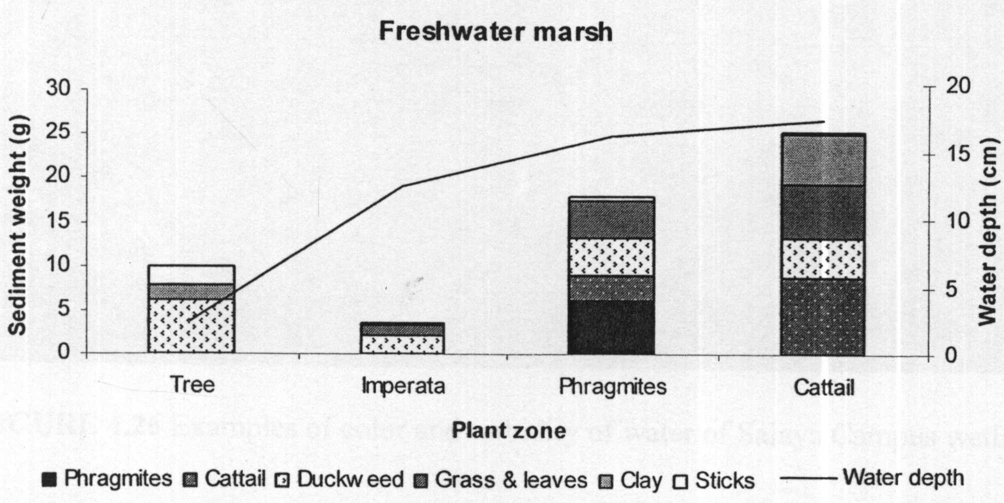


FIGURE 4.25 Amount of sediments in each plant zone of Salaya Campus wetlands

4.2.3. Water quality

In general, colors and smells of water between the wet meadow and the freshwater marsh were similar. Their colors ranged from tea-like brown to pale orange (Figure 4.26). Weak smell of rotten plant materials was generally detected. Five physical parameters including temperature, turbidity, pH, dissolved oxygen, and phosphate of water were measured. Their means were compared between both wetlands and are shown in Table 4.3. Statistical analysis indicated that water of both wetlands was only significantly different in turbidity and pH. Values of the five parameters relating to different plant zones are shown in Figure 4.27. In addition, values of the parameters relating to season are shown in Figure 4.28.

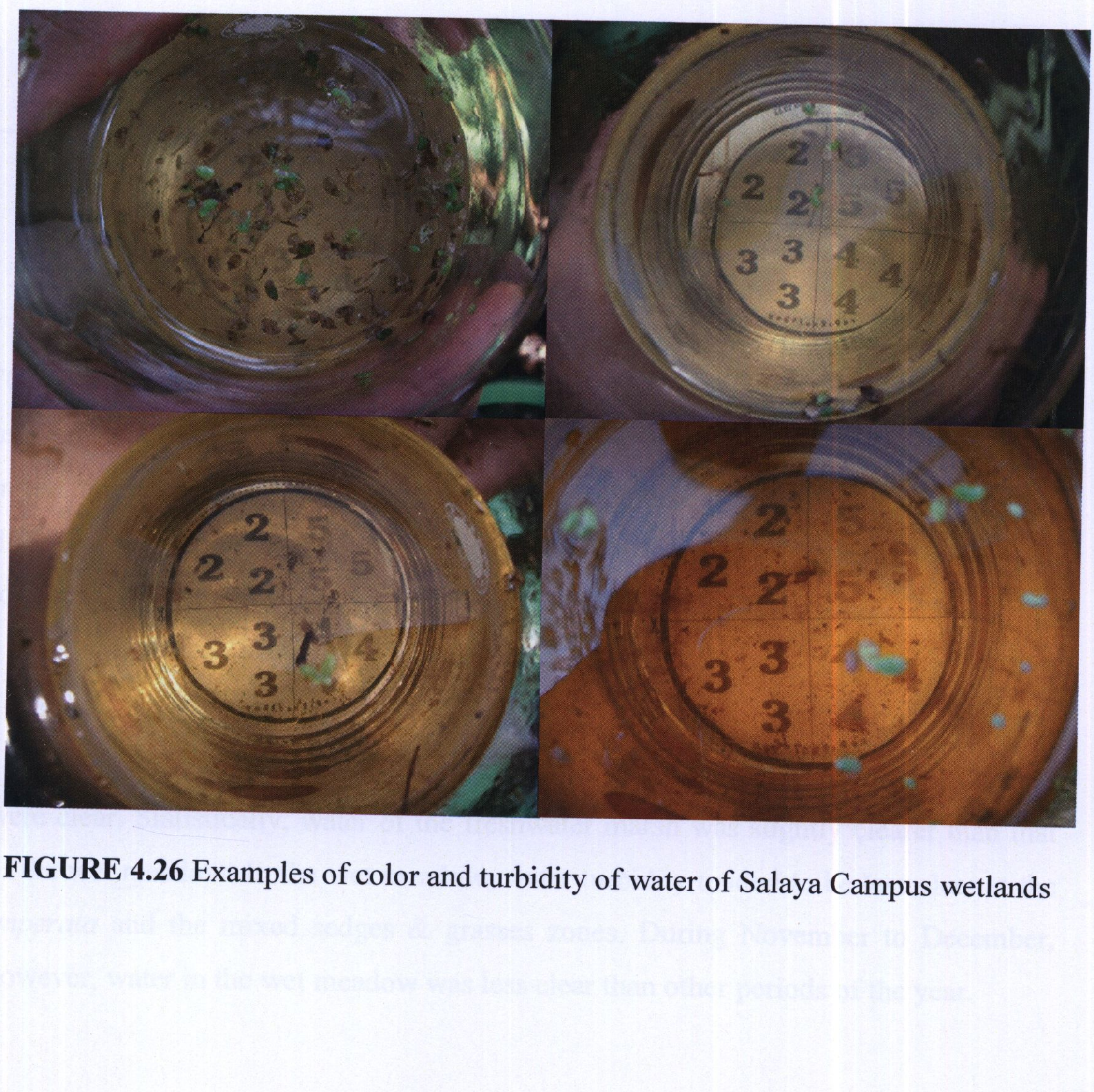


FIGURE 4.26 Examples of color and turbidity of water of Salaya Campus wetlands

TABLE 4.3 Statistical values of physical parameters of water compared between the wet meadow and the freshwater marsh of Salaya Campus, with 5% significance level. Independent samples t-test was calculated for temperature and turbidity while non-parametric Mann-Whitney U test was calculated for pH, dissolved oxygen (DO), and phosphate (P)

	Wet meadow		Freshwater marsh			
	Mean	n	Mean	n	Statistic	p-value
Temperature (°C)	25.87	52	25.09	62	1.954	p>0.05
Turbidity	4.1	52	4.8	63	-3.835	p<0.05*
pH	6.2	12	7.3	31	-5.031	p<0.05*
DO (mg/l)	5.76	12	6.34	31	-0.400	p>0.05
P (ppm)	0.03	1	0.37	23	-1.508	p>0.05

4.2.3.1. Temperature

Average temperature of water of the wet meadow was about 26 °C and that of the freshwater marsh was about 25 °C. However, the water temperatures of both wetlands were not statistically different. Such temperatures were in the ranges of room temperature. Small fluctuations of the temperatures occurred in different plant zones. Additionally, seasonal water temperatures generally decreased to about 20 °C during December to February.

4.2.3.2. Turbidity

In general, water turbidities of both wetlands of Salaya Campus were clear. Statistically, water of the freshwater marsh was slightly clearer than that of the wet meadow. In the wet meadow, water turbidity tended to be less clear at the *Imperata* and the mixed sedges & grasses zones. During November to December, however, water in the wet meadow was less clear than other periods of the year.

4.2.3.3. pH

Although water in the freshwater marsh had a slightly higher pH than in the wet meadow, pH of water in both sites was in neutral range which aquatic animals can survive. Furthermore, pH values were under the surface water criteria which determined the pH values between 5-9 (ONEP, 1994).

4.2.3.4. Dissolved oxygen (DO)

Average DO values between the two wetlands were not significantly different. They were about 6 mg/l, under the surface water criteria (ONEP, 1994) that aquatic animals can survive. In contrast to the freshwater marsh, DO values of water in the wet meadow fluctuated greatly in different plant zones. Cattail zone of the wet meadow was the zone that had lowest average value of DO.

4.2.3.5. Phosphate (P)

Although, the phosphate value is not yet determined by the surface water criteria, amounts of phosphate in rivers near residential areas normally are between 0.01-0.1 ppm. For water of Salaya Campus wetlands, the values of phosphate were about 0.3 ppm in the freshwater marsh. In the wet meadow, the value was as low as 0.03 ppm. However, such a value of the wet meadow came from only one sample because of some errors occurred from the test kit. So, it might not be a good representative for phosphate in the wet meadow.

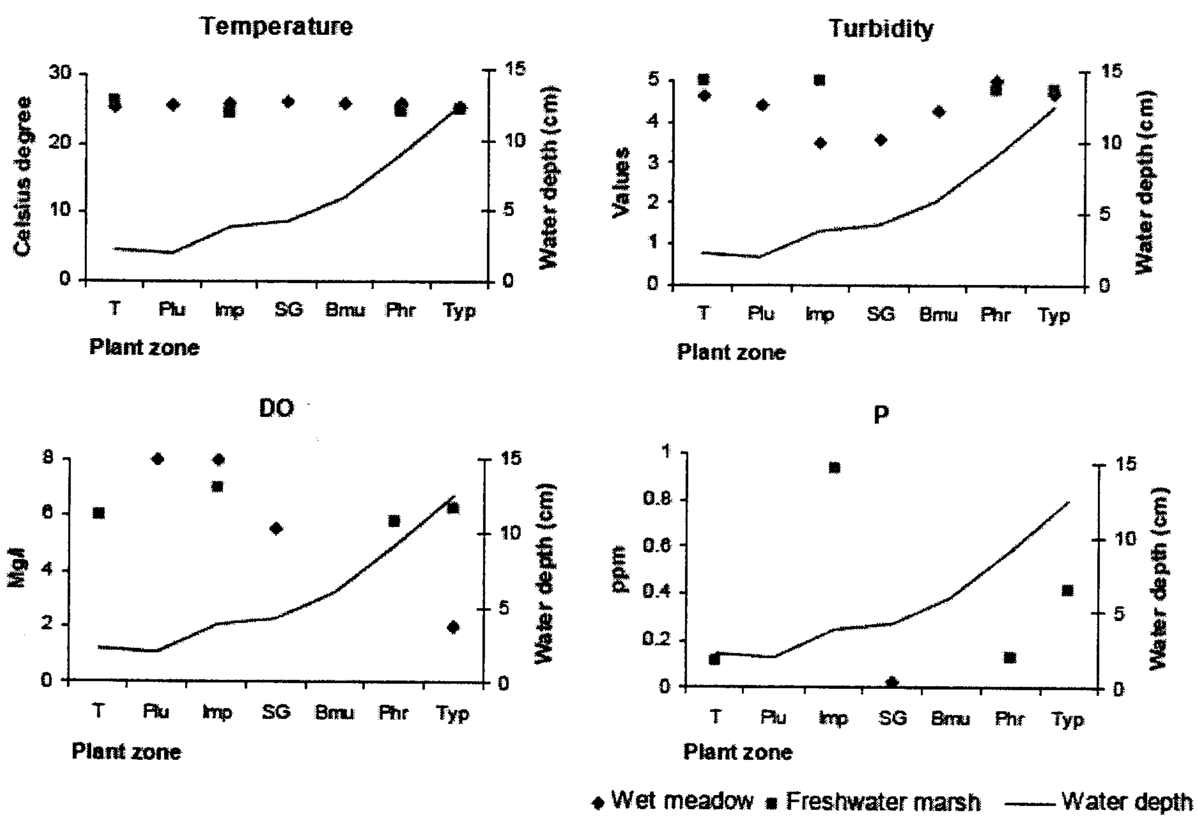


FIGURE 4.27 Physical parameters of water of Salaya Campus wetlands in relation to plant zones (T, trees zone; Plu, *Pluchea*-dominated zone; Imp, *Imperata*-dominated zone; SG, mixed sedges & grasses zone; Bmu, *Brachiaria mutica* zone; Phr, *Phragmites*-dominated zone; Typ, *Typha* -dominated zone)

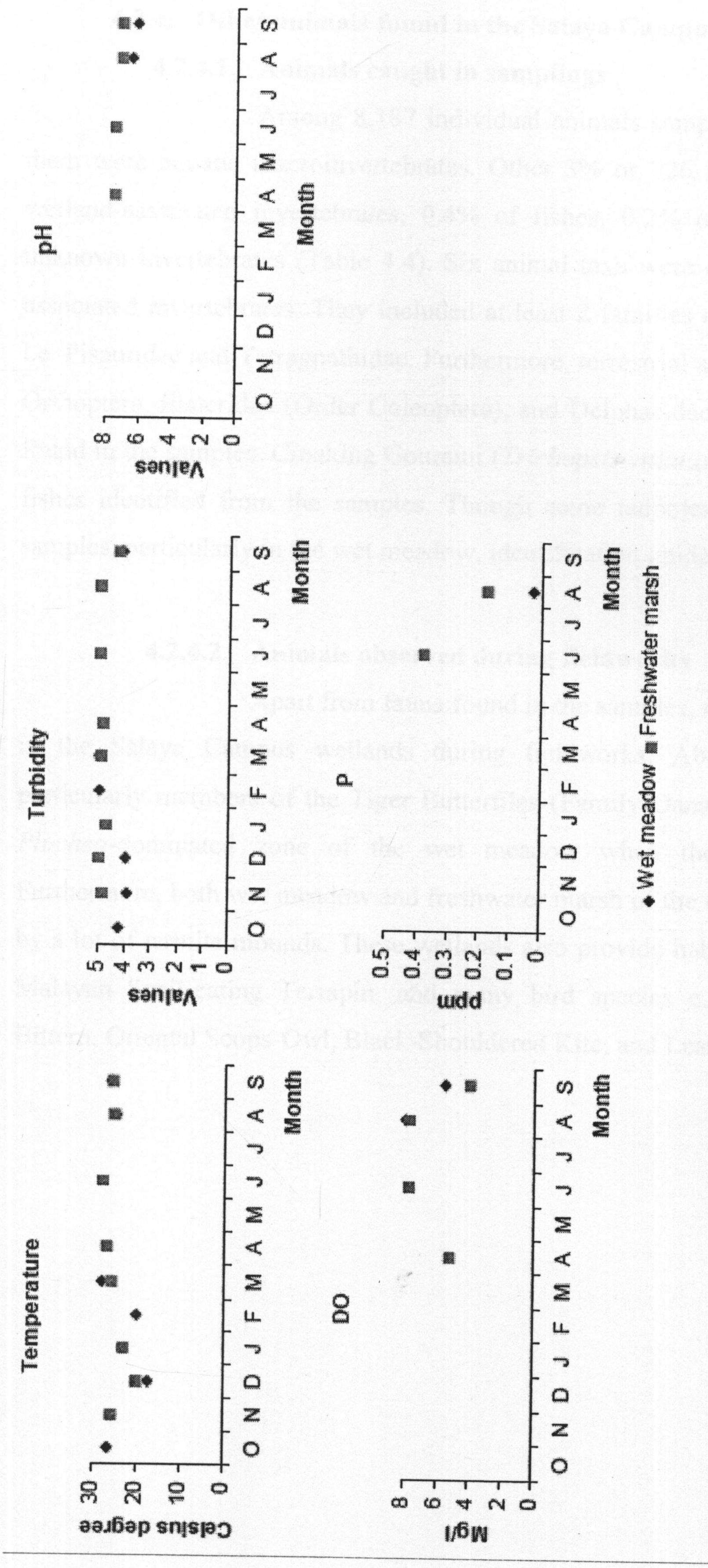


FIGURE 4.28 Physical parameters of water of Salaya Campus wetlands in one year

4.2.4. Other animals found in the Salaya Campus wetlands

4.2.4.1. Animals caught in samplings

Among 8,187 individual animals sampled in this study, 97% of them were aquatic macroinvertebrates. Other 3% or 226 individuals were 1.6% of wetland-associated invertebrates, 0.4% of fishes, 0.2% of tadpoles, and 0.6% of unknown invertebrates (Table 4.4). Six animal taxa were classified as the wetland-associated invertebrates. They included at least 2 families of spiders (Order Aranea) i.e. Pisauridae and Tetragnathidae. Furthermore, terrestrial animals such as Millipede, Orthoptera, Elateridae (Order Coleoptera), and Delphacidae (Order Hemiptera) were found in the samples. Croaking Gourami (*Trichopsis vittatus*) was only one species of fishes identified from the samples. Though some tadpoles were also found in the samples, particularly in the wet meadow, identification guide is still required.

4.2.4.2. Animals observed during fieldworks

Apart from fauna found in the samples, many animals were found in the Salaya Campus wetlands during fieldworks. Abundances of butterflies, particularly members of the Tiger Butterfiles (Family Danaidae), were found at the *Pluchea*-dominated zone of the wet meadow when the plants are flowering. Furthermore, both wet meadow and freshwater marsh of the campus are characterized by a lot of termite mounds. These wetlands also provide habitats for water monitors, Malayan Snail-eating Terrapin, and many bird species e.g. Plain Prinia, Yellow Bittern, Oriental Scops-Owl, Black-Shouldered Kite, and Lesser Whistling-Duck.

TABLE 4.4 Lists and number of individuals of other animals collected in samples in this study

Order/taxa	Family/taxa	Wet meadow	Freshwater marsh	Total
Wetland-associated invertebrates				
Aranea	Unknown	46	31	77
	Pisauridae	28		28
	Tetragnathidae	6	1	7
Coleoptera	Elateridae	8	1	9
Hemiptera	Delphacidae	1		1
Millipede		1		1
Orthoptera			4	4
Vertebrates				
Fish	*Trichopsis vittatus*	17	17	34
Tadpole		12	1	13
Unknown invertebrates				
Coleoptera		6	6	12
Diptera		2	2	4
Hemiptera		3		3
Lepidoptera		2		2
Unknown		26	5	31

4.3. Wetland Bioassessment

4.3.1. Vegetation indices

Ten vegetation indices were chosen, three of them were structural indices including Shannon diversity index, grass-like species, and dominance taxa. The others were functional indices including Floristic Quality Assessment Index (FQAI), exotic species, sensitive species, tolerant taxa, aquatic guild, and litter persistent taxa. Values of each index plotted against sampling month (Figure 4.29) indicated that all the functional indices, except monocarpic species, were sensitive to distinguish the differences between wet meadow and freshwater marsh of Salaya Campus.

When wetlands of Salaya Campus were compared with a Ramsar site, Sam Roi Yot wetland, at Khao Sam Roi Yot National Park, Prajaub Kirikhun Province, (Chareonsiri and Parr, 1994), it was found that both campus wetlands were highly impacted by human disturbances with the freshwater marsh being more highly disturbed than the wet meadow (Table 4.5).

TABLE 4.5. The human disturbance scores for wetland bioassessment , see Appendix A for the human disturbance rating criteria (Gernes and Helgen, 2002) (N/A, no data available)

Human disturbance gradient (HDG)	Sam Roi Yot	Wet meadow, Salaya campus	Freshwater marsh, Salaya Campus
Buffer landscape disturbance (Extent and intensity)	6	12	12
Landscape (immediate) Influence (Extent and intensity)	0	12	12
Habitat alteration—immediate landscape (within and beyond buffer)	0	6	12
Hydrologic alteration	7	7	14
Chemical Pollution	N/A	N/A	N/A
Total	**13**	**37**	**50**

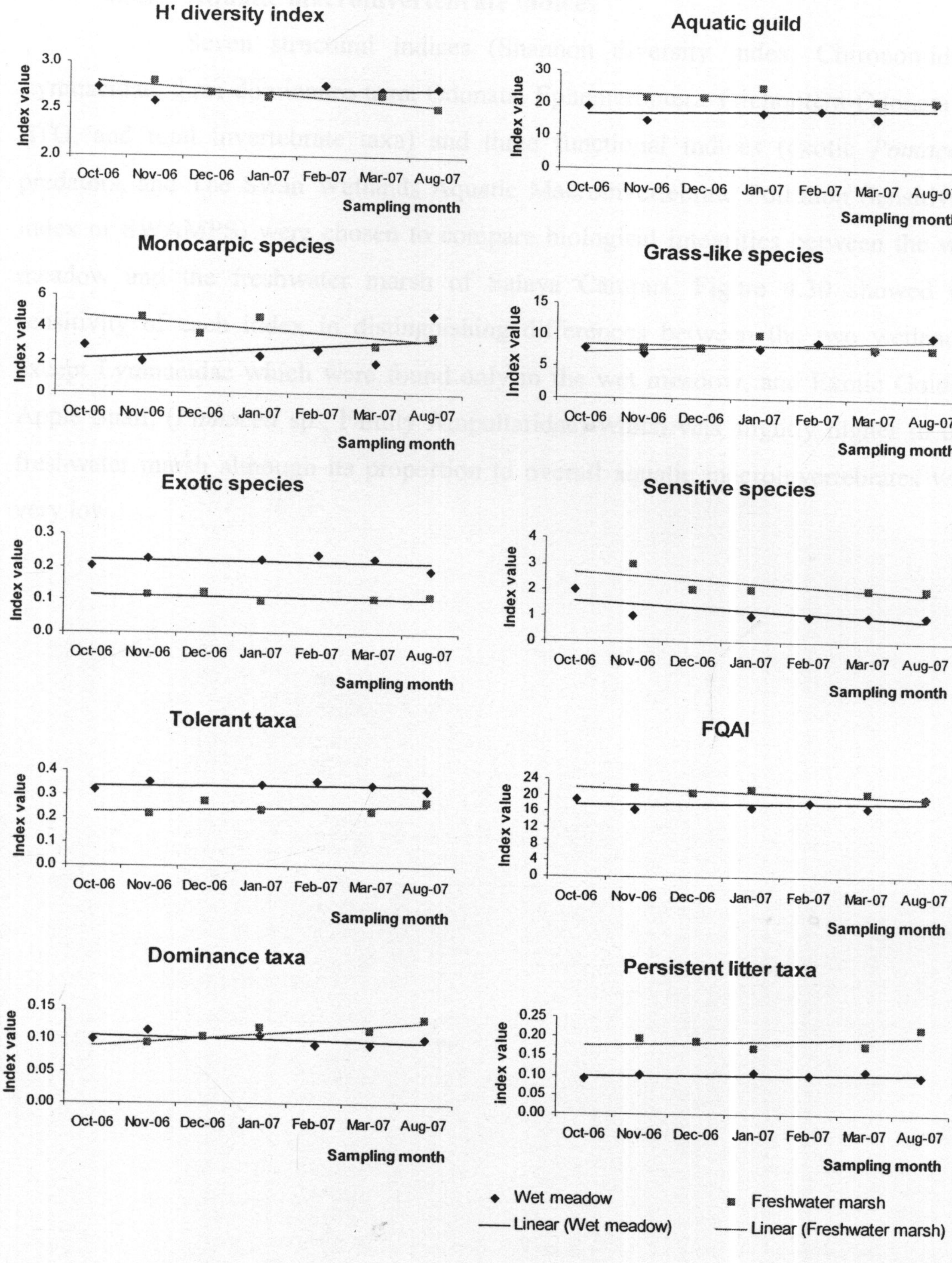


FIGURE 4.29 Values of vegetation indices for wetland bioassessment compared between the wet meadow and the freshwater marsh (linear lines are trend lines presenting average values of index for each wetland)

4.3.2. Aquatic macroinvertebrate indices

Seven structural indices (Shannon diversity index, Chironomidae, Lymnaeidae, three dominance taxa, Odonata, Ephemeroptera-Trichoptera-Odonata or ETO, and total invertebrate taxa) and three functional indices (exotic *Pomacea*, predators, and The Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity index or SWAMPS) were chosen to compare biological integrities between the wet meadow and the freshwater marsh of Salaya Campus. Figure 4.30 showed no sensitivity of each index in distinguishing differences between the two wetlands, except Lymnaeidae which were found only in the wet meadow, and Exotic Golden Apple Snail, (*Pomacea* sp., Family Ampullaridae) which was slightly higher in the freshwater marsh although its proportion to overall aquatic macroinvertebrates was very low.

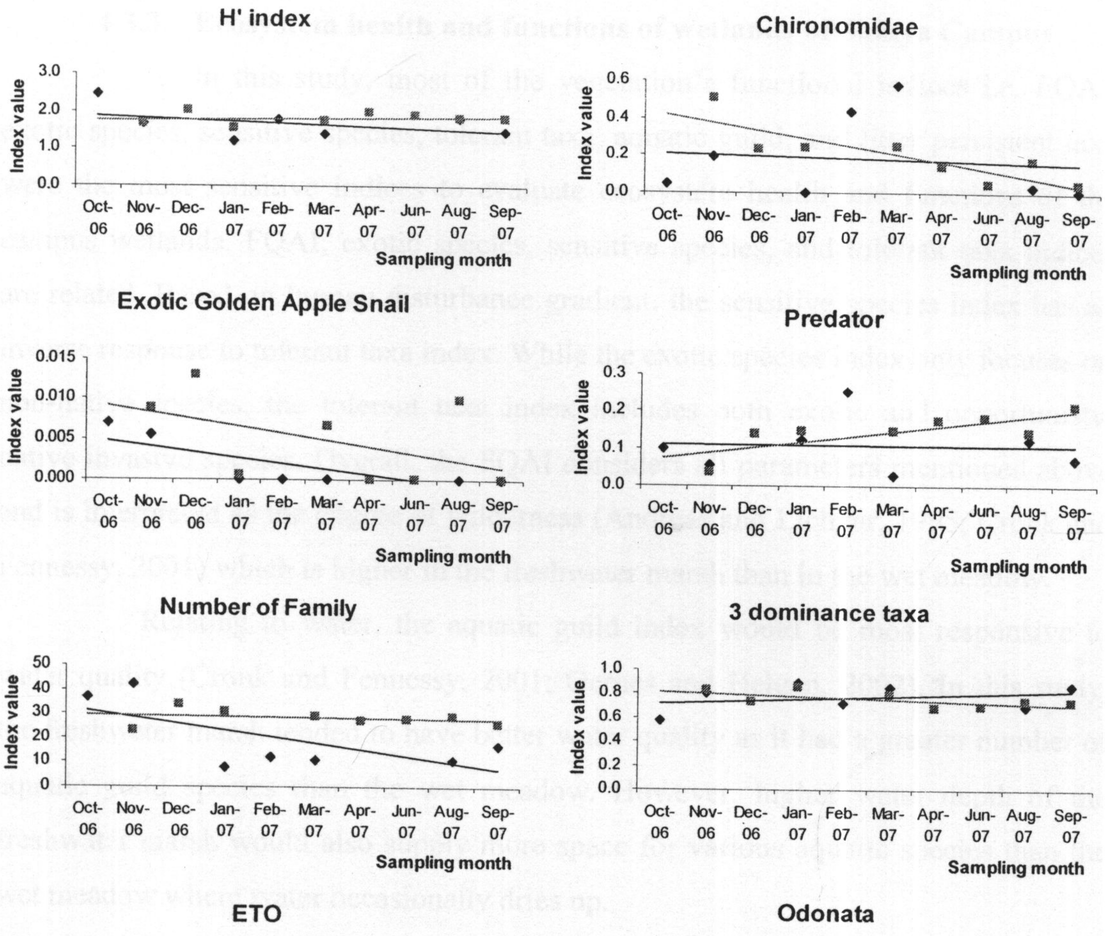


FIGURE 4.30 Values of vegetation indices for wetland bioassessment compared between the wet meadow and the freshwater marsh (linear lines are trend lines presenting average values of index for each wetland)

4.3.3. Ecosystem health and functions of wetlands of Salaya Campus

In this study, most of the vegetation's functional indices i.e. FQAI, exotic species, sensitive species, tolerant taxa, aquatic guild, and litter persistent taxa were the most sensitive indices to evaluate ecosystem health and functions of the campus wetlands. FQAI, exotic species, sensitive species, and tolerant taxa indices are related. Based on human disturbance gradient, the sensitive species index has an inverse response to tolerant taxa index. While the exotic species index only focuses on non-native species, the tolerant taxa index includes both exotic and opportunistic native invasive species. Overall, the FQAI considers all parameters mentioned above and is interpreted as the degree of wilderness (Andreas and Lichvar, 1995; Cronk and Fennessy, 2001) which is higher in the freshwater marsh than in the wet meadow.

Relating to water, the aquatic guild index would be most responsive to water quality (Cronk and Fennessy, 2001; Gernes and Helgen, 2002). In this study, the freshwater marsh tended to have better water quality as it had a greater number of aquatic guild species than the wet meadow. However, higher water depth of the freshwater marsh would also supply more space for various aquatic species than the wet meadow where water occasionally dries up.

Based on species that are resistant to decomposition like *Phragmites* sp. and *Typha* sp., the litter persistent index is responsive to nutrient cycling, particularly carbon cycling (Gernes and Helgen, 2002). The index value calculated from this study indicated higher impacts of the persistent litter to nutrient cycling in the freshwater marsh.

As Gernes and Helgen (2002) and Haugerud (2003) found that taxa richness and abundances of aquatic macroinvertebrates tend to decrease in response to human disturbances. Diversity index, three-dominance taxa index, and total invertebrate taxa index indicated that the aquatic macroinvertebrate community of the freshwater marsh tended to be more impacted by human disturbances than the community of the wet meadow. On the other hand, predator index and Lymnaeidae index indicated tendency of higher human disturbances in the wet meadow. With the exception of Lymnaeidae index, however, other statistical values of the aquatic macroinvertebrate indices showed non-significant differences between the wet meadow and the freshwater marsh of Salaya Campus. As snails of Lymnaeidae are herbivores, Lymnaeidae index associates with wetland plants. Increase in human disturbances that impacted plant community caused abundance of Lymnaeidae to decrease (Haugerud, 2003; Thongprasert, 2008). In this study, significant difference in proportional abundance of Lymnaeidae resulted from absence of this kind of snails in the wet meadow. It was also interesting that both wetlands of Salaya Campus were only slightly impacted by golden apple snails (*Pomacea* sp.), a global invasive species (GISP, 2004). Furthermore, test of macroinvertebrate sensitivity to human disturbance using SWAMPS index (Chessman et al., 2002, cited in DWAF, 2004) and nutrient enrichment criteria indicated water quality status associated with SWAMPS values that the wetlands of Salaya Campus were possibly mildly nutrient enriched or polluted (Table 4.6, Davis et al., 1999).

TABLE 4.6 Water quality status associated with SWAMPS values for wetlands of Salaya Campus. Modified from Davis et al. (1999)

	Values of Salaya Campus wetlands		
SWAMPS	**Wet meadow**	**Freshwater marsh**	**Water quality status**
> 60			Good water quality
50-60	59.53	58.22	Doubtful quality, possible mild nutrient enrichment or pollution
40-50			Probable moderate enrichment or pollution
< 40			Probable severe enrichment or pollution

4.4. Wetlands of Salaya Campus as An Outdoor Ecology Classroom

4.4.1. General review of campus-based ecological exercise

There has been considerable ecological study at Faculty of Science, Mahidol University; ecological exercises have been included in curriculum for third year, undergraduate biology students for more than 10 years. At the beginning many field trips were organized during the course. But, after 1995 proportion of field trips have been minimized and finally served as option due to problems in organization and increase in student's number. Instead, Salaya Campus play more important role as a place for developing ecological exercises. After the publication of birds at Salaya campus (Brockelman et al., 1993) and information of plant taxonomy contributed by the lecturers at that time, capacities of the campus for maintaining biodiversity as well as ecological learning source were demonstrated.

Ten years of campus-based ecological exercises at Salaya Campus have resulted in massive knowledge accumulation and some added values as follow:

4.4.1.1. Track changes on environment

Dynamic pattern of bird communities in Salaya Campus earned from campus-based ecological exercises can demonstrate effect of changes in land use and urbanization to wetland ecosystems in the Lower Central Plain. Following the exercise on bird observation each year, data of bird communities around the campus has been accumulated. In contrast with other surveys, such an exercise was able to reduce time consumption by taking advantages of a lot of manpower. However, most of the observers are students who had less experience in bird watching. Available guides of some common birds found in the campus helped narrow the observation scope from national to local species, in addition to accurate identification led by teachers and teaching assistants during the exercise. Since the exercise was done during November every year, this continuous data pictured recent relative abundance of residential and migratory birds in the campus. In the past, Red Collared Dove *Streptopelia tranquebarica* was the most dominant species in the campus. At present, Rock Pigeon *Columba livia* is the most abundant species but not distinctly different to the following ranks of highest abundant species. This indicated that the bird community of the campus has changed over the past ten years, from the community that was composed of dominant species to a community that had a more even distribution. Although alternative habitats for some birds were maintained in some campus areas where gardens and tree plantations were created, most marshy fields disturbed by land filling and construction due to campus development resulted in a decrease in the number of birds in this habitat. Furthermore, vegetation clearance from canal surfaces and borders impacted the number of occupying birds since their resources were destroyed. Therefore, insectivores and wetland birds were groups of birds that tended to decrease.

4.4.1.2. Invasive alien species inventory

Ecology of exotic colonizing plants was able to be addressed based on colonizing plant data from the exercises during 1998-2003. Among 77 species sampled from yards and street isles around Salaya Campus, 13 of them are exotic to Thailand. *Zoysia matrella* was the exotic species that had the largest area coverage due to introduction for lawn planting. *Ruellia tuberosa*, *Chloris barbata*, and *Brachiaria mutica* are other exotic species that naturally invaded the campus areas. However, their impacts to the ecosystems were unknown.

4.4.1.3. Local biodiversity foundation

As ecological exercises have been done at the campus for almost 10 years, a lot of biodiversity foundation such as birds and plants has been accumulated. Suitable management of this knowledge could provide students a practical tool for more self-study. Consequently, a local fieldguide book "Plants of Salaya Campus, Mahidol University" containing 114 illustrations of common plants species in 47 families and short description on habit and habitat for each species has been developed (Department of Biology, 2002), followed by a colorful poster collection of birds and plants of the campus including Birds of Salaya Campus, Terrestrial Plants of Salaya Campus, Aquatic Plants of Salaya Campus, Wild Flowers of Salaya Campus I and II, and Some Shrubs and Trees of Salaya Campus.

Based on strong, accumulated knowledge foundation of plants, exercises about insect communities on plants were designed as a model for studying species interaction approach. However, knowledge foundation of insects in Salaya Campus was rare. Complete taxonomy of highly diverse insects in this area might consume more time before developing such exercises. With a limited time, building up the practical studies could simplify those factors. By cooperating with the course coordinator, rapid surveys were done in order to classify taxonomic groups of plant-associated insects and to determine certain species of plants that insect communities had been obviously found. Moreover, color posters represented some pictures of insect groups that might be found in the campus were prepared in order to help students in identification.

4.4.1.4. Improving ecological literacy among Biology students

Note-taking, field techniques, field experiments, and data analysis are basic skills provided by campus-based ecological exercises. A lot of materials, as mentioned above, have been developed for enhance practical exercises. Quality in note-taking has been controlled since 1980. However, copying fieldnote is a major obstacle for improving ecological literacy. To solve the problem, issue on taking field note was discussed among teachers and students. It was assumed that copied fieldnote occurred when it was implied as a product for earning good grade rather than a skill that students could qualify. So, criteria in grading field notes has been adjusted which emphasizes more on details and significant data that is referred to, as well as individual development in taking notes.

4.4.2. Recent development of wetland-based ecological exercises

The previous campus-based ecological exercises demonstrated an important role of ecosystems on campus for ecological education. During the first period of the development of these campus-based exercises, the campus wetlands accounted for a part of an outdoor ecological classroom. However, such role of the campus wetland seemed to be diminished as campus development drastically changed the original ecosystems on campus. To promote importance of the wetlands in the period that Salaya Campus is influenced by urbanization, wetland-based ecological exercises were increasingly focused in recent years to improve student's ecological literacy and attitudes toward natural wetlands on Salaya Campus. Ecological exercises with 30% time in proportion to total wetland exercises were implemented in 2006 and exercises with 60% time were implemented in 2007.

4.4.2.1. Impacts of wetland ecological exercises with 30% time in proportion to total exercises

4.4.2.1.1. Rapid Biodiversity Inventory

Besides taking fieldnotes, students learned to use simple techniques and maps for a rapid biodiversity survey as a first step for ecological study. From class presentation, diversity of plants and animals that students found varied among different habitats. Although, the total number of organisms of all habitats was not compiled, species richness of organisms found in the campus within 2 hours was over students' expectation, particularly, in the wet meadow where a large number of butterflies in at least 9 species were found. Students also found a green snake, a Snail-eating Terrapin, a Sooty-headed Bulbul, a Black-shouldered Kite, 13 species of invertebrates (excluding the butterflies), and 25 species of plants in this wetland.

4.4.2.1.2. Environmental Gradients, Species Distribution and Community

After the exercise, students found that different plant species were distributed in different ranges of water depth. For example, most sedges were found in shallow water near the edge of the marsh. Swamp morning glory (*Ipomoea aquatica* Forssk.) and exotic paragrass (*Brachiaria mutica* (Forssk.) Stapf) was found in medium range of water depth (5-25 cm). And cattail (*Typha angustifolia* L.) was mostly found in higher depth than 25 cm, whereas floating species like duckweed (*Lemna perpusilla* Torr.) was commonly distributed in every depth. Since the distributions of plants in this exercise were not in clusters, students described such community under the individualistic concept, i.e. that species coexist together because of similarities in their requirements and tolerances but not a result of strong interactions following evolutionary theory (Smith and Smith, 2006).

4.4.2.1.3. Ecological literacy of wetland-based exercises in 2006

As students were connected to the campus wetlands through the two short wetland exercises mentioned above, they discovered the fascinating biodiversity of the wetlands in their backyard. They learned more about general concepts in community ecology addressed in textbook (Smith and Smith, 2006), as well as ecological attributes of local wetland plant community, through field practices.

4.4.2.2. Impacts of wetland ecological exercises with 60% time in proportion to total exercises

4.4.2.2.1. Interspecific Competition and the Niche of a Species

Despite observation on wetland plant distribution along gradients of water depth, students conducted a four-week field experiment. After one month of the experiment, students observed slight competition between the cattail (*T. angustifolia* L.) and exotic paragrass (*B. mutica* (Forssk.) Stapf) at a realized niche between water depths of 5-20 cm. Cattail tends to be a better competitor since it influenced paragrass to minimize fundamental niche, having higher percent coverage in shallower area, in comparison with paragrass in separated growth plot. However, students recommended that a longer experimented period is required for clearer observation on the competition interaction.

4.4.2.2.2. Mini EcoBlitz

A quick ecological survey adapted from BioBlitz exercise (Lundmark, 2003), "*Mini EcoBlitz*", provided students with knowledge on biodiversity of wetlands and other campus ecosystems, mapping skills, and further perspectives on campus managements. From 8.00 am to 11.00 am, the survey done by 7 groups of students found 638 species of plants, 97 species of birds, and 163 species of other vertebrates and invertebrates. Among these, 33 species of plants, 11 species of birds, and 25 species of other vertebrates and invertebrates were found in the wet meadow. By exchanging experiences among different groups, the students found that environments of Salaya Campus were managed differently depending on user's perspectives. Whether or not the managements were intended, some benefits may occur to both humans and wildlife. In addition, students learned that a place with which they are familiar contains a lot of biodiversity which was previously unknown to them. Characterized by unique plants and animals, the wet meadow surprised students as a neighboring area within Salaya Campus that they had never seen.

4.4.2.2.3. Individual Projects

This exercise was the most empowering process since teachers and teaching assistants acted as mentors. Most students were able to find topics of ecological study of their interests after the end of the semester due to experiences earned from the former exercises. However, they invested a lot of time discussing about observation methods and results with teachers and teaching assistants. Among 64 individual projects, 20 of them were related to the campus wetlands (Table 4.7). Although students complained about the difficulty in developing the project, finally, most of them did good work. However, some students realized that even being third year biology students who could memorize all the scientific process, in practice, they could not demonstrate their ability of converting observations in real ecological settings to the scientific process. They also lacked fieldwork skills. Since most experiences in their biological studies were laboratory-based, they hardly practiced such skills in any real habitats.

4.4.2.2.4. Ecological literacy of wetland-based exercises in 2007

Apart from a longer time in connecting students to the wetlands on campus, students learned wetland biodiversity either by survey, or field experiment. They learned competitive interaction between two wetland plant species which resulted in separation of species distribution along water depth gradient. Impacts of human activities on biodiversity and ecosystems on campus were recognized from direct observation. Most of all, students were encouraged to use their ability to convert observations in real ecological settings to scientific process.

Wetland inquiry was shown by many students as individual projects involving wetlands on campus were developed.

4.4.2.3. Student attitudes toward wetlands and Salaya Campus ecosystems

Most biology students generally had positive values on wetlands and nature of Salaya Campus before taking ecological exercises in 2006. Forty percent of them had negative values on weeds on the campus while 30% were not sure whether bulldozing all weeds was needed. In the case of wetlands, 60% of students were either uncertain, or prefered ponds and canals with no weeds on water surface and along the banks. 90% of students were not sure or thought that marshy fields are sources of diseases such as Leptospirosis and Dengue Haemorrhagic Fever. Means, medians, and standard deviations of student's attitude scores evaluated by the questionnaire are shown in Table 4.8. Students' attitudes before participating in ecological exercises conducted in 2007 were not significantly different to those in 2006 (Table 4.9). Most students seemed to empathise with nature. However, a constraint on ecological knowledge of wild plants engendered negative values of weedy areas on the campus, including wetlands. Their environmental perspectives were biased towards anthropocentric views.

As indicated by students' self reports in their field notes, the exercises built up their hands-on experiences and sense of place. However, the two short wetland exercises (30% of total time spent on ecological exercises) was insufficient to modify students' negative values of the campus wetlands (Figure 4.31a), since the attitude assessment survey indicated non-significant difference between students' attitudes before and after taking the course (Table 4.9).

Since the results from the ecological exercises in 2006 required more inputs in the wetland exercises, more intensive wetland exercises comprising 60% of the period of total ecological exercises were implemented in 2007 to test their impact on attitudes. The evaluation of students' attitudes was repeated at the end of the semester. Students reported that the intensive wetland exercises help building up their ecological knowledge, hands-on experiences, and a sense of place. Most students reported that the *"Individual projects"* exercise strongly increased their self-esteem of doing as ecologists do. The attitude assessment survey indicated that students' attitudes were improved (Figure 4.31b), their post-course attitude assessment score being significantly higher than the score before taking the course (Table 4.9). Since ecological knowledge and local wetland values among students were built up, the ecological exercises integrating place-based education, experiential learning, and empowerment process proved to be an effective approach for ecological education (Table 4.10). Positive changes in attitudes are one of the critical processes for conserving wetlands on campus. For sustainable wetland conservation, however, further exercises engaging students in taking actions for wetlands are required.

TABLE 4.7 Wetland-based individual projects of undergraduate biology students in General Ecology Class in 2007

Organism	Topic of individual projects
Plant	1. Impacts of *Leucaena leucocephala* (Lam.) de Wit on the diversity of plants at a wetland's edge
	2. An adaptation of Indian Almond (*Terminalia catappa* L.) in a wetland
	3. Colonization by Swamp Morning Glory (*Ipomoea aquatica* Forssk.)
	4. Impact of pond depth on the abundance of Swamp Morning Glory (*Ipomoea aquatica* Forssk.)
	5. Distribution of Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms) In a canal beside the waste-water treatment ponds
Bird	1. Feeding behavior, the diving time, and distances from human of Little Grebe (*Tachybaptus ruficollis*) in the wastewater treatment ponds
Reptile	1. Diurnal behavior, abundance, and frequency of occurrence of Water Monitor (*Varanus salvator*)
	2. Heights and densities of trees used by Water Monitor (*Varanus salvator*) for sun bathing
Insect	1. Distribution of termite mounds in a wetland
	2. Distribution of dragonflies and their habitat structures around the College of Music
	3. Habitat separation of dragonflies and damselflies
	4. Distances in territory defense of damselflies
	5. Relationship between midges and hibiscus flowers
	6. Habitats and flying behaviors of craneflies
	7. Distribution and tolerance of water beetles in the waste-water treatment ponds
	8. Impact of water quality on the distribution of water striders
	9. Impact of water quality on the distribution of water beetles
Snail	1. Impact of substrate diversity on the distribution of Golden Apple Snail (*Pomacea* sp.)'s eggs
	2. Relationship between distances from water and size of Golden Apple Snail (*Pomacea* sp.)
	3. Impact of water quality on sizes of Golden Apple Snail (*Pomacea* sp.)

TABLE 4.8 Descriptive statistics of students' attitude scores from the attitude assessment survey

		N	Mean	Median	SD	Min	Max
2006	**pre-course**	50	6.2	6.5	4.8	-7	18
	post-course	36	7.2	7.5	4.9	-1	15
2007	**pre-course**	64	6.0	6.0	4.7	-8	14
	post-course	48	8.6	9.0	4.8	-4	17

TABLE 4.9 Non-parametric Mann-Whitney U test statistics comparing students' attitude scores from the attitude assessment survey, p-value = 0.05

	pre-course 2006, 2007	2006 pre-, post-course	2007 pre-, post-course
Mann-Whitney U	1588.0	789.5	1029.0
z-score	-0.069	-0.970	-2.990
p-value	0.945	0.332	0.003*

TABLE 4.10. Learning process provided by wetland-based ecological exercises (N/A, no data available)

Learning steps	**30% additional wetland exercises (2006)**	**60% additional wetland exercises (2007)**
Ecological knowledge & skills	Yes	Yes
Interests of the campus wetlands	Yes	Yes
Attitude changes	No	Yes
Ideas in ecological study of the campus wetland	No	Yes
Actions for campus wetland conservation	N/A	N/A

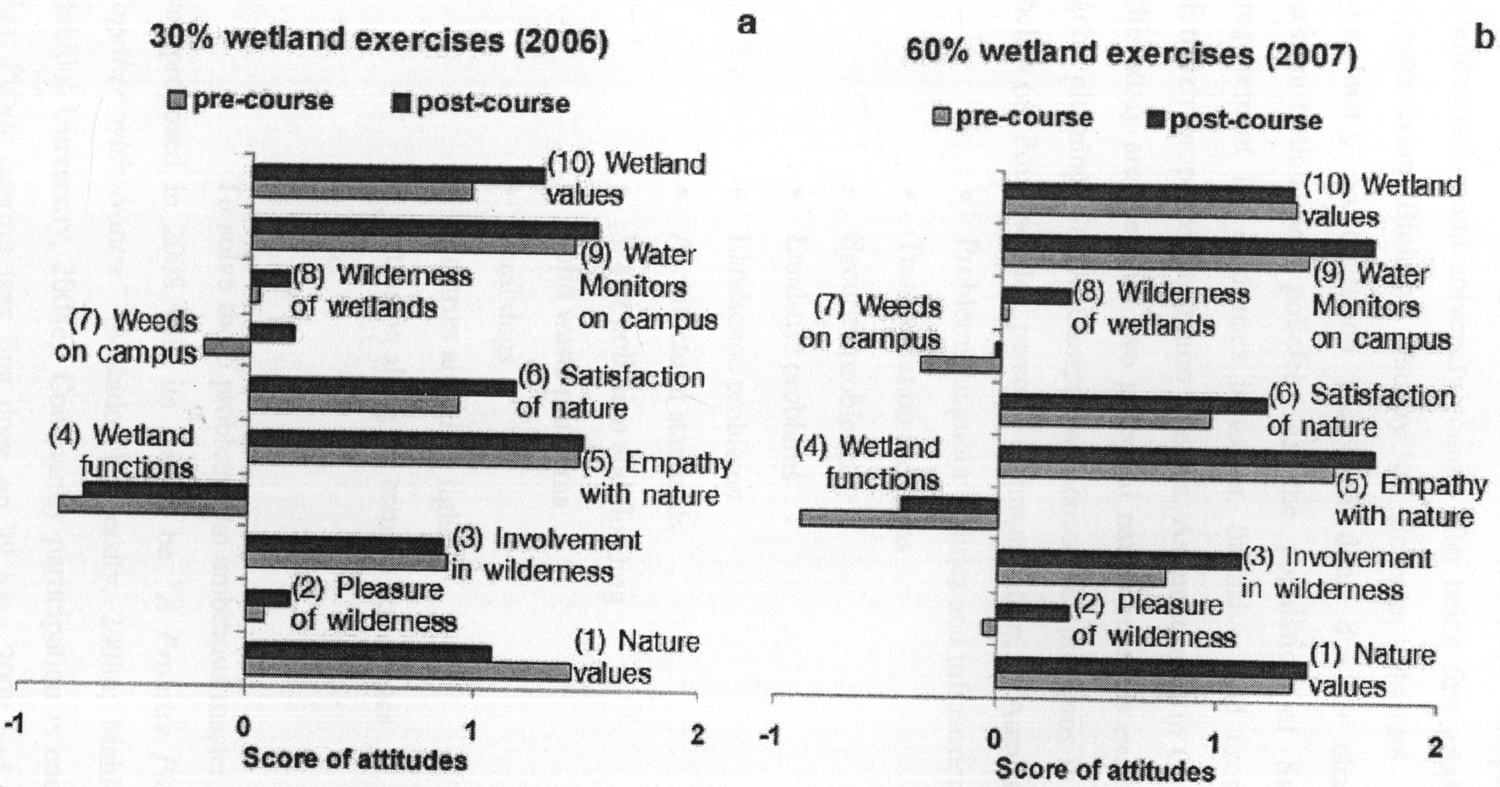


FIGURE 4.31 Average scores of students' attitudes towards the wetlands and university's ecosystems: a) when 30% wetland exercises were conducted in 2006 (pre-course, n = 50; post-course, n = 36); b) when 60% wetland exercises were conducted in 2007 (pre-course, n = 64; post-course, n = 48). Numbers in brackets referred to statements in the questionnaire. Negative scores mean negative attitudes while positive scores mean positive attitudes.

4.5. Wetlands as Part of Campus Ecology and Management

4.5.1. General review of Salaya Campus master plan 2008

Although nature reserves of Salaya Campus were approved by the administration and university council after being first proposed in 1993 (Center for Conservation Biology, Faculty of Science, Mahidol University, unpublished document), no operation has been done due to changes in the university administration and policies. As the population of Salaya Campus increase, requirement for land uses increases. Intensive land uses impact to many areas formerly proposed for nature reserves. As mentioned in Chapter III, the wetlands in this study are the only two proposed nature reserves existing on campus. Without good planning, Salaya Campus will encounter problems in campus development as below (A. Poungsomlee, personal communication, 26 August 2008):

- Problems on public utilities and infrastructure
- Transportation problems
- Security problems
- Land-use problems
- Landscape problems
- Architectural standards
- Water pollution and flooding
- Solid waste problems
- Feral dogs
- Electrics and night lights
- Intrusion along the campus boundaries
- Etc.

To solve these problems, an ambitious master plan of Salaya Campus was proposed in 2008 with its aim to be *"A Promise Place to Live and Learn Together with Nature"* (Mahidol University, 2008a; Mahidol University, 2008b; Mahidol University, 2008c). Community participation is encouraged in this master plan. Public hearing was first done on 29 May 2008 and the second event on 6 October 2008. Information is shared and opinions can be exchanged through the university website (http://intranet.mahidol/life%5Fon%5Fcampus/). The concept of campus development in this master plan is similar to an approach in integrative analysis of the city which focuses on a relationship between society and environment, also various societal and geographic scales and sectors involve in this relationship (Ross et al., 2000). Based on urgent landscape renovation policy, the Salaya Campus Development and Restoration of Physical Systems and Environment Project was established. Present operations are:

- *Welcome Plaza development project*: The university sign and front gate are being renovated. "*Community Forest*" will be planted as a linear park along the gate. 322 trees of *Dipterocarpus alatus* Roxb. ex G.Don will be planted together with 852 yellow-flowering trees and shrubs. The reason that *D. alatus* is selected may be because it is a tree which the royal family selected for ex-situ conservation (Jutamard, 2004). Mahidol University is probably willing to extend this royal initiative.

- *Main road landscape renovation project*: Half of the main roads will be divided for developing pedestrian and bicycles routes. 1,691 trees (Table 4.11) will be planted along roadsides. Based on *Clean & Clear* concept, lawns with tree plantation will be created in the inner areas of the campus. Moreover, a parking building will be constructed to reduce parking lot areas. Right now, tram routes are developed for transportation service on campus.

- *Feral dog-free zone campaign*: Under the responsibility of the Faculty of Veterinary Science, feral dogs present on campus are investigated and control plans based on animal welfare are developed.

Further projects supposed to be done including

- *Construction of auditorium and learning center project*
- *Security system development project*
- *Dormitory landscape renovation project*
- *Solid waste management project*

In addition, one of the policies in this master plan is preserving 70% green areas or open areas on Salaya Campus. The main campus nature reserve will be established in the south of the campus (Figure 4.32). It comprises of Medical Herb Garden (5.92 ha or 0.06 km^2) and extended areas including the freshwater marsh. Total area of this nature reserve will be equal to 21.6 ha (0.22 km^2), or about 10% of total campus areas.

4.5.2. Did the master plan reflect concern about the campus context (natural settings, site history, current infrastructure, and population and development pressures)?

There were obvious concerns on current infrastructure and population and development pressures. Increase in the university population and cars obviously impacted on competition for parking spaces. Despite tram service, construction of a parking building will provide more space for parking. Additionally, auditorium and learning center supposed to be constructed in near future can serve various academic and recreational activities for the campus. Surprisingly, this auditorium will be the first auditorium of the campus since its establishment in 1975.

Attempts to preserve all large existing trees and create "*Community Forest*" reflected concerns on the campus green areas which usually declined during campus development. In addition to terrestrial landscape, the master plan also involves in managing wetland landscape including ponds, canals, and the freshwater marsh. However, the wet meadow is the only wetland on campus that was not recognized by the plan.

4.5.3. Did the master plan provide for protection of native organisms?

The *Clean & Clear* concept with lawns and tree plantation habitats should be concerned as it may impact to most native wild species, leading to a reduction in the campus biodiversity (Brockelman et al., 1993). Most trees selected for the plantation are acceptable as they are native to Thailand. However, some are exotic species which are usually introduced as ornamental plants (Table 4.11). Although no evidence of invasiveness of these exotic species in Thailand, costs in maintenances such landscape were not addressed in the master plan. It was not clear that how much watering, pesticides, herbicides, and chemical fertilizers will be applied. Also, trees should be planted from seedlings or small saplings to allow extensive development of the root system. As a result, the trees can resist strong wind when grow up.

It is accepted that the recent campus development reduce bird biodiversity in the area. Many people including the vice president of Mahidol University also think about solving this obvious effect seriously. The campus used to be a bird watching place for many conservation groups. As the campus is a disturbed area anyway, consideration should be made to restore some native and high profile species like fireflies.

4.5.4. Did the master plan preserve natural habitats, i.e. wetlands?

Yes, preserving natural habitats, particularly the freshwater marsh in the south of the campus, was included in the university's policies. Landscape design (Figure 4.32) showed small ponds in the western part of the freshwater marsh, walk boards built across the wetland and towers for bird observation. However, impacts from human disturbances after this plan should be concerned. On the other hand, the wet meadow was not included in the recent nature reserve. Unfortunately, this area is proposed to be converted into the university's commercial zone.

4.5.5. Did the master plan involve reducing the use of resources?

Initiative in reducing driving spaces while developing pedestrian and bicycle routes was a good example of energy saving measures. Other measures in reducing the use of resources were not clearly addressed in the master plan.

4.5.6. Did the master plan view the landscaped campus as part of the local or original ecosystem?

In addition to tree plantation, improvement of canal system and its interconnection with ponds and the freshwater marsh was proposed by the master plan. This landscape imitates a unique characteristic of the Lower Central Plain which networks of canals occur in most river basins (Takaya and Thiramongkol, 1982).

4.5.7. Did the master plan recognize the function of the landscaped campus as a tool for teaching ecology and environment?

After this recent master plan, Salaya Campus was expected to be *"A Promise Place to Live and Learn Together with Nature"*. The area of 21.6 ha (0.22 km^2) including the botanical herb garden and the freshwater marsh was not only proposed for the campus nature reserve, but also a nature learning park. Bird watching towers and board walks will be built to allow more access on the campus nature.

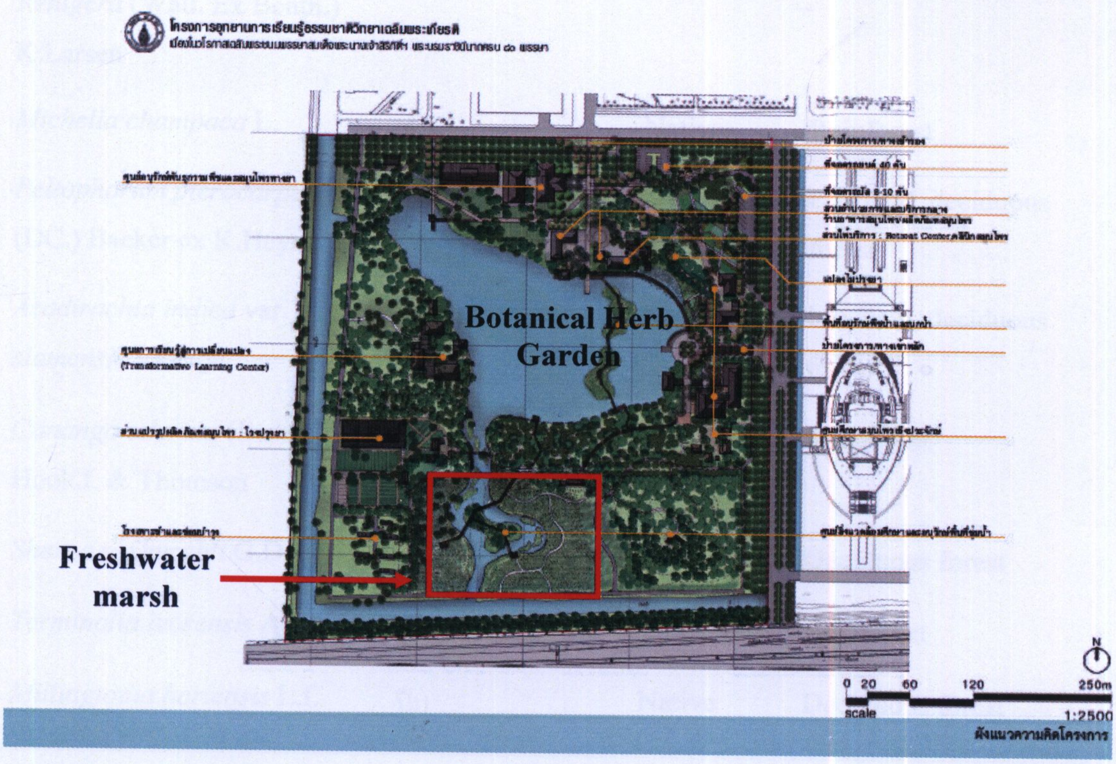


FIGURE 4.32 Nature reserve of Salaya Campus proposed by the master plan 2008

TABLE 4.11 List of trees going to be planted in Salaya Campus after the ambitious master plan 2008

Scientific name	Thai name	Native/Exotic to Thailand	Natural habitat
Dipterocarpus alatus Roxb. ex G.Don	ยางนา	Native	Lowland, deciduous forest
Pterocarpus macrocarpus Kurz	ประดู่บ้าน	Native	Deciduous forest
Cochlospermum regium (Mart. & Schrank) Pilg.	ฝ้ายคำ	Exotic	Savanna
Cassia javanica subsp. *Renigera* (Wall. Ex Benth.) K.Larsen	ชัยพฤกษ์	Exotic	Deciduous forest
Michelia champaca L.	จำปา	Native	Rainforest
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	นนทรี	Native	Lowland, deciduous forest
Azadirachta indica var. *siamensis* Valeton	สะเดา	Native	Lowland, deciduous forest
Cananga odorata (Lam.) Hook.f. & Thomson	กระดังงาไทย	Exotic	Rainforest
Shorea roxburghii G.Don	พะยอม	Native	Deciduous forest
Terminalia ivorensis A.Chev.	หูกระจง	Exotic	Rainforest
Millingtonia hortensis L.f.	ปีบ	Native	Deciduous forest

CHAPTER V
DISCUSSION

5.1. Wetland Ecosystem of Salaya Campus

5.1.1. Wetland types and their plant diversity

Although the fragmented wetlands of Salaya Campus comprise only 4% of the campus area, they represent an ecosystem of the Lower Central Plain where high plant diversity remains. The diversity of plants in wetlands is related to water level and flooding duration (Mitsch and Gosselink, 2000). Differences in hydrology and plant communities caused the two campus wetlands to be classified as a wet meadow and a freshwater marsh based on Keddy (2004). The wet meadow in the north of the campus is generally dryer than the freshwater marsh in the south of the campus. As hydrological disturbances of most existing wetlands of the Lower Central Plain result in permanent water level, freshwater marshes are commons than wet meadows.

Since the campus' wet meadow was seasonally flooded, it was mainly covered by sedges and grasses. *Imperata cylindrica* (L.) P.Beauv. is a grass species that dominated the shallow zone while *Phragmites vallatoria* (Pluk. ex L.) Veldkamp is a grass species that dominated the deeper zone of the wet meadow. Furthermore, *Panicum repens* L., *Eleocharis dulcis* (Burm.f.) Hensch. and *Cyperus digitatus* Roxb. were the most abundant species in the mixed sedges and grasses zone. This wet meadow was also characterized by a wide distribution of *Pluchea indica* (L.) Less. This native shrub is obligate to either salt or freshwater marsh (Muchjajib, 1995). Its composite flowers attract many pollinators, particularly butterflies. It was traditionally used as a medicinal plant (Mukhopadhyay et al., 1983; Traithip, 2005, Muchjajib, 1995), and was also studied as a plant for phytoremediation of Cr contaminated soil (Sampanpanish et al., 2006).

The transition zone of the wet meadow was mostly covered by trees. *Leucaena leucocephala* (Lam.) de Wit, *Acacia auriculaeformis* A.Cunn. ex Benth., and *Tabebuia rosea* (Bertol.) DC. were the top three abundant tree species. They are all exotic species which were planted on the campus at the beginning of campus establishment (Brockelman et al., 1993). Among these, *L. leucocephala* (Lam.) de Wit was listed in 100 of the World's Worst Invasive Alien Species (Lowe et al., 2000). Though it helps soil restoration and has been grown in agroforestry (Brewbaker, 1987), seedlings of other species established under these dense trees were reduced (Jurado et al., 1998). Additionally, some intermediate areas between the transition zone and the core wet meadow were dominated by *Brachiaria mutica* (Forssk.) Stapf, or paragrass. This is a semi-aquatic, stoloniferous perennial grass of African origin (Suwankul and Suwanketnikom, 2001) which is widely distributed in various water depths (0-50 cm in this study). The grass is a potential invasive species that can exclude native species in many parts of the world (Finlayson et al, 1997; Langeland and Burks, 1998; Williams and Baruch, 2000). As in this study, plant diversity was very low in paragrass-dominated areas.

In contrast, the freshwater marsh of Salaya Campus was permanently flooded, and dominated by cattail, *Typha angustifolia* L., a common obligate wetland species of Thailand. Although *Typha* sp. is widely used for water treatment (Koottatep et al, 2001; Coon, 2000; Chaipattana Foundation, 2001), it should be concerned that increase in dominance of cattail due to an increase in water level of a wetland can cause plant diversity to be reduced (Keddy, 2004). Since cattail can exist in high and persistent water where oxygen exchange between soil and atmosphere is limited (Mitsch and Gosselink, 2000), it will exclude other less competitive species. Besides being grown as an ornamental plant, fresh leaves and flowers of cattails are generally exploited for bouquets and backdrop decorations. Additionally, dried leaves are used for handicrafts such as bags, baskets, and mats in some villages.

In spite of cattails, some parts of the deep zone of the campus' freshwater marsh were also covered by *P. vallatoria* (Pluk. ex L.) Veldkamp. In addition, remnants of *Acrostichum aureum* L. were found among the zones dominated by *T. angustifolia* L. and *P. vallatoria* (Pluk. ex L.) Veldkamp. This large aquatic fern generally has a wide ranging distribution from salt marshes near coastal areas to freshwater marshes of inner lands (Muchjajib, 1995). Though the fern has less abundance in the campus' marsh, its combination with *T. angustifolia* L. and *P. vallatoria* (Pluk. ex L.) Veldkamp was a characteristic of marshes in the Lower Central Plain. Since *A. aureum* L. has a distinct form and beautiful fronds, it is commonly used as an ornamental plant.

Higher plant diversity was found in the shallow zone (approximately less than 15 cm) of the campus' marsh. Plant communities dominated by *Imperata cylindrica* (L.) P.Beauv. were gradually succeeded by cattails, water fern *Ceratopteris thalictroides* (L.) Brongn., and sedges and grasses, e.g. *Fimbristylis miliacea* (L.) Vahl, *Eleocharis dulcis* (Burm.f.) Hensch., and *P. vallatoria* (Pluk. ex L.) Veldkamp. Like that of the wet meadow, the transition zone of the freshwater marsh was dominated by trees. However, it seemed to maintain some of the original characteristics of the area before the establishment of Salaya Campus (Takaya and Thiramongkol, 1982) since it is composed of *Combretum quadrangulare* Kurz and bamboos, and was surrounded by small ponds and canals (Figure 5.1). Besides *Lemna perpusilla* Torr. and *Pistia stratiotes* L., *Wolffia globosa* (Roxb.) Hartog & Plas which is the smallest flowering plant on earth was also a floating species found on the campus' marsh, particularly on a small canal between the transition zone and the marsh. Because of its extremely tiny size, this species abundance was underestimated as it mixed with *L. perpusilla* Torr. In addition, some parts of the northern edge of the marsh were covered by clusters of *Azolla pinnata* R. Br. As no line transect cut across the marsh's edge, therefore this aquatic fern was not included in the list of wetland plants in this study.

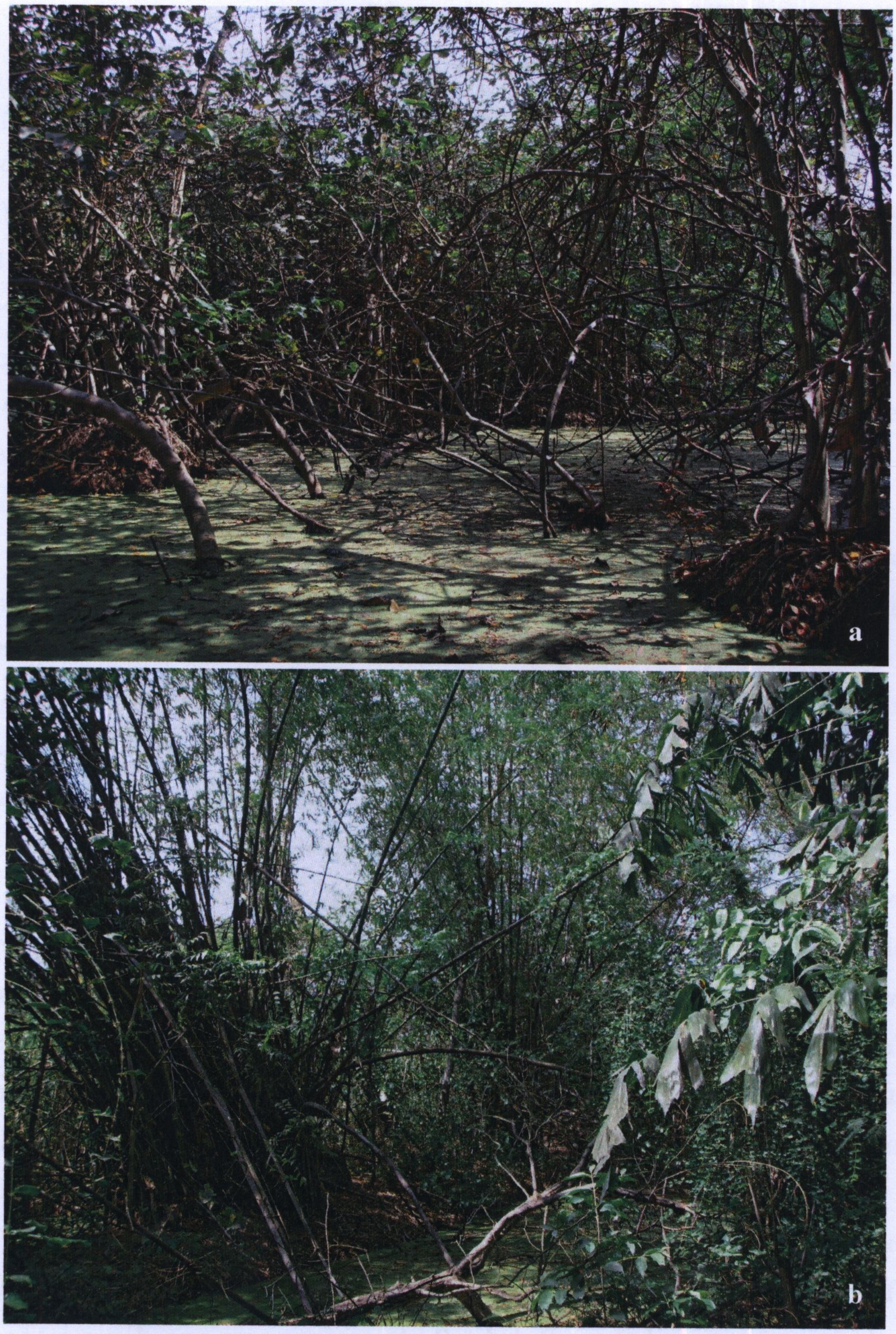


FIGURE 5.1 Some of original characteristics of the Lower Central Plain before establishing Salaya Campus remained in tree zone of the freshwater marsh (a, *Combretum quadrangulare* Kurz; b, bamboos)

5.1.2. Impacts of hydrology on wetland plant communities

Water level and duration of flooding influenced distribution and composition of plants on the wetlands of Salaya Campus. High levels of water decrease the rate of oxygen diffusion into wetland soils. Since plant roots' respiration is affected, plants become stressed as anoxic conditions occur (Cronk and Fennessy, 2001). As a result, species that can not adapt to flooding such as most shrubs and trees are excluded at deeper water level. Besides water depth, duration of flooding plays an important role in segregating plant communities (Casanova and Brock, 2000; Mitsch and Gosselink, 2000; Cronk and Fennessy, 2001). Like Keddy (2004), the different types of Salaya Campus wetlands together with variation of plant zones (Figure 4.9) demonstrated consequences of responses to hydrology.

The wet meadow which has lower water levels and occasional flooding maintained more plant zones than the freshwater marsh. The zone which covered the most area of the wet meadow was that of sedges and grasses. It can be subdivided into the *Imperata*-dominated, mixed sedges & grasses, and the *B. mutica* zone which depended on tolerances to flooding, although their distribution occurred in similar ranges of depth. These zones were habitats that succeeded tree- and shrub-dominated zones and were where water level increases and duration of flooding is longer. The dry period during March to June, however, may allow woody plant seeds to germinate. But, they will be killed by occasional flooding while wet meadow plants regenerate from buried seeds (Keddy, 2004). Among these grass zones, the *B. mutica* zone showed high potential of invasion of this exotic grass in deep water. Like the freshwater marsh, areas of the wet meadow having highest water level is usually dominated by *Phragmites* and *Typha*. Nevertheless, water level in most of these zones dried up during dry season allowing other flood-intolerant species to germinate.

Unlike the wet meadow, the freshwater marsh is produced by longer duration of flooding than the wet meadow. As on Salaya Campus, the majority of the freshwater marsh area was permanently flooded. So, marsh species commonly are tolerant to flooding, especially *Typha*. However, nearly dry periods are still required for freshwater marsh in order to allow seed regeneration (Keddy, 2004). Such a process helps maintain species diversity like that which occurred in the dry season int the shallower zone of the freshwater marsh dominated by *Imperata* as mentioned above. Otherwise, anoxic conditions from permanent flooding will allow highly competitive species like *Typha* to dominate. As an illustration of how *Typha* distribution may be limited, a case occurred in the wet meadow of the campus. Since a distinct dry period of 4 months occurred on the wet meadow, it was longer enough to kill some cattails. So, the plants did not regenerate unless the wet meadow was re-flooded. Consequently, the distribution of cattails on the wet meadow was limited.

Quantitative measurement of zonation extends more understanding on plant community structure of Salaya Campus wetlands. Besides a difference in the number of plant zones between the wet meadow and the freshwater marsh, their patterns of community structure were also different. Along gradients of water depth, the zonation of the wet meadow occurred with clustered species boundaries, aggregated species mode distribution, and hierarchical structure. This structure was similar to the hierarchical community-unit addressed by Hoagland and Collins (1997) (Figure 2.3b). In contrast, the zonation of the freshwater marsh was similar to a hierarchical continuum in which boundaries and modes of species response curves are not clustered, but a hierarchical structure was present as shown in Figure 2.3d (Hoagland and Collins, 1997).

In the case of the wet meadow, one group of species response curves occurred along a gradient of water depth (Figure 4.10), although 7 visually dominant plant zones (Figure 4.9) were observed. Clustered boundaries of species response curves may relate to hydrology in the wet meadow which has low water levels (average 6 cm) of flooding alternating with a dry period in most of this wetland area, and a slightly inclined slope. Such conditions allow most plant species to be similarly distributed along the depth gradient. As water occasionally dries up, most plants frequently occurred at the lowest ranges of water depth. *Cayratia trifolia* (L.) Domin is a dominant species that causes hierarchical structure in this wetland. Although this species did not appear as a visually dominant zone, facultative characteristics allow it to occur in either upland or wetland, and its climbing habit allows the species to be distributed in deeper areas.

On the other hand, zonation pattern of the coenocline in the freshwater marsh are supported by the species response curves. A sharper slope and a high, persistent water level (Figure 4.9) which limits oxygen in wetland soils and is critical for root respiration influence plant species of this wetland to shift their niches in order to minimize interspecific competition (Smith and Smith, 2006). As a result, species boundaries and modes in the community structure model of the campus wetlands were not aggregated (Figure 4.10). As in the wet meadow, a hierarchical structure was found in the freshwater marsh though it cannot be seen in the coenocline. *Lemna perpusilla* Torr. or duckweed is the dominant species in this marsh. Because it is a floating species, it is not surprising that the duckweed can distribute to where water is present. However, its abundance is limited by shading particularly in the *Phragmites* and the *Typha*-dominated zones. So, abundance of the duckweed decreased in the deeper area.

5.1.3. Habitat selection of aquatic macroinvertebrates

Study of wetland plant communities, sediment analysis, and measurement of water quality indicated attributes of Salaya Campus wetlands that were suitable for as habitats of various aquatic macroinvertebrates. Large amount of decaying plant materials in sediments, tea-like brown color and rotten plant smell of water were natural characteristics of water in wetlands that are composed of dense vegetation. Therefore, most aquatic macroinvertebrates found in the wetlands were associated with wetland plants, particularly snails. However, differences in plant communities influenced to groups of aquatic macroinvertebrates. From the results, most of shredders who chewing either on living plants or decayed plant materials were found in the wet meadow dominated by sedges and grasses. In contrast, large amounts of scrapers, or those who are grazers, were found in the freshwater marsh dominated by cattails. Besides plant-associated aquatic macroinvertebrates, components of clay in the sediments supported high proportions of collector-gatherers among feeding guilds and burrowers among habit guilds which mostly referred to Chironomidae larva, Oligochaeta, and Polychaeta. Moreover, the aquatic macroinvertebrates found in the campus wetlands are those that can adapt to water in lentic ecosystems. Unlike streams and rivers, Chironomids and snails are common in wetlands of Salaya Campus. Such a finding was similar to that of Weller (1994).

Different periods of the year also had impact on the diversity of aquatic macroinvertebrates. Fluctuation in aquatic macroinvertebrates was most obvious seen in the wet meadow where drying up of water during the dry season cause the aquatic macroinvertebrates to disappear. Although persisting water level in the freshwater marsh during the dry season allowed many aquatic macroinvertebrate taxa to occur, their abundances were reduced. So, the best period for studying aquatic macroinvertebrates is during November to January when the diversity of aquatic macroinvertebrates reaches a peak.

5.1.4. Taxonomic problems of aquatic macroinvertebrates of Thailand's palustrine wetlands

Since there is no local guide to identify aquatic macroinvertebrates of freshwater palustrine wetlands, various guides were used to help identify the aquatic macroinvertebrates of Salaya Campus wetlands. They included an illustrated guide from North America (McCafferty, 1998), an insect guide from Australia (CSIRO, 1991), a pictorial guide from Singapore (Ng, 2000), a guide for the Mekong River and its tributaries (MRC, 2006), a pictorial guide for streams and ponds in Thailand (Kanjanavanit and Tilling, 2000), a guide to freshwater snails of Thailand (Chitramvong, 1992), and a guide to water bugs of Thong Pha Phum District in western Thailand (Lekprayoon, 2006). The results showed about 97% of total macroinvertebrates could be identified at least to family level. Family-level identification not only requires less time in lab analyses but it also requires less training and experience to accomplish. For distinguishing impaired biological conditions of wetland environments, the family-level identification is just as effective as genus/species-level identification (NCTC, 2006). Appendix E showed some aquatic macroinvertebrate taxa that encountered taxonomic problems in this study (J.R. Milne, personal communication, March 20, 2008)

5.1.5. Standardized simple techniques for studying aquatic macroinvertebrate communities

The large numbers of aquatic macroinvertebrates and some wetland-associated animals found in this study demonstrated the efficiency of using simple field techniques for studying aquatic macroinvertebrate communities. Such techniques are based on low cost equipment and practicality in fieldwork. Because access to the wetlands of Salaya Campus is difficult due to dense vegetation as mentioned above, equipment for aquatic macroinvertebrate sampling and water quality measurement have to be portable. Their compact size is also required as many types of equipment have to be handled for various parameter measurements. Moreover, quick and easy application is needed as a lot of samples have to be taken.

Instead of dip net or grab samplers, a 8"x11" pond net commonly found in any fishing shop can be used for sampling aquatic macroinvertebrates. Sample collection should be standardized. In this study, one scoop sample within ten-seconds was determined to be suitable because a pilot study indicated that a longer time of scooping resulted in a large animal sorting load from too much sample mass. Such an exact sampling time also helped obtained similar-sized samples.

For measurement of water turbidity in the campus wetlands, a limitation in using the secchi disk is visual obstruction due to dense emerging vegetation and floating plants. To solve this problem, a turbidity plate (Figure 3.2b, c) applied in the Stream Detectives Project (Kanjanavanit and Moonchinda, 2002) was used. Besides being easier portable, such a turbidity plate is easier to use and is more available than the secchi disk.

Because most portable devices in water quality measurement are expensive, MU test kits developed by the Technology Innovation Unit and the Department of Chemistry, Faculty of Science, Mahidol University were selected (Figure 3.2d). Such kits are inexpensive compared to digital or electronic devices. Their application based on quick and easy chemical reactions that can test a lot of samples in the field. Since many chemicals are used in the kits, careful keeping is necessary to maintain their properties. Otherwise, errors like that which occurred in phosphate testing in this study may occur. Compared to laboratory testing which has 1-10% errors, application of the kits may have higher errors of about 10-50%. It was recommended that the kits are appropriate for environmental screening, not for serious tests in which exact measurement is needed (SCMU Technology Innovation Unit and the Department of Chemistry, 2006).

5.2. Functions and Values of Wetlands of Salaya Campus

5.2.1. Effects of multiple indices

Because single biological index only reflects equilibrium between a community and some aspects of the environment, using different categories of index measurement systems, or metrics, can give more information about community including physical, chemical, and biological aspects of environment. With multiple indices, better indication of biological integrity such as water quality, habitat structure, energy source, and biotic interaction is supposed to be characterized. Furthermore, they are sensitive to wider range of types of pollution and environmental stresses (NCTC, 2006). For example in this study, the Shannon diversity index showed similarity in species abundance and evenness between the northern and the southern campus wetlands. But, it does not mean that functions of both wetlands were similar. Results from FQAI, exotic species, sensitive species, tolerant taxa, aquatic guild, monocarpic species, and litter persistent taxa indices reflected the differences. Although aquatic macroinvertebrate indices are more commonly used for evaluation of pollution and environmental stresses than vegetation indices, in the dry season when the aquatic macroinvertebrates are absent, the vegetation indices can substitute. So, multiple indices composed of various categories of index measurement systems are more effective to evaluate wetland health and functions than the single biological index.

5.2.2. Influence of human disturbance on wetlands of Salaya Campus

The freshwater marsh of Salaya Campus was more disturbed by man than the wet meadow since it is located on the roadside. Despite a garbage dumping site nearby, some garbage was thrown away directly on the edge of the wetland. At present, the land near the freshwater marsh is filled and being developed. Being a smaller area (0.02 km^2) than the freshwater marsh, the wet meadow (0.06 km^2) is also vulnerable to decreased species and habitat diversity (Smith and Smith, 2006).

The vegetation's functional index measurement system showed impacts of exotic plants, highly competitive species, hydrologic disturbance, and persistent litter which were different between the freshwater marsh and the wet meadow because their hydrology were different. Invasion of the exotic, facultative wetland plant species, *Brachiaria mutica* (Forssk.) Stapf, (Finlayson et al, 1997; Langeland and Burks, 1998; Williams and Baruch, 2000) had a major impact on the wet meadow which is seasonally flooded. At the edge of the wetland where this grass dominated, plant diversity was very low. In contrast, the invasion of exotic plants in the freshwater marsh was not as obvious as the former site.

Hydrologic disturbance (high and persistent water level) in the freshwater marsh caused rapid spread of the cattail, *Typha angustifolia* L., which is a highly competitive species (Keddy, 2004). Boers and Zedler (2006) explained that when flooding is prolonged, wetland soil releases phosphorous which is uptake by cattails causing acceleration in cattail monoculture. Although nutrient uptake by wetland plants such as *Typha* sp. is widely used for water treatment (Koottatep et al, 2001, Coon, 2000), monoculture with cattails will cause open water to be eliminated, and habitat diversity and plant species richness will decrease (Apfelbaum, 2006). Moreover, massive high population of cattails in the freshwater marsh produced persistent litter (Figure 4.24, 4.25). This may affect carbon cycling (Gernes and Helgen, 2002) since the freshwater marsh may not have the same quantity of available nutrients or detrital energy as readily decomposable litter (Cronk and Fennessy, 2001).

In addition, consistency in the Lymnaeidae index for aquatic macroinvertebrates and the aquatic guild index for the plant community was detected for the wetlands of Salaya Campus. As a high and persistent water level in the freshwater marsh allowed many aquatic plant species to occur, availability of food in this wetland was suitable for survival of the Lymnaeidae. Moreover, occasional drought in the wet meadow which is a stress for many snails (Gérard et al., 2008) influenced the Lymnaeidae to be absent.

Although non-significant differences were detected, a higher proportion of dominant species and a lower diversity index of aquatic macroinvertebrates in the freshwater marsh than in the wet meadow was also impacted by high and persistent water level. Since, the possibility of mild nutrient enrichment was indicated by the SWAMPS index, such a condition may be related to a large number of scrapers in the Family Planorbidae (Figure 4.15b). Because prolonged nutrient enrichment of the freshwater marsh supports algae growth (Hann et al., 2001), foods for the scrapers are abundant. However, further study is required for confirming relationships among scrapers, nutrient, and algae.

Unlike impacts from exotic plants, the wetlands of Salaya Campus had a very small proportion of tiny golden apple snails (*Pomacea* sp.). This finding contrasts with the invasion of the golden apple snail in ponds and canals of the campus, as well as rice fields, and other wetlands in which high densities of the snails resulted in plant biomass reduction (Lach et al., 2000; Carlsson et al., 2004; Carlsson and Lacorsière, 2005). However, those studies of herbivory by the golden apple snails were experimented in field enclosures containing one particular plant species. Mostly, the selected plants were the dominant species in natural wetland such as *Eichhornia crassipes* (C.Mart.) Solms. It seems to be disturbed wetlands that are invaded by the golden apple snails. But, abundances of the snails in low disturbed, emergent wetlands like those of Salaya Campus have hardly been studied. Low numbers of golden apple snails found in the campus wetlands may be related to the number of aquatic macroinvertebrate predators and the diversity of plants. Further studies are needed to explain this condition.

5.2.3. Application of multiple indices for bioassessment of wetlands in the Lower Central Plain

At a larger scale, the development of multiple indices for evaluating health and functions of wetlands of the Lower Central Plain requires a standard protocol for implementing such vegetation and aquatic macroinvertebrate indices developed from this study. The protocol would need to be applicable to the various wetlands of the Lower Central Plain having a different human disturbance gradient (from no human disturbance as reference sites to highly degraded wetlands). For these wetlands, a scatter plot of each index value against human disturbance gradients will be used as criteria for determining an index score. Then, the sum of the total index scores will be plotted against human disturbance gradients as criteria for classifying wetlands as being in excellent condition, moderate condition, and poor or impaired condition (Gernes and Helgen, 2002). In addition, such a protocol and a procedure for developing multiple indices for wetland bioassessment can be adapted for either ecological exercises for biology students of Mahidol University or a simple manual for wetland biomonitoring like that of the Stream Detective Project (Kanjanavanit and Moonchinda, 2002). This could be a strategy for building up ecological literacy and awareness on wetland ecosystems, particularly in the Lower Central Plain.

5.3. Wetlands of Salaya Campus as an outdoor ecology classroom

5.3.1. Lessons learned from wetland-based ecological exercises

By challenging students participating in wetland exercises, risk minimization and building up student's self-confidence have to be considered. Panich (2004) emphasized that risk is common in any challenging activity, encountering the risk is the only way to produce self-confidence. However, this must be based on safe exercises. Hot weather, tiredness, dirtiness, and dangerous animals are examples of risk that students participating in wetland exercises may encounter. By persuading students to start the exercises in early morning, allowing them to have water and snacks in their backpack, offering them boots or waders, and reminding them to dress properly for fieldwork, students' enthusiasm in learning will increase.

Barriers to learning about wetlands should be clarified in order to gain effective wetland exercises. Ecological misconceptions of the university's wetlands e.g. to bulldoze all weeds on campus and occurrence of mosquito breeding sites in wetlands was a major learning barrier. Such perceptions may be transferred into negative action because they are stable elements of an individual's conceptual framework and highly resistant to change (Munson, 1994). Ajzen (1985) suggested that a person's behavioral and normative beliefs are subjected to change as events unfold and new information becomes available. The exercises engaged students in the study of wild habitats and ecosystems on campus including natural wetlands developed students' constructive integration of knowledge. Such learning influenced their thought reconstructions about weeds and wetlands (Ballantyne and Packer, 1996).

In addition, constructive integration of knowledge can effectively be developed by the ecological exercise focusing on the empowerment process. Students constructed their knowledge of wetlands and ecological world views through enquiry and direct experience in the field. Even though conducting exercises for constructive integration of knowledge requires a lot of time, manpower, and requires willingness to change, it is important in building up students' self-esteem. Hungerford and Volk (1990) identified empowerment as one of the three variables influencing environmental citizenship behaviour because it can give human beings a sense that they can make changes and helps resolve important environmental issues. For undergraduate biology students, the empowerment ecological exercise also helps develop knowledge and skills in fieldwork, preparing them according to their professional life (MacFarlane *et al*, 2006).

Other exercises that involve wetland functions and mosquitoes' breeding sites are required to clarify the importance of the campus wetlands. Despite the fact that mosquitoes can breed without wetlands, even in artificial containers (Sheppard et al., 1969; Strickman and Kittiyapong, 2003), Weller (1994) clarified two reasons why people believed a marsh is a breeding site of mosquitoes. They are 1) that most people experience only the edge of marsh where shallow water is preferred by mosquitoes for breeding, and 2) the misidentification of midges as mosquitoes. In the wetlands of Salaya Campus, only 1% of invertebrates found in the freshwater marsh were mosquitoes whereas 2% were found in the wet meadow were mosquitoes.

Environmental awareness among undergraduate biology students may not be fully nurtured unless the ecological exercises integrated approaches for building up environmental attitudes and values (Iozzi, 1989). It is necessary that balance between the environmental knowledge-education approach, and the attitudes/values-education approach should be met (Ballantyne and Packer, 1996). This is a reason why students' attitudes toward wetlands and the university's ecosystems in the first year of this study were not improved. Additionally, the exercises in the second year emphasized an experiential learning cycle which is a feedback process involving concrete experience, observation, and reflections, formation of abstract concepts and generalization, and testing implications of concepts in new situations (Beard and Wilson, 2006). Consequently, students' attitudes toward wetlands and the university's ecosystems were significantly improved.

5.3.2. Educational values of the wetlands of Salaya Campus

Compared to long-distance field trips (Table 5.1), ecological exercises based on Salaya Campus ecosystems required lower investment in organization, and allowed students to stay close to nature for a longer time. Moreover, the students could intensively learn both general concepts in ecology and their local ecosystems which bear more connection to their future livelihoods (Sobel, 2005; Orr, 2005). Because Salaya Campus comprises mainly a man-made, built semi-urbanized landscape with some remnants of natural wetlands, it is a mesocosm of the Lower Central Plain of Thailand where most natural wetlands are gradually being degraded by urbanization. Using various ecosystems on campus as outdoor ecological classroom provided students with knowledge and skills on man-made and urban ecology which is an essential issue in an overcrowded world (Hale, 1993; Capra, 2005; Gilbert, 1989; McMichael, 2000). At the same time, values of the campus wetlands have been developed among the students through additional wetland exercises which emphasized the attitudes/values education approach (Table 5.1). Ecological knowledge and skills together with direct experience gained from these exercises significantly motivate students in caring and concern for nature, particularly the wetlands and natural ecosystems on campus (Chawla, 1998). So, the wetland exercises in this study are a tool to build up awareness of the university's wetlands since the exercises focus on both ecology and place.

Cameron (2008) suggested that narratives of places influence human responsiveness, and that places and memories will be increasingly important to people as age increases. Narratives of the university's wetlands and their educational values presented to the university community may inspire people's responsiveness to the wetlands. With a psychological conservation perspective that "*humans need natural spaces to relieve the modern-day stresses of crowded and fast-paced living. Breathing clean air, viewing green plants, and caring for and observing animals can improve mental health and relieve some forms of stress and depression.*" (Knapp, 2003, p. 24). The university's wetlands can also be used for aesthetic values. So, environmental awareness on wetlands is expected to be built up among a wide range of the university community.

TABLE 5.1 Comparison of educational approaches used in ecological exercises for undergraduate biology students of Mahidol University during 1995-2007

	Field trips (before 1995)	Campus-based, knowledge education (1995-2005)	Campus-based, knowledge, and attitudes/values education	
			30% additional wetland exercises (2006)	60% additional wetland exercises (2007)
• Investment in organization	High	Low	Low	Low
• Time close to nature	Short	Long	Long	Long
• Ecological literacy	General	Intensive	Intensive	Intensive
• Connection to students' livelihoods	Low	High	High	High
• Student empowerment	By default	By default	By design	By design
• Awareness of local ecosystems	By default	By default	By design	By design

5.4. Wetlands as A Part of Campus Ecology and Management

5.4.1. Management and restoration of Salaya Campus wetlands

Compared with a Ramsar site and the largest freshwater marsh of Thailand, Sam Roi Yot wetland, Salaya Campus wetlands are not much different in vegetation structure. However, the location of Sam Roi Yot wetland next to coastal wetland provides habitats for a higher diversity of birds (Chareonsiri and Parr, 1994; BCST, 2004). Besides plants and aquatic macroinvertebrates, birds and other wetland-associated animals found during this study indicated that wetlands of Salaya Campus still maintain some degree of original state or wilderness. However, some functions of the campus wetlands may be diminished because of the invasion of exotic plants, hydrologic disturbance that causes cattail monoculture, and mild nutrient enrichment. Though these factors do not as obviously impact the campus wetlands as impairment, exotic species removal, proper hydrology management, and some wetland restoration are needed to sustain biodiversity of the wetland communities.

Physical removal by cutting cattails below the water surface during the dry season, or water level modification by one to three year of deep flooding (1.2 m or deeper for *T. angustifolia* L.) have been recommended to control the distribution of cattails (Apfelbaum, 2006). However, impacts to the natural community should be of concern in any control effort. Effectiveness of the control techniques also depend on the species of cattails, hydrology, topography, climate, and other biological and physical environments. Experimental studies are a challenge for effective control of cattail distribution in Salaya Campus wetlands.

Despite high financial and time investment, similarity in functions and biodiversity between created/restored and natural wetlands has not been demonstrated (Campbell et al, 2002; Zedler and Callaway, 1999). Based on maximizing human benefits and minimizing inputs of time and energy, Casagrande (1997) suggested that restoring wetlands can be a success by restoring ecological processes. So, knowledge of wetland ecology is critically important for effective wetland restoration (Callaway, 2004; Zedler, 2000). A restored wetland needs to maintain some heterogeniety and specific habitat characteristics such as hydrological fluctuation and existing plant covers that allow natural recolonization, proliferation of wildlife, and wetland biodiversity (Balcombe et al., 2005; Brown, 1999; Kirkman and Sharitz, 1994).

Hansson and his colleagues (2005) demonstrated that wetlands with shallow depth, large surface area, and diversity of plant zones have high biodiversity compared with small, deep wetlands which may function in nutrient retention, but have less biodiversity. Most of all, community participation in planning, implementation, and evaluation of the restoration of wetlands on campus are required. Consequently, both social and biophysical benefits from the wetlands are provided (Casagrande, 1997).

5.4.2. Firefly reintroduction for education and ecotourism

In addition to plantation of a high profile species like *Dipterocarpus alatus*, Salaya Campus can be promoted as a site for watching fireflies *Luciola aquatilis* sp. nov. Thancharoen (Coleoptera: Lampyridae), another high profile insect (Thancharoen, 2007). Research on reintroduction of fireflies to the freshwater marsh should be considered as part of restoration and management of Salaya Campus wetlands. Results from aquatic macroinvertebrate communities indicated the existence of *L. aquatilis* in the freshwater marsh, only 15 individuals or about 0.03% of total aqutic macroinvertebrates were found. *L. aquatilis* is a common firefly found in many wetlands of Thailand such as ditches, ponds, swamps, and rice fields. The specific characteristic of producing light causes the fireflies to be a species of interest. *L. aquatilis* were once abundant in Salaya Campus but their population might have declined due to habitat destruction and light pollution from campus development (Thancharoen, 2007; Thancharoen et al., 2007). Ecological study of *L. aquatilis* in the freshwater marsh of Salaya Campus and field experiments in reintroduction are required to conserve this firefly species on campus. This initiative is not only support ecological and educational functions of the campus nature reserve, but it may also bring the Salaya Campus as a first place in Thailand where firefly reintroduction is successful. Therefore, the campus will also benefit from students' recreation which can be extended to ecotourism activities for both student communities and community at large.

5.4.3. Management of Salaya Campus landscape

In general, the ambitious master plan for Salaya Campus showed plans for developing physical structure. However, some operations for developing biological structure of the campus landscape have to be concerned. As the recent master plan aims to create the campus as *"A Promise Place to Live and Learn Together with Nature"*. In this case, "*Nature*" should be defined for both terrestrial and wetland landscape. For terrestrial landscape, quality of the green areas on campus has to be promoted. An alternative way is to redefine the "*Campus beauty*" (Simpson, n.d.). In fact, it is not expensive to preserve native biodiversity (though some are perceived as weeds), by introducing native species for landscaping, and to conduct integrated pest management (Keniry, 1995). Therefore this will not only reduce conflicts between the display of campus's appearances and ecological, educational, and social values of natural areas, but also costs in maintenances of the landscape (Hocking, 2000; Harris et al., 2001).

The "*Nature*" defined for wetland landscape in the recent master plan already included canals, ponds, and the freshwater marsh. In details, it should refer to some wilderness of ponds and canals such as *Combretum quadrangulare* Kurz, bamboos, and some wild plants on their edges (Takaya and Thiramongkol, 1982). In case of the freshwater marsh, observation towers and walk boards proposed in the master plan will benefits university people in easily access to nature. However, these facilities should be located outside the core wetland to ensure that human activities do not impact to the wetland ecosystem.

Besides the freshwater marsh, the wet meadow should be defined as another "*Nature*" of the wetland landscape. Although location of this wetland was proposed for developing the university's commercial area, its diverse plants and aquatic macroinvertebrate communities found in this study (Figure 4.8 and Table 4.2) indicated potential of this area as another nature reserve. At present, the wet meadow is a rare habitat of the Lower Central Plain. Preserving this type of wetland will provide the Salaya Campus with extensive wetland biodiversity. To minimize conflict in land-use plan, however, at least area on the west of the wet meadow (Figure 4.8) including mixed sedges & grasses, *Pluchea*, *Phragmites*, and *Typha*-dominated zones is recommended for the nature reserve (Figure 5.2). Also, this wetland can be another place for the firefly reintroduction program.

Based on ecological services of wetlands, creating wetland-connected pond and canal systems on campus not only provides wildlife habitats and recreational activities but also mitigates flooding. Since participation of university communities is important in campus management, encouraging research and education for sustainable campus ecology and management will help the master plan to reach its goal.

Because learning is not limited to the classroom, it is necessary that educational values of the campus landscape should be considered. The wetland-based ecological exercises mentioned above have improved function of the landscaped campus as a tool for education. Since people's cognitions and values are influenced by place (Sobel, 2005; Cameron, 2008), the ways the campus is managed will influence their environmental actions. Thus, environmentally sound campus management will demonstrate good example for environmentally responsible action (Keniry, 1995). Moreover, the environmentally sound campus cannot be underestimated when looking forward to qualify for the top rank of university. Management that provides a win-win situation for both university and its wetlands should be one of Mahidol University's strategic plans.

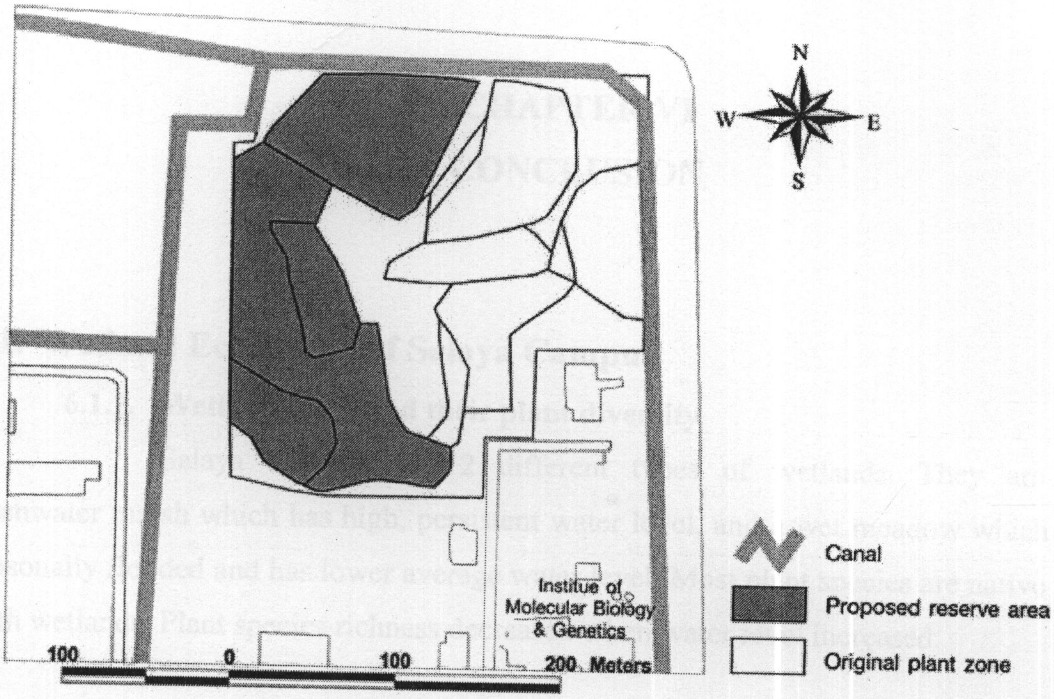


FIGURE 5.2 Additional proposed reserve area of the wet meadow in the north-east side of the university where firefly reintroduction should also be made

CHAPTER VI
CONCLUSION

6.1. Wetland Ecosystem of Salaya Campus

6.1.1. Wetland types and their plant diversity

Salaya Campus has 2 different types of wetlands. They are a freshwater marsh which has high, persistent water level, and a wet meadow which is seasonally flooded and has lower average water level. Most plant species are native in both wetlands. Plant species richness decreased when water level increased.

6.1.2. Impacts of hydrology on wetland plant communities

Water level and duration of flooding influenced distribution and composition of plants on the wetlands of Salaya Campus. Seven visually dominant plant zones occurred along water depth gradients of the wet meadow, from shallow to deep, i.e. tree zone, *Pluchea*-dominated zone, *Imperata*-dominated zone, mixed sedges & grasses zone, *B. mutica* zone, *Typha*-dominated zone, and *Phragmites*-dominated zone, respectively. A slightly inclined slope with low and occasional dry period may have resulted in boundaries and modes of the species response curves in this wetland to be clustered, while *Cayratia trifolia* (L.) Domin is a dominant species causing a hierarchical structure to occur. As a result, plant communities of the wet meadow followed the hierarchical community-unit model (Hoagland and Collins, 1997). In contrast, only four visually dominant plant zones i.e. tree, *Imperata*, *Phragmites*, and *Typha*-dominated zones, occurred along water depth gradients of the freshwater marsh. Interspecific competition due to high and persistent water level of this wetland may have caused no aggregation of boundaries and modes of species. However, a hierarchical structure occurred due to the dominance of duckweed (*Lemna perpusilla* Torr.) in the species response curves. This zonation pattern is similar to the hierarchical continuum model (Hoagland and Collins, 1997).

6.1.3. Habitat selection of aquatic macroinvertebrates

Snails and Chironomids are common in wetlands as they are associated with wetland plants and sediments. Differences in plant communities and periods of the year influenced groups of taxa and abundances of aquatic macroinvertebrates. November to January was the best period to study aquatic macroinvertebrate communities.

6.1.4. Taxonomic problems of aquatic macroinvertebrates of Thailand's palustrine wetlands

Family-level identification is suitable for identification of aquatic macroinvertebrates for evaluating health and functions of wetlands. However, local guides are required for complete identification of aquatic macroinvertebrates of freshwater palustrine wetlands.

6.1.5. Standardized simple techniques for studying aquatic macroinvertebrate communities

The simple techniques and low cost equipment used in this study can be applied by non-scientists e.g. local communities, and school children for studying aquatic macroinvertebrate communities in wetlands.

6.2. Functions and Values of Wetlands of Salaya Campus

6.2.1. Effects of multiple indices

The Shannon diversity index which is commonly used in biodiversity study is not enough to evaluate health and functions of ecosystems. A better indication of ecosystem's biological integrity in wetlands can be obtained from multiple indices measuring different structures and functions of biological communities.

6.2.2. Influence of human disturbance on wetlands of Salaya Campus

The freshwater marsh of Salaya Campus was more disturbed by man than the wet meadow. Modified hydrology resulting in high and persistent water level in the freshwater marsh caused rapid distribution of cattails, the possibility of mild nutrient enrichment, and decrease in biodiversity. In contrast, the wet meadow was mainly impacted by invasion of exotic grass *Brachiaria mutica* (Forssk.) Stapf. However, both wetlands of Salaya Campus have no impact from the exotic, golden apple snail (*Pomacea* sp.). In general, both wetlands were not impaired.

6.2.3. Application of multiple indices for bioassessment of wetlands in the Lower Central Plain

Multiple biological indices for evaluating health and functions of Salaya Campus wetlands in this study can be developed for larger scale wetland biomonitoring, particularly those in the Lower Central Plain of Thailand.

6.3. Wetlands of Salaya Campus as an outdoor ecology classroom

6.3.1. Lessons learned from wetland-based ecological exercises

Effective wetland-based ecological exercises require a balance between the environmental knowledge-education and the attitudes/values-education approaches. Minimizing risks in fieldwork encouraged students to experience wetlands. An experiential learning and empowerment process clarified students' ecological misconceptions. So, both ecological knowledge and wetland values we developed among students.

6.3.2. Educational values of the wetlands of Salaya Campus

Salaya Campus wetlands demonstrated their educational value for ecological exercises which minimized investment in class organization, allowed students to stay close to nature for a longer time, provided students with fundamental ecological concepts, as well as, introduced them to their local ecosystems. Learning on campus wetlands either by formal or informal education could also provide mental benefits to university communities. Such environments can be used for increasing the appreciation and understanding of the university community of the biodiversity in their backyard. Consequently, awareness of wetlands and campus ecosystems could then be motivated.

6.4. Wetlands as A Part of Campus Ecology and Management

6.4.1. Management and restoration of Salaya Campus wetlands

Exotic species removal, proper hydrology management, and cattail distribution control should be parts of restoration and management of Salaya Campus wetlands. Such operations should be based on ecological knowledge, focusing on restoring ecological process, and require participation of university communities in planning, implementation, and evaluation of restoration.

6.4.2. Firefly reintroduction for education and ecotourism

As a high profile insect originally found in the wetlands of Salaya Campus, reintroduction of fireflies *Luciola aquatilis* sp. nov. Thancharoen (Coleoptera: Lampyridae) is expected to be done as further research on the campus wetlands. This will not only promote ecological and educational functions of the campus nature reserve, but also ecotourism served by the university.

6.4.3. Management of Salaya Campus landscape

The recent master plan of Salaya Campus in 2008 is environmental oriented. It proposed landscaping that promotes both green terrestrial areas and original wetland ecosystem. However, recognition on the wet meadow as a rare wetland of the Lower Central Plain is necessary. Developing commercial zone on the area where the wet meadow exists has to be revised for reserving some part of this wetland. Thus, ecological knowledge and natural history of wetlands on campus is critical to effective campus landscaping. Encouraging university communities in doing research and education based on the campus landscape could be an additional approach in the campus management.

6.5. Overall conclusion

Natural wetlands existing in Salaya Campus were proven to maintain their vital biodiversity and ecological functions. They also serve as an important animal refuge in a semi-urbanized area. The wetland-based ecological exercises developed for undergraduate biology students were examples that demonstrating additional values in education provided by natural areas in the backyard. Mysterious flora and fauna communities in the wetlands are still challenging for research and study. The roles of the wetlands obviously support the university's missions. In turn, appreciation that students earned from the wetlands can build up awareness of the campus ecosystems. In parallel to the recent master plan of Salaya Campus, environmental education processes, particularly for the wetlands on campus, and a high profile species, firefly, reintroduction are recommended as a complementary strategy for the university communities. Therefore, sustainable campus development will be achieved.

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APPENDIX

APPENDIX A

EXAMPLE OF SCORING SHEETS FOR THE HUMAN DISTURBANCE GRADIENT SCORES

(from Gernes and Helgen, 2002)

Site: Study: Raters: Date:

[ ] points **Factor 1. Buffer landscape disturbance**

Extent and intensity

	Best – as expected for reference site, no evidence of disturbance	(0)
	Mod.- predominately undisturbed, some human use influence	(6)
	Fair – significant human influence, buffer area nearly filled with human use	(12)
	Poor–nearly all or all of the buffer human use, intensive landuse surrounding wetland	(18)

	Best		Mod.
	Mature (>20 yr) woodlot, forested		Old field, CRP or rangeland,
	Mature prairie		Restored prairie (<10 yr)
	Other long recovered area		Young (<20 yr) second growth woodlot
	Other wetlands		Shrubland

	Fair		Poor
	Residential with unmowed areas		Urban development
	Active pasture		Industrial development
	Less intensive agriculture		Intensive residential/mowed
	Turf park, Golf course		Intensive agriculture
	Newly fallowed fields		Mining in or adjacent to wetland
	High road density in buffer area or impervious surfaces		Active construction activity

Remarks or comments:

[ ] points **Factor 2. Landscape (immediate) Influence**

Extent and intensity

	Best – landscape natural, as expected for reference site, no evidence of disturbance	(0)
	Mod.- predominately undisturbed, some human use influence	(6)
	Fair – significant human influence, landscape area nearly filled with human use	(12)
	Poor – nearly all or all of the landscape in human use, isolating the wetland	(18)

	Best		Mod.
	Mature (>20 yr) woodlot, forested		Old field, CRP or rangeland,
	Mature prairie		Restored prairie (<10 yr)
	Other long recovered area		Young (<20 yr) second growth woodlot
	Other wetlands		Shrubland

	Fair		Poor
	Residential with unmowed areas		Urban development
	Active pasture		Industrial development
	Less intensive agriculture		Intensive residential/mowed

Appendix A. Scoring sheets for human disturbance gradient scores (Continued)

	Turf park, Golf course		Intensive agriculture
	Newly fallowed fields		Mining in or adjacent to wetland
	High road density or impervious surfaces in immediate landscape		Active construction activity

points

Factor 3. Habitat alteration—immediate landscape

(within and beyond buffer)

Severity and extent of alteration

	Best – as expected for reference, no evidence of disturbance	(0)
	Mod. –low intensity alteration or past alteration that is not currently affecting wetland	(6)
	Fair – highly altered, but some recovery if previously altered	(12)
	Poor – almost no natural habitat present, highly altered habitat	(18)

Vegetation removal disturbances

	Mowed, Grazed		Shrub removal
	Tree plantations		Course woody debris removal
	Tree removal		Removal of emergent vegetation

Substrate/soil disturbances and sedimentation

	Grading/bulldozing		Vehicle use
	Filling		Sediments input (from inflow or erosional)
	Dredging		Livestock hooves
	Other		

Other

	Fish stocking or rearing		Other

Remarks or comments:

points

Factor 4. Hydrologic alteration

Severity and degree of alteration

	Best – as expected for reference, no evidence of disturbance	(0)
	Mod. –low intensity alteration or past alteration that is not currently affecting wetland	(7)
	Fair – less intense than "poor", but current or active alteration.	(14)
	Poor – currently active and major disturbance to natural hydrology	(21)

	Ditch inlet		Berm or dam
	Tile inlet		Road bed or RR bed
	Point source input		Levee
	Installed outlet, weir		Unnaturally connected to other waters
	Dredged		Dewatering in or near wetland
	Graded or fill		Source water changes
	Other		Drainage

Remarks or comments:

Appendix A. Scoring sheets for human disturbance gradient scores (Continued)

points

Factor 5. Chemical Pollution

Severity and degree of pollution

	Best - chemical data as expected for reference and no evidence of chemical input	(0)
	Mod.- selected chemical data in low range, little or no evidence of chemical input	(7)
	Fair - selected chemical date in mid range, high potential for chemical input	(14)
	Poor - chemical input is recognized as high, with a high potential for biological harm	(21)

Checklist:

	High Cl conc (water)		Known MMCD treatment
	High P conc. (water)		Evidence of altered DO regime
	High N conc. (water)		Other treatment
	High Cu conc. (sediment)		High input potential
	High Zn conc. (sediment)		Other

Remarks or comments:

points

Additional factors and concerns

Used in exceptional cases as described below

Maximum of (4) additional points added to the cumulative disturbance total for reasons described below. Apply on factors 4 and 5.

Factor 1 – Buffer and landscape

Factor 2 – Landscape (immediate influence)

Factor 3 –Habitat alteration

Factor 4– Hydrologic alteration

Factor 5 – Chemical pollution

Additional factors

Total final disturbance score

Site Name:_______________

APPENDIX B

DEFINITIONS USED FOR ASSIGNING COEFFICIENTS OF CONSERVATISM TO PLANT SPECIES FOR USE IN CALCULATING THE FQAI INDEX

(from Cronk and Fennessy, 2001; Andreas and Lichvar, 1995)

Coefficient of Conservatism	Species Characteristics
Value of 0	Opportunistic native invasive species and all non-native species
Values of 1-3	Species that are widespread and are not an indicator of a particular community, that tolerate moderate disturbance, and are found in a variety of communities
Values of 4-6	Species that are typical of a successional phase of some native community; species that display fidelity to a particular community, but tolerate moderate disturbance
Values of 7-8	Species that are typical of relatively stable conditions; typical of well established communities that have sustained only minor disturbance
Values of 9-10	Species that exhibit high degrees of fidelity to a narrow set of ecological conditions

APPENDIX C

LIST OF PLANT SPECIES FOUND IN SALAYA CAMPUS WETLANDS

C-value is coefficient of conservatism defined in Appendix B (Cronk and Fennessy, 2001; Andreas and Lichvar, 1995)

Scientific name	Thai name	Wetland characteristic	Native/Exotic	Life cycle	Habit	C-value
Acacia auriculaeformis A.Cunn. ex Benth.	กระถินณรงค์	UPL	Exotic	Perennial	ExT	0
Achyranthes aspera L.	พันงูขาว	UPL	Native	Annual	H	3
Acrostichum aureum L.	ปรงไข่	OBL	Native	Perennial	AqF	5
Aeschynomene indica L.	โสนหางไก่	OBL	Native	Annual	S	4
Alternanthera philoxeroides (Mart.) Griseb.	ผักเป็ดน้ำ	OBL	Native	Annual	AqH	5
Aniseia martinicensis (Jacq.) Choisy	จิงจ้อ	FACU	Native	Perennial	C	3
Ardisia elliptica Thunb.	รามใหญ่	OBL	Native	Perennial	S	5
Areca sp.	หมาก	FACU	Native	Perennial	Pa	3
Azima sarmentosa (Blume) Benth.	หนามพุงดอ	FAC	Native	Perennial	C	1
Brachiaria mutica (Forssk.) Stapf	หญ้าขน	FACW	Exotic	Perennial	ExG	0
Canavalia rosea (Sw.) DC.	ถั่วคล้า	FAC	Native	Perennial	C	3
Caryota bacsonensis Magalon	เต่าร้าง	FACU	Native	Perennial	Pa	3
Cayratia trifolia (L.) Domin	เถาคัน	FAC	Native	Perennial	C	1

Appendix C. List of plant species (Continued)

Scientific name	Thai name	Wetland characteristic	Native/Exotic	Life cycle	Habit	C-value
Ceratopteris thalictroides (L.) Brongn.	กูดเขากวาง	OBL	Native	Annual	AqF	7
Chromolaena odoratum (L.) R.M.King & H.Rob.	สาบเสือ	FACU	Exotic	Annual	ExH	0
Coccinia grandis (L.) Voigt	ตำลึง	FACU	Native	Perennial	C	3
Cocos nucifera L.	มะพร้าว	FACW	Exotic	Perennial	ExP	0
Combretum quadrangulare Kurz	สะแกนา	FACW	Native	Perennial	T	3
Commelina diffusa Burm.f.	ผักปลาบ	OBL	Native	Annual	H	3
Cynodon dactylon (L.) Pers.	หญ้าแพรก	FAC	Exotic	Perennial	ExG	0
Cyperus difformis L.	กกขนาก	OBL	Native	Annual	H	5
Cyperus digitatus Roxb.	กกรังกา	OBL	Native	Perennial	H	4
Cyperus imbricatus Retz.	กกสามเหลี่ยมเล็ก	OBL	Native	Annual	H	5
Desmanthus virgatus (L.) Willd.	ถั่วเดสแมนทัส	UPL	Exotic	Perennial	ExS	0
Diplazium sp.	กูด?	OBL	Native	Annual	F	7
Eclipta prostrata (L.). L.	กะเม็ง	OBL	Native	Annual	H	5
Eleocharis dulcis (Burm.f.) Hensch.	แห้วทรงกระเทียม	OBL	Native	Perennial	H	4
Fimbristylis miliacea (L.) Vahl	หญ้าหนวดปลาดุก	OBL	Native	Annual	H	4
Hygrophila erecta (Burm.f.) Hochr.	ต้อยติ่งนา	OBL	Native	Annual	H	6

Appendix C. List of plant species (Continued)

Scientific name	Thai name	Wetland characteristic	Native/Exotic	Life cycle	Habit	C-value
Imperata cylindrica (L.) P.Beauv.	หญ้าคา	FAC	Native	Annual	G	2
Ipomoea aquatica Forssk.	ผักบุ้ง	OBL	Native	Perennial	Cr	3
Lablab purpureus (L.) Sweet	ถั่วแปบ	FACU	Native	Perennial	C	3
Leersia hexandra Sw.	หญ้าไทร	FACW	Native	Perennial	G	5
Lemna perpusilla Torr.	แหนเป็ด	OBL	Native	Perennial	AqH	4
Leucaena leucocephala (Lam.) de Wit	กระถิน	UPL	Exotic	Perennial	ExT	0
Ludwigia hyssopifolia (G.Don) Exell	เทียนนา	OBL	Native	Annual	H	5
Melochia corchorifolia L.	เส้งเล็ก	FAC	Native	Perennial	S	4
Merremia gamella (Burm.f.) Hallier f.	เถาสะอึกใหญ่	FACU	Native	Perennial	C	3
Microstachys chamaelea (L.) Müll.Arg.	สร้อยนก	FACU	Native	Perennial	S	3
Mikania cordata (Burm.f.) B.L.Rob.	ยามขี้ไก่	UPL	Native	Annual	C	3
Panicum repens L.	หญ้าชันกาด	FACW	Native	Annual	G	4
Paspalum scrobiculatum L.	หญ้าปล้องหิน	FACW	Native	Annual	G	5
Passiflora foetida L.	กะทกรก	FACU	Native	Annual	C	3
Phragmites vallatoria (Pluk. ex L.) Veldkamp	แขม	OBL	Native	Perennial	G	4
Phyllanthus reticulatus Poir.	ก้างปลาเครือ	UPL	Native	Perennial	S	2

Appendix C. List of plant species (Continued)

Scientific name	Thai name	Wetland characteristic	Native/Exotic	Life cycle	Habit	C-value
Pistia stratiotes L.	จอก	OBL	Native	Perennial	AqH	1
Pithecellobium dulce (Roxb.) Benth.	มะขามเทศ	FACU	Exotic	Perennial	ExT	0
Pluchea indica (L.) Less.	ขลู่	OBL	Native	Perennial	S	4
Rottboellia exaltata L.f.	หญ้าโขย่ง	FACU	Native	Annual	G	2
Saccharum spontaneum L.	เลา	OBL	Native	Perennial	G	4
Samanea saman (Jacq.) Merr.	จามจุรี	FACW	Native	Perennial	T	3
Sarcostemma secamone (L.) Bennet	จมูกปลาหลด	FACW	Native	Perennial	C	5
Schoenoplectus articulatus (L.) Palla	แห้วทรงกระเทียมหัวแหวน	OBL	Native	Perennial	H	4
Scoparia dulcis L.	กรดน้ำ	OBL	Native	Annual	H	7
Sesbania grandiflora (L.) Desv.	แค	UPL	Exotic	Perennial	ExT	0
Sesbania javanica Miq.	โสน	OBL	Native	Annual	S	4
Solanum trilobatum L.	มะแว้งเครือ	UPL	Native	Annual	C	3
Sphenoclea zeylanica Gaertn.	ผักปอด	OBL	Native	Perennial	H	6
Streblus sp.	ข่อย	UPL	Native	Perennial	T	3
Synedrella nodiflora (L.) Gaertn.	ผักแครด	FAC	Native	Annual	H	3
Tabebuia rosea (Bertol.) DC.	ชมพูพันธ์ทิพย์	UPL	Exotic	Perennial	ExT	0

Appendix C. List of plant species (Continued)

Scientific name	Thai name	Wetland characteristic	Native/Exotic	Life cycle	Habit	C-value
Terminalia catappa L.	หูกวาง	FACW	Native	Perennial	T	3
Tinospora baenzigeri Forman	ชิงช้าชาลี	FACU	Native	Perennial	C	3
Typha angustifolia L.	ธูปฤาษี	OBL	Native	Perennial	H	0
Urena lobata L.	ขี้ครอก	UPL	Native	Perennial	S	3
Vernonia cinerea (L.) Less.	หมอน้อย	UPL	Native	Annual	H	3
Wolffia globosa (Roxb.) Hartog & Plas	ไข่น้ำ	OBL	Native	Perennial	AqH	5

APPENDIX D
LIST OF AQUATIC MACROINVERTEBRATES FOUND IN SALAYA CAMPUS WETLANDS

Order/taxa	Family/taxa	Life stage	Feeding group	Habitat guild	SWAMPS score
Acarina	Acarina	Adult	Parasite	Climber	
Amphipoda	Amphipoda	Adult	Scraper	Swimmer	
Cladocera	Cladocera	Adult	Collector-filterer	Swimmer	
Coleoptera	Helodidae	Larva	Shredder-detritivore	Climber	66
	Hydrophilidae	Adult	Collector-gatherer	Swimmer	60
		Larva	Predator	Climber	60
	Noteridae	Adult	Predator	Swimmer	36
		Larva	Predator	Burrower	36
	Dytiscidae	Adult	Predator	Swimmer	50
		Larva	Predator	Climber	50
	Lampyridae	Larva	Predator	Climber	
	Hydraenidae	Adult	Scraper	Clinger	
	Chrysomelidae	Adult	Shredder-herbivore	Sprawler	65
		Larva	Shredder-herbivore	Clinger	65
	Curculionidae	Adult	Shredder-herbivore	Clinger	
Collembola	Collembola	Adult	Collector-gatherer	Skater	
Decapoda	Decapoda	Adult	Omnivore	Semiaquatic	
Dictyoptera	Blattodea	Adult	Shredder-detritivore	Sprawler	

Appendix D. List of aquatic macroinvertebrates (Continued)

Order/taxa	Family/taxa	Life stage	Feeding group	Habitat guild	SWAMPS score
Diptera	Chironomidae	Larva	Collector-gatherer	Burrower	44
		Larva in case	Collector-gatherer	Burrower	44
		Pupa	Collector-gatherer	Burrower	44
	Ceratopogonidae	Larva	Predator	Sprawler	65
		Pupa	Predator	Sprawler	65
	Chaoboridae	Larva	Predator	Sprawler	
		Pupa	Predator	Sprawler	
	Stratiomyidae	Larva	Collector-gatherer	Sprawler	48
	Culicidae	Larva	Collector-filterer	Swimmer	66
		Pupa	Collector-filterer	Swimmer	66
	Dolichopodidae	Larva	Predator	Sprawler	
	Ephydridae	Larva	Collector-gatherer	Burrower	59
		Pupa	Collector-gatherer	Burrower	59
	Syrphidae	Larva	Collector-gatherer	Burrower	
		Pupa	Collector-gatherer	Burrower	
	Psychodidae	Larva	Collector-gatherer	Burrower	
		Pupa	Collector-gatherer	Burrower	
	Thaumaleidae	Larva	Scraper	Clinger	66
	Tipulidae	Larva	Shredder-detritivore	Burrower	35
		Pupa	Shredder-detritivore	Burrower	35

Appendix D. List of aquatic macroinvertebrates (Continued)

Order/taxa	Family/taxa	Life stage	Feeding group	Habitat guild	SWAMPS score
	Sciomyzidae	Larva	Parasite	Burrower	
	Numatocera	Pupa			
	Muscidae-Anthomyiidae	Larva	Predator	Sprawler	
Ephemeroptera	Baetidae	Larva	Collector-gatherer	Clinger	69
Gastropoda	Planorbidae	Adult	Scraper	Sprawler	66
			Shredder-herbivore	Sprawler	66
	Lymnaeidae	Adult	Shredder-herbivore	Sprawler	58
	Ampullaridae	Adult	Shredder-herbivore	Sprawler	
	Bithyniidae	Adult	Scraper	Sprawler	
Hemiptera	Belostomatidae	Adult	Predator	Climber	
	Pleidae	Adult	Predator	Swimmer	67
		Larva	Predator	Swimmer	67
	Mesoveliidae	Adult	Predator	Skater	58
		Nymph	Predator	Skater	58
	Hydrometridae	Adult	Predator	Skater	
	Nepidae	Adult	Predator	Climber	
	Veliidae	Adult	Predator	Skater	60
	Naucoridae	Adult	Predator	Swimmer	
	Gerridae	Adult	Predator	Skater	
	Herbridae	Adult	Predator	Climber	

Appendix D. List of aquatic macroinvertebrates (Continued)

Order/taxa	Family/taxa	Life stage	Feeding group	Habitat guild	SWAMPS score
	Notonectidae	Adult	Predator	Swimmer	46
	Micronectidae	Adult	Predator	Swimmer	
	Saldidae	Adult	Predator	Climber	
Hirudinea	Hirudinea	Adult	Predator	Clinger	
Isopoda	Isopoda	Adult	Shredder-detritivore	Sprawler	
Lepidoptera	Pyralidae	Larva	Shredder-herbivore	Climber	66
		Pupa	Shredder-herbivore	Climber	66
Nematoda	Nematoda	Adult	Collector-gatherer	Burrower	46
Odonata	Coenagrionidae	Larva	Predator	Climber	47
	Libellulidae	Larva	Predator	Sprawler	73
	Corduliidae	Larva	Predator	Sprawler	72
	Aeshnidae	Larva	Predator	Climber	65
Oligochaeta	Oligochaeta		Collector-gatherer	Burrower	55
Ostracoda	Ostracoda	Adult	Collector-filterer	Sprawler	
Polychaeta	Polychaeta	Adult	Collector-gatherer	Burrower	

APPENDIX E

TAXONOMIC PROBLEMS OF SOME AQUATIC MACROINVERTEBRATE TAXA FOUND IN WETLANDS OF SALAYA CAMPUS

(J.R. Milne, personal communication, 20 March 2008)

Order/taxa	Family/taxa	Stage	Reference	Notes
Diptera	Muscidae-Anthomyzidae	Larva	McCafferty, 1998	cannot see "short, scattered, well-developed spines" that should be present on prolegs
Diptera	Ptychopteridae	Larva	MRC, 2006; McCafferty, 1998	does not key out, long breathing tube from abdomen apex
Diptera	Sciomyzidae	Larva	MRC, 2006; McCafferty, 1998	does not key out, looks like maggot, no unusual features
Diptera	Syrphidae	Larva	MRC, 2006; McCafferty, 1998	does not look like examples in pictures
Diptera	Thaumaleidae	Larva	McCafferty, 1998	no mention of long thin sclerotised siphons from abdominal apex in larval descriptions of McCafferty (1998)

Appendix E. Taxonomic problems of some aquatic macroinvertebrate (Continued)

Order/taxa	Family/taxa	Stage	Reference	Notes
Diptera	Nematocera Tipulidae?	Pupa	McCafferty, 1998	looks similar to Tipulidae pupa illustrated in Fig. 16.5, McCafferty (1998) but not exactly the same
Ephemeroptera	Baetidae	Nymph	CSIRO, 1991	gills, antennae, legs missing in most specimens - need a better way of collecting and preserving them; perhaps *Cloeon* sp., see MRC (2006)
Hemiptera	Saldidae?	Nymph?	CSIRO, 1991; MRC, 2006: Cheng et al., 2001	Cheng et al. (2001) indicate 3-segmented antennae but specimen seems to be 4; a row of many spines along anterior margin of clypeus
Hemiptera	Micronectidae	Adult	MRC, 2006	keys out to Corixidae in CSIRO (1991) and Cheng et al. (2001)
Lepidoptera	Pyralidae	Larva	McCafferty, 1998	no key; Family Crambidae according to MRC (2006); probably *Elophila* sp.

Appendix E. Taxonomic problems of some aquatic macroinvertebrate (Continued)

Order/taxa	Family/taxa	Stage	Reference	Notes
Odonata	Aeshnidae	Nymph	CSIRO, 1991; MRC, 2006; McCafferty, 1998	keys out to Aeshnidae/Gomphidae couplet in McCafferty (1998) and MRC (2006) and couplet 2 in CSIRO (1991) but antennae have 5 segments, not 4 or 6-7 as required by all 3 keys, so can not go any further
Coleoptera	?	Larva	CSIRO, 1991; MRC, 2006; McCafferty, 1998	keys out to Elmidae using MRC (2006) but does not fit descriptions of McCafferty (1998) or CSIRO (1991)
Coleoptera	?	Larva	MRC, 2006	keys out to couplet 14 of MRC (2006)
Coleoptera	?	Adult	CSIRO, 1991; MRC, 2006; McCafferty, 1998	can not key out using any key
Oligochaeta			MRC 2006	keys out to Annelida using MRC (2006) but not further - lacks setae

BIOGRAPHY

NAME	Miss Chutamas Sukhontapatipak
DATE OF BIRTH	13 January 1978
PLACE OF BIRTH	Suphanburi, Thailand
INSTITUTIONS ATTENED	Mahidol University, 1996-1999: Bachelor of Science (Biology)
	Mahidol University, 2000-2008: Doctor of Philosophy (Biology)
RESEARCH GRANTS	The Commission on Higher Education, 2001-2005
	Biodiversity Research and Training Program (BRT), 2006-2008

Tel. (66)87-495-0560

E-mail: tae_chu@yahoo.com