東北学院大学教養学部論集
第152号　(平成21年3月)

Herbaceous Aquatic Vegetation in Lake Tonle Sap at Peak Flooding : A Case Study at Chong Khnies, Southern Siem Reap

HIRABUKI Yoshihiko, ARAKI Yuji, DOURNG Powkhy,
TSUKAWAKI Shinji, SUZUKI Kunio,
IM Sockrithy and CHAY Rachna

Herbaceous Aquatic Vegetation in Lake Tonle Sap at Peak Flooding : A Case Study at Chong Khnies, Southern Siem Reap

HIRABUKI Yoshihiko[1], ARAKI Yuji[2], DOURNG Powkhy[3], TSUKAWAKI Shinji[4], SUZUKI Kunio[5], IM Sockrithy[6] and CHAY Rachna[6]

[1]Faculty of Liberal Arts, Tohoku Gakuin University, Tenjinzawa 2-1-1, Izumi-Ku, Sendai 981-3193, Japan (tel/fax, +81-22-773-3706 ; e-mail, yhira@izcc.tohoku-gakuin.ac.jp) ; [2]Asian Natural Environmental Science Center, The University of Tokyo, Nishitokyo 188-0002, Japan; [3]Peace In Tour Angkor, Siem Reap, Cambodia ; [4]Institute of Nature and Environmental Technology, Kanazawa University, Kanazawa 920-1192, Japan ; [5]Graduate School of Environment and Information Sciences, Yokohama National University, Yokohama 240-8501, Japan ; [6]National Authority for the Protection of the Site and Management of Angkor and Region of Siem Reap, Cambodia

Abstract

At the height of the flood period in 2003, the herbaceous aquatic vegetation in Lake Tonle Sap was surveyed in fifty quadrats established over various vegetation types, in the southern part of Siem Reap City, Cambodia. Twenty-four plant species, exhibiting five growth-form types, were recorded, there being a heterogeneous distribution of vegetational assemblages. Overall, a gradual change in vegetation zones from the area of "the permanent lake" to the upper reaches of "the floodplain" (width surveyed = ca. 7.5 km) was determined as follows : open water area with no herbaceous aquatic plants → free-floating plants → free-floating plants and floating-emergent plants, or submerged plants → submerged plants and floating-leaf plants → emergent plants. Large seasonal fluctuations in water level (< ca. 7 m) and land-use patterns on the floodplain by local people during the dry season strongly affected herbaceous aquatic vegetation.

Keywords : distributional pattern, floodplain, growth-form, herbaceous aquatic plants, Lake Tonle Sap, seasonal water level changes

Nomenclature : "*Index Kewensis*" (http://www.ipni.org/ipni/plantnamesearchpage.do/ ; The Royal Botanic Gardens, Kew, 2007)

Introduction

Lake Tonle Sap, a natural reservoir of the Mekong River, is the largest inland water body in Southeast Asia, being characterized by considerable changes in water-level between the flood and dry seasons. During peak flooding, the maximum depth reaches to more than 8 m from a minimum of about 1 m and the overall waterlogged area expands to

ca. 9,000-14,000 km^2, approximately four times the size of the lake in the dry season (CNMC/NEDECO, 1998a, b ; FAO, 2003 ; Colin and Eleanor, 2005). Additionally, the lake (including the floodplain) plays an important role in the economy and culture of Cambodia, being a major source of fish, wood, fertile agricultural land and some natural resources (Mekong River Commission, 1997 ; CNMC/NEDECO, 1998a, b ; FAO, 2003 ; Colin and Eleanor, 2005).

This report describes the results of a preliminary survey of the herbaceous aquatic vegetation in Lake Tonle Sap during peak flooding. As the first step in our plant ecological research under the auspices of three scientific projects, we wished to determine (1) which plants grew in the lake and (2) their horizontal and vertical distribution both in "the permanent lake" and over "the floodplain", the former being filled with freshwater throughout the year despite considerable changes in water depth, and the latter having variable inundation and water availability regimes on a site-by-site basis, depending upon micro-topography.

Because information on the flora of Lake Tonle Sap and its surrounding lowlands is limited (e.g., McDonald *et al.*, 1997 ; Sokhun, 1997 ; CNMC/NEDECO, 1998b ; Araki *et al.*, 2007), and human-induced degradation has sharply increased, further accumulation of basic knowledge is an indispensable step in the conservation and sustainable management of this unique ecosystem (Mekong River Commission, 1997 ; CNMC/NEDECO, 1998a, b).

Study Area

Field investigations were carried out in the Chong Khnies Area, southern part of Siem Reap City, located near the northwestern shoreline of Lake Tonle Sap (Fig. 1 ; 13° 16′N, 103° 49′E ; ca. 1-6 m a.s.l.). The area studied included both the permanent waterlogged area and inundated floodplain (the latter ca. 8 km in width ; Okawara and Tsukawaki, 2002 ; Mildenhall and Tsukawaki, 2002).

As a whole, the topography of the area studied inclined very gently from north to south, although many artificial channels, shallow ponds and banks of various scales have been constructed over the floodplain. During the dry season, several types of secondary vegetation, such as paddy fields, lotus ponds, meadows, degraded scrub and *Barringtonia acutangula* Korth.-dominant woodlands, can be physiognomically distinguished.

CNMC/NEDECO (1998b) listed ca. 200 plant species in the Tonle Sap area, the introduced vegetational pattern on the floodplain having four major habitat types (after McDonald *et al.*, 1997) ; (1) Short-tree and shrubland vegetation, (2) Stunted swamp forest,

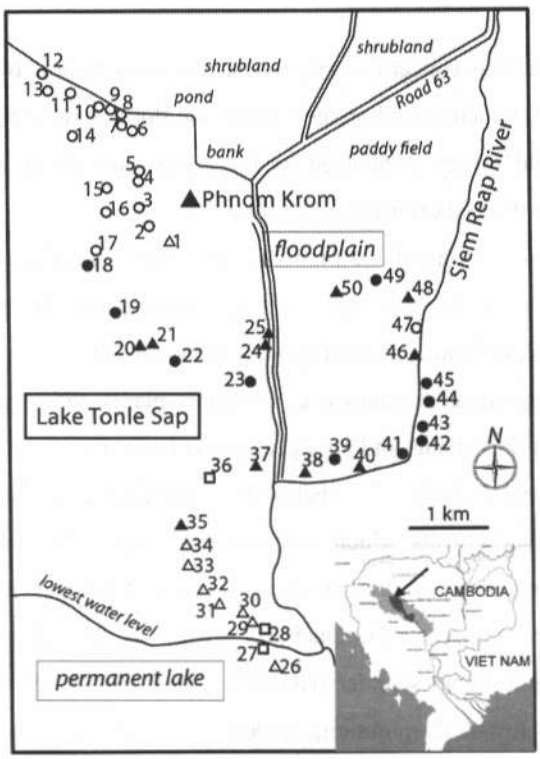

Fig. 1. Map showing the Chong Khnies study area and quadrats surveyed for herbaceous aquatic vegetation. Symbols attached to quadrat numbers (1-50) represent vegetation types in Table 1 (□=Type I, △= Type IIa, ▲= Type IIb, ○= Type IIIa, ●= Type IIIb). Small map indicating "the permanent lake" (in black) and "the floodplain" (in grey) is quoted from "*The Tonle Sap Great Lake*" (FAO, 2003), and arrow shows the study area.

(3) Herbaceous vegetation and (4) Submerged aquatic vegetation. Recently, Araki *et al.* (2007) carried out phytosociological surveys in the same area as the present study (excluding permanent waterlogged sites such as rivers, channels and ponds), and detected the following seven vegetation types : (1) Cultivated field, (2) Fallow field, (3) Shrub, (4) Tall shrub, (5) Scrub, (6) Open forest and (7) Closed forest, depending on both large seasonal water level fluctuations and human impact. They also identified vigorous invasion and/or regeneration of *Barringtonia acutangula* over the floodplain, and estimated that the woodland dominated by *Barringtonia acutangula* was a major vegetation type of this ecotone (Araki *et al.*, 2007).

The climate of terrestrial areas surrounding the floodplain was seasonal dry tropical. Annual mean temperature was 28.2℃, with only 12% of annual precipitation (1,425 mm/year) falling during the dry season in Siem Reap City (MRCS, 2003). The surface soil of the floodplain was reddish-brown/yellowish-brown soft sandy clay and clayey sand.

Methods

Because this report was concerned only with herbaceous aquatic plants, the shrubs, trees and lianas, almost all of which are submerged during the flood season (e.g., Araki *et al.*, 2007), were omitted. The field survey, conducted by boat, was carried out from 30 October to 7 November 2003, under the highest water-level condition.

After general observations of the plants in the study area, fifty quadrats (5 m × 5 m) were established so as to include various physiognomically distinct vegetation types (Fig. 1). Vegetation descriptions at each quadrat were carried out as follows ; (1) for free-floating plants, floating-emergent plants (i.e., emergent plants with expanded floating stems and/or ramets), floating-leaf plants and emergent plants (refer Fig. 2), coverage was evaluated for each species ("+" and 1-100% ; "+"=below 1%), and (2) for submerged plants (including suspended-submerged individuals which had lost root connection with the soil ; CNMC/ NEDECO, 1998b), frequency by dredge samples was adopted (anchor rope length 10 m, dredges repeated five times at each quadrat). Water depth and quadrat location were measured by LCD digital depth sounder (HONDEX PS-7, Honda Electronics Co. Ltd.) and GPS (GPSMAP76, GARMIN Corporation), respectively. Voucher specimens were collected for each species.

Following this field survey, compensative observations were undertaken at a number of

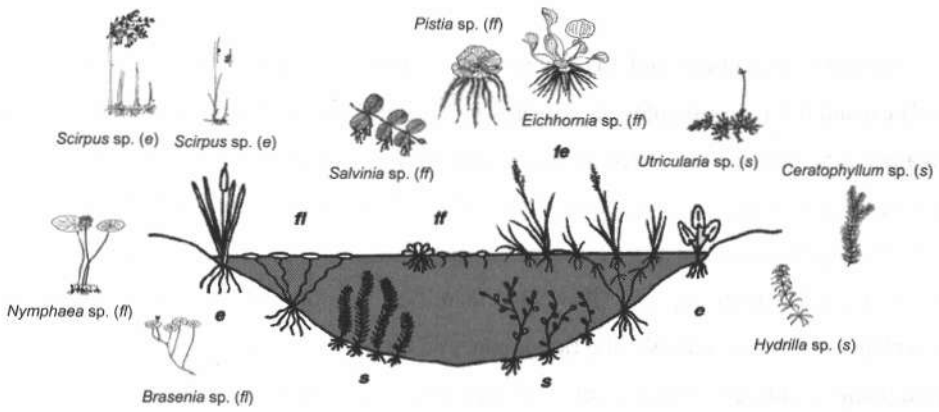

Fig. 2. Schematic diagram showing five growth-form types of herbaceous aquatic plants. *e*=emergent plants, *fl*=floating-leaf plants, *fe*=floating-emergent plants, *s*=submerged plants, *ff*=free-floating plants. Refer Table 1 for the species detected in the present study. Original illustrations are from "Introduction to Freshwater Vegetation" (Riemer, 1984).

quadrats in December 2004 (peak wet season) and May-August from 2004 to 2007 (dry season), in order to determine the reappearance and seasonality of the characteristic species. Identification of specimens was based on McMakin (1988), Noda *et al.* (1994), Dy Phon (2000) and herbarium specimens (Bangkok Forest Herbarium, Bangkok Herbarium of the Department of Agriculture and The Kyoto University Museum).

Results and Discussion

1. Number of Species

The total number of herbaceous aquatic plants encountered was only 24, although the study area was extensive enough to contain various habitats (Table 1).

On the other hand, indicator species such as *Utricularia aurea* Lour., *Najas minor* All., *Nymphoides hastata* (Dop) Kerr, *Nymphoides indica* Kuntze, *Marsilea crenata* C.Presl and *Azolla imbricata* (Roxb.) Nakai, considered to be easily endangered by water pollution and land reclamation, were found to be growing vigorously in shallower and permanent waterlogged habitats.

2. Growth of Floating-leaf Plants and Emergent Plants

Five species of free-floating plants, four of submerged plants, eight of floating-emergent plants, five of floating-leaf plants and two of emergent plants were distinguished (Table 1).

Low rates of frequency and coverage (except *Nymphoides indica*), and a low number of species, both of floating-leaf plants and emergent plants, were notable phenomena on the floodplain, water conditions and agricultural activities (mainly paddy field cultivation) drastically changing with the seasons (e.g., Araki *et al.*, 2007). During the low water season, larger numbers of herbaceous species of emergent plants were found in both wet and sunny habitats. Accordingly, almost all of the emergent plants must have been submerged by flooding in this study area.

3. Vegetational Assemblages Corresponding with Growth-forms

Table 1 shows the floristic similarity of herbaceous aquatic vegetation among fifty quadrats. In the present analysis, three types of vegetational assemblages were recognized, two of them being further divided into two sub-types (Table 1). The characteristics of each vegetation type and its habitat are summarized as follows (refer Figs. 1 and 3).

Table 1. Synthetic table of herbaceous aquatic vegetation in the period of peak flooding. Range of abundance is shown in parenthesis by either coverage-based scale ("+" and 1-100%; "+"=below 1%) or frequency-based scale (I-V; n=5 for each site surveyed: I=20%, II=40%, III=60%, IV=80%, V=100%). Abbreviations of growth-form types are also indicated.

Vegetation type		I	II a	II b	III a	III b	Total
Number of quadrats		3	8	11	17	11	50
Coverage on the surface (%)	mean	0	15.3	96.8	48.1	16.2	43.6
	range	0	0.1-100	90-100	0-90	0-100	0-100
Number of species (/quadrat)	mean	0	2.0	10.2	8.1	4.5	6.3
	range	0	1-3	6-18	3-12	1-8	0-18
Number of species (/vegetation type)							
Emergent plants	(*e*)	0	0	2	0	1	2
Floating-leaf plants	(*ff*)	0	0	4	5	2	5
Floating-emergent plants	(*fe*)	0	0	7	7	3	8
Submerged plants	(*s*)	0	1	3	4	3	4
Free-floating plants	(*ff*)	0	3	5	3	2	5
Total		0	4	21	19	11	24
Water depth (m)	mean	5.0	4.4	3.1	2.0	3.4	3.1
	range	4.5-5.9	2.6-6.1	2.0-4.3	0.6-2.9	2.7-4.0	0.6-6.1

							Frequency
Limnophila geoffrayi Bonati	*fe*	·	·	·	I (1-5)	·	2
Nymphoides hastata (Dop) Kerr	*ff*	·	·	·	I (+-10)	·	2
Nymphaea nouchali Burm. f.	*ff*	·	·	I (−)	II (+-10)	·	6
Ceratophyllum demersum Klein ex Cham.	*s*	·	·	·	IV (I-V)	·	13
Echinochloa crus-galli (L.) P.Beauv.	*fe*	·	·	I (+-5)	I (1-5)	·	5
Marsilea crenata C.Presl	*ff*	·	·	II (+-1)	II (1-5)	·	7
Pseudoraphis brunoniana (Wall. & Griff.) Pilg.	*fe*	·	·	I (+-1)	IV (+-30)	·	14
Nymphoides indica Kuntze	*ff*	·	·	II (1-5)	V (+-80)	I (3)	21
Nelumbo nucifera Gaertn.	*e*	·	·	I (+)	·	II (+-95)	5
Najas minor All.	*s*	·	·	II (I-III)	III (I-V)	IV (I-V)	19
Hydrilla verticillata F.Muell.	*s*	·	·	III (1-V)	V (I-IV)	III (I-V)	28
Trapa natans var. *pumila* Nakano ex Verdc.	*ff*	·	·	II (+-1)	I (5)	III (+-20)	10
Hymenachne acutigluma (Steud.) Gilliland	*fe*	·	·	III(+-10)	II (1-10)	III (+-10)	15
Utricularia aurea Lour.	*s*	·	I (II)	V (I-II)	V (I-V)	IV (I-IV)	35
Ludwigia adscendens (L.) H.Hara	*fe*	·	·	V (1-40)	II (+-5)	II (+-1)	18
Polygonum tomentosum Wall.	*fe*	·	·	V (+-90)	II (+-5)	I (+-1)	17
Salvinia cucullata Roxb.	*ff*	·	IV (+)	V (3-90)	III (+-20)	III (+-20)	29
Eichhornia crassipes Solms	*ff*	·	V (+-100)	V (5-80)	III (+-10)	II (1-5)	32
Pistia stratiotes L.	*ff*	·	II (+)	V (+-10)	I (+-1)	·	16
Monochoria hastata Solms	*ff*	·	·	IV (+-40)	·	·	8
Cyperus cephalotes Vahl	*e*	·	·	II (+)	·	·	4
Ipomoea aquatica Forssk.	*fe*	·	·	II (+-10)	·	·	3
Saccharum spontaneum L.	*fe*	·	·	II (+-20)	I (1)	·	4
Azolla imbricata (Roxb.) Nakai	*ff*	·	·	I (+-1)	·	·	2

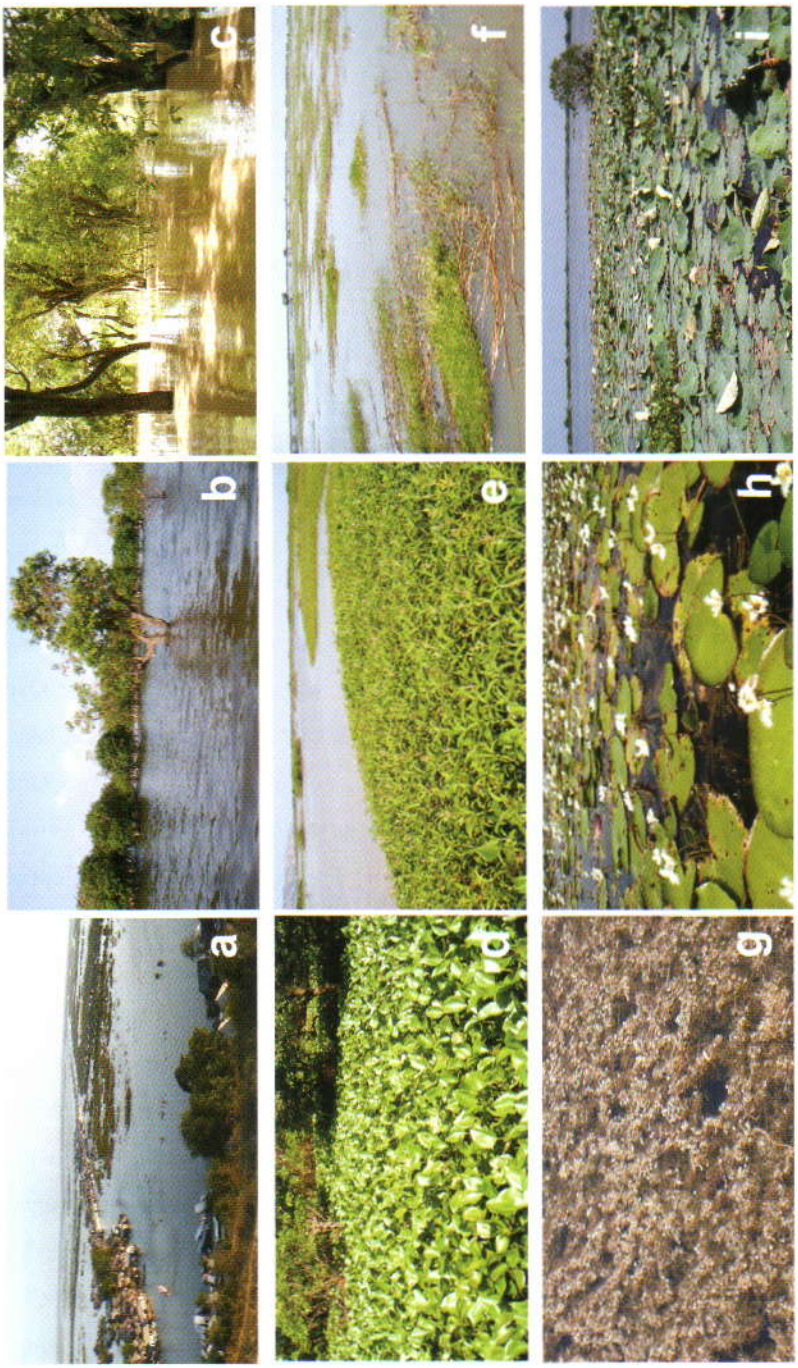

Fig. 3. Views of herbaceous aquatic vegetation, especially contributing to the zonal vegetation structure across the waterlogged floodplain of the study area. a : overview of the waterlogged study area from Phnom Krom Hill (Fig. 1), b : open water area near the permanent lake, c : *Barringtonia acutangula*-dominant forest lacking herbaceous aquatic plants, d : *Eichhornia crassipes*-dominant stand, e : *Polygonum tomentosum*-dominant stand, f : *Hymenachne acutigluma*-dominant stand, g : *Hydrilla verticillata*-dominant stand, h : *Nymphoides indica*-dominant stand, i : *Nelumbo nucifera*-dominant stand.

a) Assemblage lacking herbaceous aquatic plants (Type I)

Herbaceous aquatic plants were not found at three quadrats ; namely, (1) Q27 located in the permanent lake, (2) Q28 located in the inundated *Barringtonia acutangula*-dominant Open forest (ca. 10.8 m of the mean canopy height ; Araki *et al.*, 2007) encircling the permanent lake, and (3) Q36 located in the submerged shrub (ca. 3.8 m of the mean canopy height ; Araki *et al.*, 2007) widely spread behind the Open forest. Water depth was over 4.5 m and the water surface subject to frequent strong winds and wave action.

A similar phenomenon of vegetation and water surface environment was observed over the permanent lake (water depth ＞ca. 6 m).

b) Assemblage characterized by free-floating plants and floating-emergent plants (Type II)

In this vegetational assemblage, free-floating plants such as *Eichhornia crassipes* Solms and *Salvinia cucullata* Roxb. typically occurred. *Pistia stratiotes* L., *Monochoria hastata* Solms and some floating-emergent plants (e.g., *Polygonum tomentosum* Wall. and *Ludwigia adscendens* (L.) H.Hara) occasionally accompanying them.

Sub-type IIa (n=8) was characterized by (1) poor species' composition of free-floating plants (1-3 species/quadrat), (2) very low water surface coverage (≦10%, except for Q30 situated in a dense patch of *Eichhornia crassipes*, which had moved from the permanent lake) and (3) deeper habitat (2.6-6.1 m). Quadrats were concentrated in the disturbed woodland zone dominating *Barringtonia acutangula* (≧ca. 6.9 m mean canopy height ; Araki *et al.*, 2007), although Q1 was situated on the periphery of the wide open water area in the upper floodplain, characterized by Cultivated and Fallow fields (Araki *et al.*, 2007) in the dry season. Thus, Sub-type IIa may represent a transition between Type I and Sub-type IIb.

On the other hand, Sub-type IIb (n=11) consisted of a higher number of species (6-18 species/quadrat) with very high coverage (90-100%), the quadrats surveyed being distributed around the shallower area (2.0-4.3 m in depth) in the middle zone of the floodplain. Dense floating mats with various proportions of *Eichhornia crassipes*, *Salvinia cucullata*, *Polygonum tomentosum*, *Ludwigia adscendens*, *Monochoria hastata* and *Pistia stratiotes* typically occurred along the margins of dense patches of emergent shrubs. Shrubs which characterize the floodplain vegetation of Lake Tonle Sap (McDonald *et al.*, 1997 ; CNMC/NEDECO, 1998b ; Araki *et al.*, 2007) may anchor such floating plants by their canopies. Floating-emergent plants, such as *Ipomoea aquatica* Forssk. and *Saccharum spontaneum* L., and submerged plants, such as *Utricularia aurea*, *Hydrilla verticillata* F. Muell. and *Najas minor*,

were sometimes present.

c) Assemblage characterized by submerged plants and floating-leaf plants (Type III)

In the middle zone and upper floodplain reaches, patchily-distributed Tall shrubs, Shrubs, Cultivated fields and Fallow fields (Araki *et al.*, 2007) were dominant vegetation types in the dry season, together with variously-sized artificial channels and ponds. The assemblage of herbaceous aquatic plants mainly comprised submerged plants (e.g., *Utricularia aurea*, *Hydrilla verticillata*, *Najas minor* and *Ceratophyllum demersum* Klein ex Cham.), floating-leaf plants (e.g., *Nymphoides indica*, *Trapa natans* var. *pumila* Nakano ex Verdc. and *Nymphaea nouchali* Burm. f.) and gramineous floating-emergent plants (e.g., *Pseudoraphis brunoniana* (Wall. & Griff.) Pilg. and *Hymenachne acutigluma* (Steud.) Gilliland). This vegetation type was divided into two sub-types, and both included quadrats with poor species' composition and/or low coverage, distributing on the periphery of the suitable habitat.

Sub-type IIIa (n=17) consisted of larger numbers of species (3-12 species/quadrat), quadrats being concentrated in shallower areas (0.6-2.9 m in depth) in the north-west sector of the study area. Dominant species were *Utricularia aurea*, *Ceratophyllum demersum*, *Hydrilla verticillata* and *Nymphoides indica*. *Najas minor*, *Pseudoraphis brunoniana* and free-floating plants, such as *Eichhornia crassipes* and *Salvinia cucullata*, were sometimes present.

Compared with Sub-type IIIa, Sub-type IIIb (n=11) was distributed in deeper sites (2.7-4.0 m in depth) in the middle zone of the floodplain and lacked major species, such as *Ceratophyllum demersum*, *Nymphoides indica* and *Pseudoraphis brunoniana*. On the other hand, *Hydrilla verticillata* and *Najas minor* occasionally formed very dense mixed-patches accompanied by *Utricularia aurea*, *Trapa natans* var. *pumila* and *Hymenachne acutigluma*. The number of species occurring in such quadrats was as low as 1-8.

4. Importance of the Foodplain as a Herbaceous Aquatic Plants Habitat

In the present study, 24 herbaceous aquatic plant species, exhibiting five growth-form types (Table 1), were recognized, and a gradual change in the vegetation physiognomy (i.e., dominant growth-forms) from the permanent lake to the upper reaches of the floodplain (ca. 7.5 km in distance) was also determined : open water area with no herbaceous aquatic plants → free-floating plants → free-floating plants and floating-emergent plants, or submerged plants → submerged plants and floating-leaf plants → emergent plants. Additionally, the vegetational assemblages distributed on the floodplain occasionally

developed into dense floating or submerged mats (Fig. 3).

Fig. 4 illustrates the spatio-temporal relationship between vegetation and environment in the study area ; i.e., a comparison of seasonal phenomena corresponding to drastic fluctuations in water level. In the lowest water season, no herbaceous aquatic plants, apart from a very few free-floating forms, such as *Eichhornia crassipes*, occurred in the permanent lake, because of (1) very low sun-light transparency of the turbid lake water and (2) the action of strong waves and currents. On the other hand, many herbaceous aquatic plant species, especially (1) emergent plants, which may be characterized by rapid growth and a short life-span, and (2) free-floating plants, which could be moved and anchored, grew vigorously along the lake

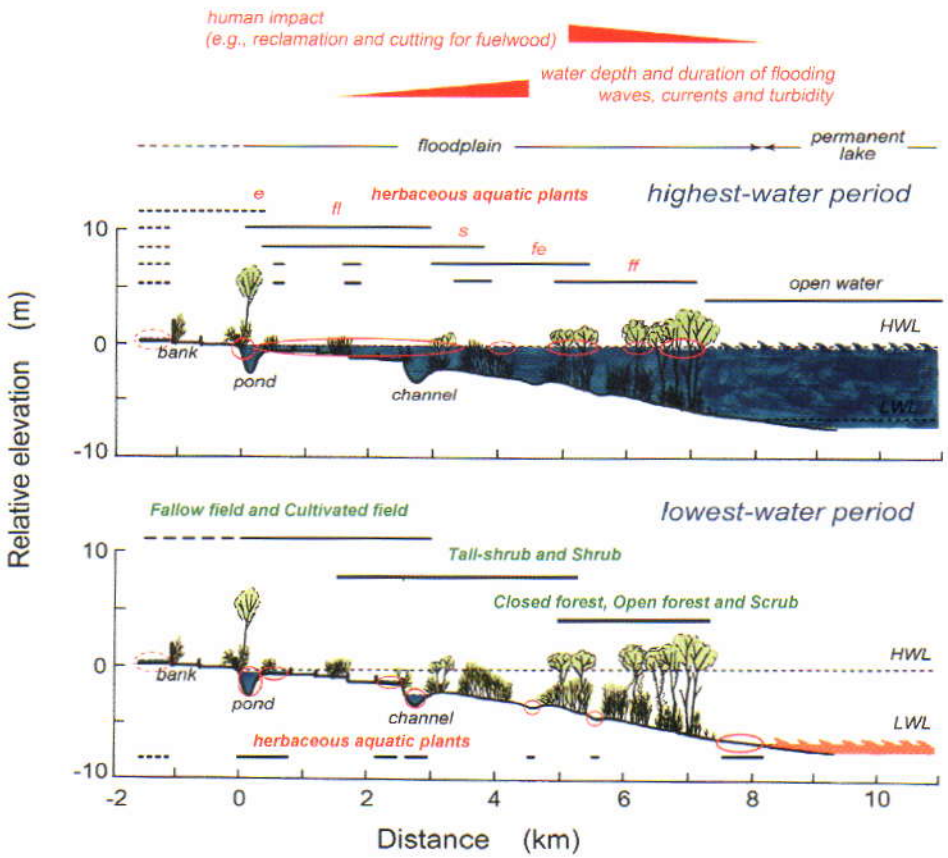

Fig. 4. Schematic diagram showing the spatio-temporal relationship between herbaceous aquatic vegetation and the study area environment ; contrastive seasonal phenomena corresponding with drastic fluctuations of water level are compared. Abbreviations of growth-forms of herbaceous aquatic plants as in Fig. 2, and for terrestrial vegetation types in the lowest-water period see text and Araki *et al.* (2007). Circles (in red) indicate dense patches of herbaceous aquatic plants. HWL=highest water level, LWL=lowest water level.

side. Such plants also survived in channels, ponds and other wet-places, including shallow depressions, on the dry floodplain.

Therefore, in order to understand the mechanisms of growth flourishes and zonal distribution of herbaceous aquatic plants on the floodplain, ecological evaluations of habitats coupled with life-history studies of each species must be conducted throughout the year. Because herbaceous aquatic plants play an important role in the diets and breeding sites of wildlife, as well as in water purification and nutrient dynamics, such surveys would also contribute greatly to clarification of the overall ecosystem of Lake Tonle Sap.

Acknowledgements

We sincerely thank Dr. Takehara A., Dr. Tomita, M., Dr. Hang, P., Mr. Ly, B. and the staff of the National Authority for the Protection of the Site and Management of Angkor and Region of Siem Reap for local research support. Many thanks are also due to the staff of the Bangkok Forest Herbarium, the Bangkok Herbarium of the Department of Agriculture and The Kyoto University Museum for help with species' identification.

This study was funded by the Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (15405004 and 18650236) and by the UNESCO Japanese Fund-in-Trust (MAB-IHP Joint Programme).

References

Araki, Y., Hirabuki, Y., Powkhy, D., Tsukawaki, S., Rachna, C., Tomita, M. and Suzuki, K. 2007. Influence of large seasonal water level fluctuations and human impact on the vegetation of Lake Tonle Sap, Cambodia. "*Forest Environments in the Mekong River Basin*" (eds. Sawada, H., Araki, M., Chappell, N.A., LaFrankie, J.V. and Shimizu, A.), 281-294. Springer.

CNMC/NEDECO. 1998a. *Natural Resources-based Development Strategy for the Tonle Sap Area, Cambodia (CMB/95/003). Final Report. Vol. 1, Main Report.* 115 pp. Cambodian National Mekong Committee, Phnom Penh.

CNMC/NEDECO. 1998b. *Natural Resources-based Development Strategy for the Tonle Sap Area, Cambodia (CMB/95/003). Final Report. Vol. 2, Sectoral Studies. Environment in the Tonle Sap Area.* 122 pp. Cambodian National Mekong Committee, Phnom Penh.

Colin, P. and Eleanor, B. 2005. *Tonle Sap, The Heart of Cambodia's Natural Heritage.* 172 pp. River Book, Bangkok.

Dy Phon, P. 2000. *Plants Used in Cambodia.* 915pp. Imprimerie Olympic, Phnom Penh.

FAO (ed.) 2003. *The Tonle Sap Great Lake.* 153 pp. Asia Horizons Books, Bangkok.

McDonald, J.A., Pech, B., Phauk, V. and Leeu, B. 1997. *Plant Communities of the Tonle Sap Floodplain. Final Report in Contribution to the Nomination of Tonle Sap as a Biosphere Reserve for UNESCO's Man in the Biosphere Program.* 30 pp.+appendices, figures and maps.

McMakin, P.D. 1988. *A Field Guide to the Flowering Plants of Thailand.* 141 pp. White Lotus, Bangkok.

Mekong River Commission. 1997. *Mekong River Basin Diagnostic Study. Final Report.* 249 pp. Mekong River Commission, Bangkok.

Mildenhall, D. and Tsukawaki, S. 2002. Holocene history of Lake Tonle Sap, Cambodia. *Geological Society of New Zealand Newsletter*, 128 : 27-33.

MRCS. 2003. *Database for Precipitation and Water Stage Data.* Mekong River Commission Secretariat, Phnom Penh.

Noda, K., Teerawatsakul, M., Prakongvongs, C. and Chaiwiratnukul, L. 1994. *Major Weeds in Thailand.* 142 pp. National Weed Science Research Institute Project, Bangkok.

Okawara, M. and Tsukawaki, S. 2002. Composition and provenance of clay minerals in the northern part of Lake Tonle Sap, Cambodia. *J. Geography*, 111 : 341-359.

Riemer, D.N. 1984. *Introduction to Freshwater Vegetation.* 207 pp. The AVI Publishing, Westport, USA.

Sokhun, T. 1997. *Review of the Forestry Sector in Cambodia. Prepared for the Project CMB/95/003, "Natural Resources-based Development Strategy for the Tonle Sap Area, Cambodia."* 42 pp. UNDP, Mekong River Commission and Cambodian National Mekong Committee, Phnom Penh.

The Royal Botanic Gardens, Kew. 2007. *Index Kewensis* (http://www.ipni.org/ipni/plantnamesearchpage.do/).