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The population structure and the individual forms of Waterhyacinth, *Eichhornia crassips* (Mart.) Solms, in Thailand.

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Abstract

Certain ecological characteristics of the Waterhyacinth, *Eichhornia crassipes* (Mart.) Solms population were studied in Thailand in 1982, in order to gain a basic knowledge for its use as a bio-resource in the future. The waters were eutrophic in the study area, where the Waterhyacinth population prospered. The biomass and the Leaf Area Index of Waterhyacinth population showed large values ranging from 1.18 to 2. 32 kg d.w./m^2 and from 5.1 to 7.1 m^2/m^2, retpectively. The diagram of the productive structure in a large biomass population was like the herb type of a terrestrial plant population. Among these populations, a high biomass population had low density, a small number of daughter stock and a large number of dead leaves, compared to small ones. The relationshp between the height and weight of an individual on semi-log coordinates growing in various places was linear (log(Weight) $= -0.041 + 0.017$(Heght)).

Among these individuals, three types of individual forms were distinguished, i.e., population type, expansion type and land form type, respectively. Each type seems to play a different role in maintaining the population in each habitat.

Introduction

The Waterhyacinth, *Eichhornia crassipes* (Mart.) Solms, is native to South America and is found throughout the warm regions of the earth. Owing to its strong growth, it has become notorious as a troublesome species (SCULTHORPE, 1967). Many authors have endeavored to elucidate its ecological characteristics and reported its high productivity (PENFOUND, 1956 : BOYD, 1970 : WOOTEN and DODD, 1976 : CENTER and SPENCER, 1981 : SATO and KONDO, 1981, 1983). On the other hand other researchers interested in an applied aspect of this weed, have tried to use it to improve polluted waters (BOYD, 1970 : WOOTEN and DODD 1976 : SATO and KONDO, 1981, 1983). Incidentally, a study to convert matter produced by this plant into a bio-resources has

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been conducted in recent years.

In Thailand, waterhyacinth was introduced into the King garden as an ornamental flower from Indonesia and has spread widely. Now it is a weed growing in canals, ponds, reservoirs near villages, lakes in lowland, dams and tributary waters along roads in the wake of road contruction, and in the water-polluted areas around the high density housing areas in the vicinity of large cities.

In this study, ecological characteristcs of Waterhyacinth populations in Thailand were investigated to gain knowlege for its possible use as a bio-resources.

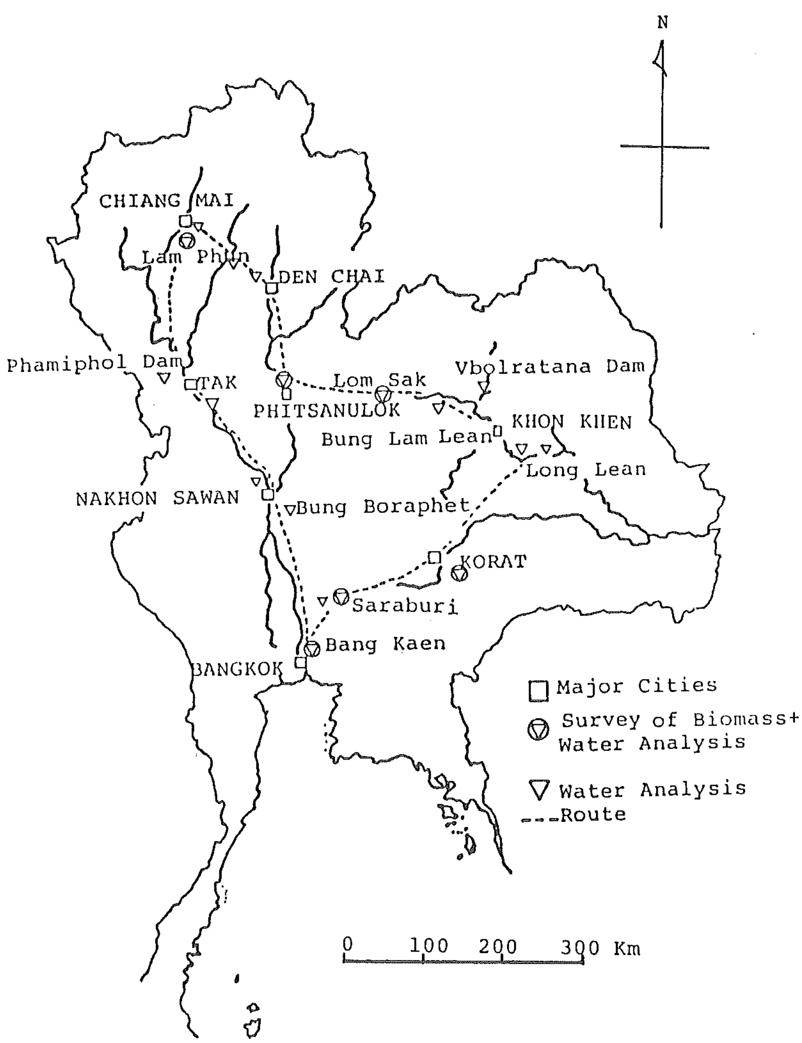

Fig. 1. Map of Thailand showing the location of the study sites where Waterhyacinth populations (○) and the physico-chemical characteristics of waters (▽) were studied.

Study Area and Methods

The field survey was carried out in Thailand from August to September in 1982. As shown in Fig. 1, the samples of Waterhyacinth for the population analysis were obtained from the pond in Khon Kaen and Korat, the pool beside the road in Lamphan, near Chein Mei, and the creek situated in the campus of Kasetsart University in Bhangkhen. Other supplementary samples for measuring individual weight and height were obtained from the river in Lomsak, the pool in Denchai and the pond in Saraburi.

The survery on Waterhyacinth populations were undertaken in a uniform and monospecific stand by harvesting the plants in the quadrat with 50×50 cm^2 area. Although the basal part of leaves was about 30 cm under the water surface, the length of the longest leaf of a plant was regarded as the height of the plant. The number of constituent individuals and the number of individual shoots were counted in each quadrat. Then the plant body was divided into four organs, blades, petioles, stolons and roots, and they were weighed in the fresh weight in the field, immediately. Next, materials were dried to a constant weight in an oven at 80°C, and were weighed in the laboratory. The biomass of Waterhyacinth population was calculated as the sum of each organ.

The Leaf Area Index (LAI) was calculated from the Specific Leaf Area (SLA) of the blades, which was measured in Lamphan and Khon Kaen. The LAI values of the population in Korat and Bhangkhen were estimated from the SLA value gained in Khon Kaen.

In Bhangkhen,the diagram of the productive structure of Waterhyacinth stand was obtained by using the stratified clip method. The areal part was vertically cut into 10 cm length classes from the base of petioles, and then each organ of each part was weighed in the fresh weight. In this study, blades were regarded as a photosynthetic organ, and petioles and underwater part were regarded as a non-photosynthetic organ.

Water quality was measured at the various locations in Thailand (Fig. 1). Their analysis were determined in the fields, directly, by the portable instruments. The value was measured with a portable pH meter (YHP Co. Ltd.), and the electric conductivity was done with a portable conductivity meter (YHP Co. Ltd.). The dissolved inorganic phosphate and the dissolved inorganic nitrogen were determined with HACH's portable water quality instrument, which was made for the field survey.

Results

The present study was carried out in the latter half of the rainy season in Thailand. In this season, a large Waterhyacinth population had developed in almost all inland waters except for the mountain regions of Thailand.

As shown in Table 1, the physico-chemical characteristics of its habitats and some inland waters evidenced the eutrophic state : the concentration of dissolved inorganic

Table 1. Physico-chemical characteristics of waters in the study sites.
WH, the habitat of Waterhyacinth. E.C., electric conductivity.
DIN, dissolved inorganic nitrogen. DIP, dissolved inorganic phosphate.

location	pH	E. C. μs/cm	DIN mg/l	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l	PO_4-P mg/l	
L. Bungborapet (lake)	7.70	182.1	0.22	0.12	0.003	0.10	0.03	WH
Nakorn Sawan (river)	8.08	174.3	0.48	0.18	0.004	0.30	0.28	
Pin River at Tak	8.02	173.3	0.30	0.10	0.002	0.20	0.01	
Phamiphol Dam	8.41	184.7	0.47	0.17	0.003	0.30	0.02	
Lamphan (pool)	6.90	259.0	0.77	0.42	0	0.35	0.14	WH
Chiang Mai (river)	7.03	252.0	1.01	0.36	0	0.65	0.12	
Mae The (river)	8.36	607.0	0.50	0.10	0	0.40	0.03	
Meran Yoru (river)	8.04	226.0	1.07	0.32	0	0.75	0.11	
Phisnulok (river)	6.12	41.5	1.63	0.53	0	1.10	0.18	WH
Huulsanemsai (river)	8.04	311.0	0.47	0.12	0	0.35	0.06	
Uoolratana Dam	8.09	180.0	0.63	0.22	0.005	0.40	0.05	
Khon Kaen (pond)	5.97	50.4	1.14	0.43	0.007	0.70	0.07	WH
Bung Lam Learn (pond)	7.53	859.0	0.89	0.33	0.005	0.55	0.11	WH
Long Leang (pond)	7.94	387.0	0.66	0.21	0.004	0.45	0.04	
Saraburi (pond)	6.77	171.0	0.87	0.32	0	0.55	0.06	WH
Pra Peaw (pond)	7.12	10.6	1.47	0.52	0	0.95	0.05	WH
Ban Non Long Charg (pond)	6.60	34.7	1.22	0.47	0.002	0.75	0.12	WH

Table 2. Morphological characteristics of each Waterhyacinth population.

location	total weight g d.w./m^2	distribution ratio (%)			leaf area index (m^2/m^2)	mean plant height (cm)
		blades	petioles	underwater part		
Lamphan	1180	22.6	52.8	22.7	5.1	79
Korat	2320	13.0	52.1	34.9	5.7	87
Khon Kaen	2310	15.8	65.0	19.2	6.9	92
Bhangkhen	1920	20.0	63.8	16.3	7.1	98

phosphate and dissolved inorganic nitrogen varied from 0.03 to 0.18 mg P/1 and from 0.22 to 1.63 mg N/1, respectively. However, no relation between the concentration of the nutrients and the distribution of Waterhyacinth was established from the results. The pH values of the waters in its habitats were neutral.

The morphological characteristics of each Waterhyacinth population about the height of population, the LAI, the distribution ratio of each organ are shown in Table 2. The population height (the average height of individuals) was 78.6 cm in Lamphan, 87.6 cm in Korat, 91.8 cm in Khon Kaen and 98.3 cm in Bhangkhen, respectively. The mean distribution ratio of each organ (percentage in weight of each organ to the whole plant body) was 17.9 % in blades, 58.4 % in petioles and 23.5 % in the underwater part, respectively. And the mean ratio (T/R) of aerial part (T) to the underwater part (R) in the Waterhyacinth populations was 3.3. The value of the LAI of each population was

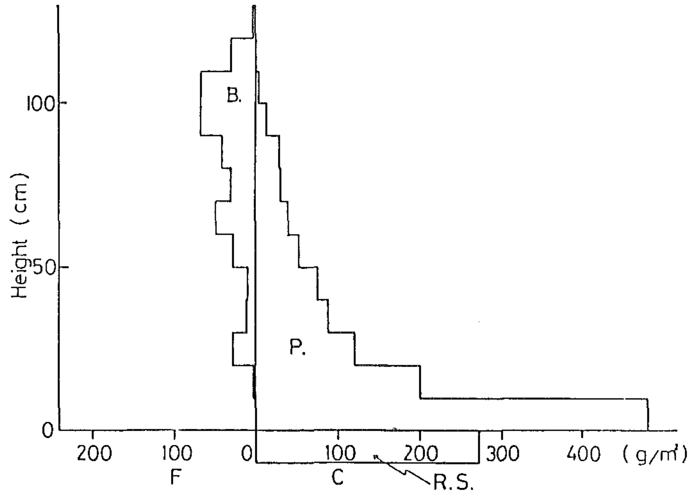

Fig. 2. The diagram of the productive structure of Waterhyacinth, *Eichhornia crassipes* (Mart.) Solms, population. F and C indicate the amount of photosynthetic organs and non-photosynthetic organs, respectively. B, P and R. S. indicate blades, petioles and underwater part, respectively.

5.1 m^2/m^2 in Lamphan, 5.7 in Korat, 6.9 in Khon Khen and 7.1 in Bhangkhen, respectively.

As shown in Fig. 2, the diagram of the productive structure of Waterhyacinth population was obtained from Bhangkhen. The tallest individual among them was about 130 cm in height and the average height was 96 cm in this population. The photosynthetic organ was concentrated in the upper part of this population. On the other hand, the petioles as the support organ were concentrated in its lower part. As above mentioned, the basal part of the petioles of this population was situated at a depth of 30-40 cm from the water surface. Therefore, when the authors assumed that its depth was 30 cm, the basal part under the water surface formed about 70 % of total petioles weight.

The characteristics of the composition of constituent plants in each population are shown in Table 3. The density of the live individuals in each population was 64 inds/m^2 in Lamphan, which was the average value of four quadrats studied at the same time, 60 inds./m^2 in Korat, 48 inds./m^2 in Khon Kaen and 32 inds./m^2 in Bhangkhen, respectively. The dead individuals were observed only in the Korat population, and the number was 12inds./m^2. The individual of Waterhyacinth is able to be divided into two parts : one is a main stock, and other is a daughter stock, namely, a new small stock which arises on the stolon streched from a main part. The density of daughter stock was 9 no./m^2 in Lamphan, which was the average value of four quadrats at the same time, 4 no./m^2 in Korat, 4 no./m^2 in Khon Kaen and nothing in Bhankhen, respectively. Therefore, the total numbers of stocks per m^2 was 73 no./m^2 in Lamphan, 64 no./m^2

Table 3. Characteristics of the individual composition of each Waterhyacinth population.

location	mean plant weight g d.w.	density (no./m²) live individuals	density (no./m²) daughter stock	density (no./m²) total stock	density of leaves no./m²	density of leaves live leaves (%)
Lamphan	15.7	64	9	73	282	51
Korat	37.6	60	4	64	169	59
Khon Kaen	48.0	48	4	52	128	81
Bhangkhen	59.9	32	0	32		

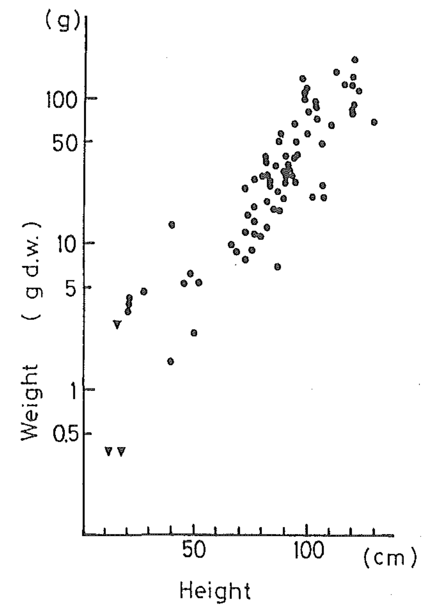

Fig. 3. The relationship between the height and the weight of an individual Waterhyacinth on semi-log coordinates growing in various places in Thailand. The regression line was shown as log (weight) $= -0.0411+0.0173$ (height) and the coefficient of correlation was 0.88. ▼ : plant with floats.

in Korat, 52 no./m² in Khon Kaen and 32no./m² in Bhangkhen, respectively. The density of leaves was 282 leaves/m² in Lamphan, 169 leaves/m² in Korat and 128 leaves/m² in Khon Kaen, respectively. And it was obvious that the percentage of the live leaves to total leaves decreased in number with the increasing density of leaves.

The average dry weight of the individuals in each population was 15.7 g in Lamphan, 37.6 g in Korat, 48.0 g in Khon Kaen and 59.9 g in Bhangkhen, respectively (Table 3).

The relationship between the height and the weight of an individual of Waterhyacinth which grew in various places is shown in Fig. 3. This shows that the relationship of both parameters is linear ($\log W = -0.0411+0.0173\,H$) on semi-log coordinates, and its coefficient of correlation is 0.88. Furthermore, the linear relationship ($\log W = -0.356 + 0.0194\ H$) between the weight of the aerial part and the height of an individual was obtained, and its coefficient of correlation is 0.93. The largest individual among all samples was collected from Saraburi, and was 196.5 g in dry weight and 121 cm in height. On the other hand, the smallest one from Saraburi was 12 cm in height and 0.4 g in dry weight. The plants with floats in their petioles were very small in size.

The individuals from Lom Sak, Saraburi and Khon Kaen had specific shape that is, the new leaves occurred on a thick stolon extended in only one direction. In these populations, there was little or no daughter stock. Both the main and the daughter stocks contained in these populations had leaves without floats. Those of Saraburi had leaves with well developed floats, and their rossette leaves exteded radially. Moreover, the daughter stocks reproduced by mother stocks was the same as that in Lamphan.

Discussion

Waterhyacinth is widespreading in the warm reions on the earth today, because of its great tolerance for temperature and polluted waters. In Thailand, however, the distribution of Waterhyacinth is not limited by the polluted waters, judging from our present study.

On the other hand, the growth of the Waterhyacinth population may be greatly influenced by the fluctuation of the water level in its habitat. From our observations in Thailand, when the water level decreases to an extreme in pools and ponds, the population of Waterhyacinth may become smaller in size, and divided into small patches. Moreover, Waterhyacinth in this habitat, which mostly dried up, changed into the smaller land form with floats in the petioles. However, the most of Waterhyacinth populations in waters maintain the large populations with large plants. The greater part of the Waterhyacinth populations studied in Thailand had a great deal of the biomass which varied from 17.9 to 38.9 kg/m^2 in fresh weight and from 1.18 to 2.32 kg/m^2 in dry weight, respectively. These values coincide with those of the previous reports in the various locations as shown in Table 4.

Table 4. Camparison of standing crop of Waterhyacinth populations in various reports.

standing crop (kg d.w./m^2)	place and data source	
2.9	Treated sewage effluent in Iowa.	Wooten & Dodd (1976)
2.3-2.5	Florida	Center & Spencer (1981)
1.28	New Orleans, Louisiana.	Penfound (1956)
1.28	Osaka, Japan	Ueki et al. (1977)
1.18-2.32	Thailand	Present study

Table 5. The values of leaf area index of some aquatic macrophyte populations.

life form	species	LAI (m^2/m^2)	locations and authors
submerged	*Vallisneria asiatica*	2.3	culture in a large concrete reservoir, Japan. (Ikusima, 1965)
	V. denseserrulata	8.5	Lake Inba-numa, Japan, 1965. (Ikusima, 1967)
	V. denseserrulata	12.5	Pond Kogo-dame, Japan, 1964. (Ikusima, 1967)
	Potamogeton crispus	4.2	culture in a large concrete reservoir, Japan. (Ikusima, 1965)
	P. malaianus	2.6	Lake Inba-numa, Japan, 1965. (Ikusima, 1967)
	P. malaianus	5.0	Lake Inba-numa, Japan, 1965. (Ikusima, 1967)
floating-leaved	*Potamogeton natans*	1.2	Urabandai, Japan, 1966. (Ikusima, 1970)
	Nymphoides indica	1.8-1.9	Lake Inba-numa, Japan, 1965, 1967. (Ikusima, 1970)
	N. peltata	1.2	Lake Suwa, Japan, Aug., 1969. (Ikusima, 1970)
	Brasenia schreberi	1.5	Urabandai, Japan, 1966. (Ikusima, 1970)
	B. schreberi	2.6	Pond Ko-numa, Japan, 1970. (Okino, 1970)
	Trapa incise	1.0	Lake Inba-numa, Japan, 1965. (Ikusima, 1970)
	T. bispinosa	1.8	Lake Suwa, Japan, Aug., 1069. (Ikusima, 1970)
	T. natnas	0.44	Lake Suwa, Japan, Summer, 1976. (Kurasawa et al., 1979)
	T. natans	2.6	Lake Kasumigaura, Japan, 1979. (Tsuchiya et al., 1983)
	T. natans	1.5	Lake Kasumigaura, Japan, 1980. (Tsuchiya et al., 1983)
emergent	*Nuphar japonicum*	1.14	Lake Suwa, Japan, summer, 1976. (Kurasawa et al., 1979)
	Phragmites communis	3.4-7.7	Lake biwa, Japan, summer, 1965. (Ikusima, 1972)
free-floating	*Eichhornia crassipes*	7.8	Florida, May. (Center & Spencer, 1981)
	E. crassipes	5.1-7.1	Thailand, 1982. (present study)
	Pistia stratiotes	3.2	Thailand, 1982. (present study)

* the value estimated from the figure in Center and Spencer (1981).

The diagram of the productive structure of Waterhyacinth population is like that of the herb type in a terrestrial plant population. Although petioles were regarded as a non-photosynthetic organ in this diagram, they may contribute to the production of this population because of their green epidermis, which use the penetrating light from the upper layer of blades.

The LAI values of Waterhyacinth populations (5.1-7.1 m^2/m^2) in the present study were larger than those of the terrestrial herbaceous population which generally ranges from 4 to 5 m^2/m^2 summerized by IWAKI (1971). The LAI values of the aquatic macrophytes reported by many authors in addition to the data of *Eichhornia crassipes*

(Mart.) Solms and *Pistia Stratiotes* L. studied in Thailand show a wide range from 0.4 to 13 m^2/m^2 (Table 5). The LAI values of Waterhyacinth populations were larger than others and close to *Phragmites communis* populations. The large LAI values of Waterhyacinth population such as in Bhangkhen may be due to their upright blade shape, which may enable those population to avoid mutual shading in spite of the dense blade growth.

To summerize the present study,the structure of the Waterhyacinth population may be able to utilize the incident solar radiation efficiently and be a great advantage to organic matter production.

It is clear that there was a relationship between the characteristics of the constituent composition within a population and its biomass. A high biomass population, for example, those of Khon Kaen and Bhangkhen, was composed of a small number of the individuals of large size. While a low biomass population, for example, those of Lamphan or the edge of a population,were composed of a large number of the individuals of small size. The relation of this plant was discussed by CENTER and SPENCER (1981).

Judging from these characteristics and the change in the amount of dead leaves in both populations, it might be suggested that the density of Waterhyactinth population decreased by the increse of the mutual shading with the growth of the population. While, judging from the difference of the amount of the daughter stocks, it may be concluded that the vegetative reproduction is active in the low biomass population and is inactive in the high population.

The population of Waterhyacinth in Korat had high biomass and high density (Table 2 and 3). It may suggest that the population is in transition from a high density population to a low one judging from the larger amount of the dead leaves and the dead plants.

As summerized in Table 6, the plant type in a low biomass population was different from that of a high one. However, it may be sure that the former type is the initial growing stage of the latter. The plant type composed of high biomass population may have an advantage of the dry matter production in crowded conditions, as noted already in the productive structure with leaves concentrated to the upper layer.

Table 6. Relationship between the population size and individual characteristics.

characteristics	high biomass population	low biomass population
individual weight	heavy	light
individual height	taller	lower
blade inclination	vertical	horizontal
form	new leaves on a thick stolon extended in only one direction	rossette extended radially
float	non-float	float

Though the plant type has not a float, it can float by the buoyancy of the petioles themselves. However, they cannot stand upright aside from the crowded condition of the population owing to their unstable form. We called them "population type" as the term.

On the other hand, the smaller plant with floats may be stable for the wave action on the edges of a population and in a running water. Therefore, its characteristics make them easy to extend the distribution area in the habitat and to colonize to other places. This type might be termed the "expansion type". The "population type" and "expansion type" are similar to the competitive stage and colonizing stage by CENTER and SPENCER (1981), respectively. However, they did not discuss on the different of the plant form under the different environmental stands, but on the change of the plant form during the growing stage of a Waterhyacinth population in a given stand. In the present study, the difference of the plant type were recongnized under the different environmental conditions independently of the growing stage of them. When there was a large fluctuation in the water level of the stand, the smaller plant with floats which is able to grow on land, in other wards "land form type", may be important for survival during the dry season and must be to play an important role in maintaining the population.

Such specific character of Waterhyacinth as the various plant type and the mode of the vegetative reproduction corresponding to the various conditions may be caused the facts in which Waterhyacinth is able to distribute into the various places of the world prevailing over the other species and to grow to a huge biomass population anywhere from the tropical to the temperate region in the world.

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