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The Spatial Distribution of Fish Species Catches in Relation to Catchment and Habitat Features in the Floodplain Lot Fisheries of Tonle Sap Lake, Cambodia

[1]Nguyen T. Hai Yen, [1]Kengo Sunada, [1]Satoru Oishi, [1]Yasusi Sakamoto, [2]Kou Ikejima and [1]Tomaya Iwata
[1]Department of Civil and Environmental Engineering, University of Yamanashi, 4-3-11 Takeda, Kofu, 400-8511, Yamanashi, Japan
[2]School of Environment, Resource and Development, Asian Institute of Technology, Pathumthani 12120, Bangkok, Thailand

Abstract: The Tonle Sap Lake area in the lower part of the Mekong River basin is the largest wetland in Southeast Asia. It contributes about 60% of the total inland fish catch of Cambodia. The floodplain fish production is an important contributor to the total catch, about 10-12 thousand tons annually from 344,308 hectares on 31 fishing lots during 1995-1999, with an average productivity of 30 kg ha^{-1}. Mapping the spatial distributions of some dominant species including *Channa micropeltes* (19%), *Channa marulius* (10%), *Trichogaster microlepis* (8%), *Pangasius hypophthalmus* sp. (7%), *Cyclocheilichthys enoplos* (5%) would support the Cambodian fisheries managers to locate the proper protected area for each specific species. The positive correlations ($p<0.05$) between *Channa micropeltes*, *Pangasius hypophthalmus*, *Cyclocheilichthys enoplos* and *Channa marulius* and the permanent water area, the inundated shrub and/or grass lands indicated the habitat preference of these species. The positive or negative correlations ($p<0.05$) between species *Channa micropeltes*, *Channa marulius*, *Pangasius hypophthalmus* sp. and *Hynicorhynchus* sp. with inundated forest, grassland, agricultural land, population, cambisol, gleysol and/or fluvisol among 29 catchment parameters indicated that these species were sensitive in responses to those catchments parameters and would significantly support the catchment management strategy.

Key words: Tonle Sap Lake, floodplain fisheries, productivity, habitat and catchments, mapping

INTRODUCTION

Tonle Sap (TS) Lake and its surrounding floodplain in the central plain of Cambodia is well known as the largest wetland in Southeast Asia (Campbell *et al*., 2006). It connects to the Mekong River though the 100 km long TS River (Fig. 1) (Keskinen *et al*., 2005). The lake area expands from 2,500 km^2 in the dry season to over 10,000 km^2 in the wet season due to the inflow of the Mekong River and lake catchment water runoff (Hak and Piseth, 1999; MRC, 2003). The TS ecosystem is the fourth most productive capture fishery in the world (Rainboth, 1996). The total annual catch, which includes the lot fisheries in the floodplain area, the bag net (Dai) fishery in the TS River, the middle scale (mobile gear) fishery and the family subsistence fishing operations, ranges between 177,000 and 400,000 tons (Van Zalinge *et al*., 2003). It contributes about 60% of total inland catch of Cambodia (Csavas *et al*., 1994; Ahmed *et al*., 1998). This total catch represents 16% to the country's

Corresponding Author: Nguyen T. Hai Yen, Department of Civil and Environmental Engineering, University of Yamanashi, 4-3-11 Takeda, Kofu, 400-8511, Yamanashi, Japan

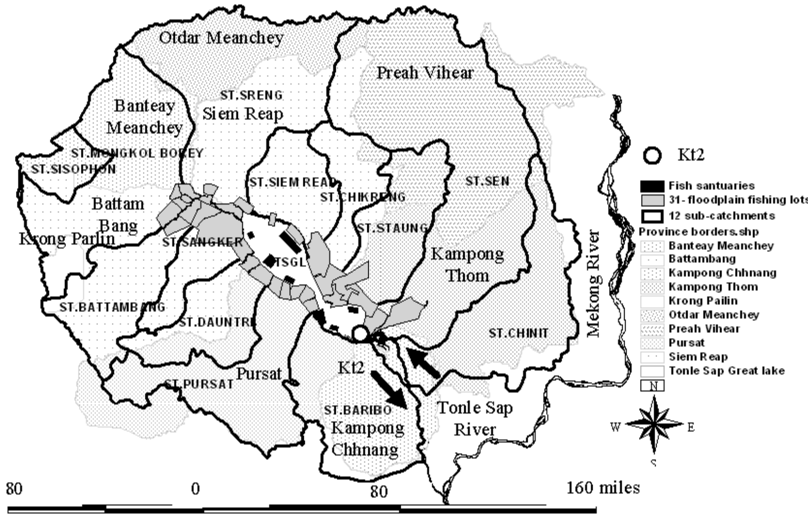

Fig. 1: Tonle Sap Great Lake, fishing lot and fish sanctuary locations, nice administrative province catchment, 12 sub-catchments. Note that the ST indicated stream, the arrows indicated water inflow and outflow from the Lake

GDP (Baird *et al*., 2003) and is the source of 60 to 80% of Cambodian's consumable animal protein (Ahmed *et al*., 1998; Baird *et al*., 2003). Especially, the TS fish catch is very important for particular about 4.2 million rural inhabitants living within the lake catchment area of 81,456 km^2 (Hak and Piseth, 1999; Leang, 2003; MRC, 2003). The lot fishery was initially set up during the French colonial period in the mid 1800s. The total area of fishing lots in the Cambodian countrywide changed over time. Data provided by the Mekong River Commission (MRC) shows that an area of more than 14,347 km^2 in 1919; 9,520 km^2 in 1940; 9,639 km^2 in 2000 and 4,160 km^2 in 2001. In the TS ecosystem, the lot areas of the five surrounding provinces were reduced from 4,631 km^2 in 2000 to 2,643 km^2 in 2001 with the aim of increasing fishing grounds for the poor. It is an industry Fishery auctioned off by the Cambodia government for a two-year period to commercial operators (The Cambodia Draft Fishing Law, 2006. http://www.apfic.org). A TS ecosystem fishing lot is typically several thousand hectares and located in the floodplain area (Fig. 1) of the lake and/or lake delta. Installing several ten km long fences along the lot boundaries and some corrals were the fishing materials and method applied in floodplain lot fishery. Note that a corral has an area (3-5 m wide and several ten m long) with three sides bordered by fences and the fourth side (towards the shore) opened as the entry gate to let fishes from lot go to corral for harvesting. The corrals are normally installed at the deepest places of the lot boundary side where it joint lake open water. The fences and corrals are only installed at the end of the floodwater receding season (Mar-May). The fishes migrating from floodplain of lot to the open lake together with water receding are trapped and caught at the corrals. After the harvesting period the installed fences and corrals are removed to aim for fishes migrating into the lot from the outside/open lake during the flood. The lot was strictly patrolled and protected from the local people's fishing activities. The annual catches of lot fishery during 1995-1999 were approximately 10,000 to 12,000 tons from 344,308 ha on 31 fishing lots around the TS Lake floodplain area. The lot fishery data for 1995-1999 were recorded by the MRC, Danish International Development Agency (Danida) and the Cambodia Department of Fishery (CDoF).

River and floodplain fish habitats have been lost, modified or fragmented because of changes in hydrological regimes caused by demands for hydroelectric power, agricultural irrigation and drinking water (MRC, 2003). Shifting cultivation practices, increased logging and encroachment have degraded watersheds and rendered resources unsustainable. Increasing agro-chemical usage from agricultural intensification and expansion as well as, increasing urban and industrial waste are believed to influence fish quality and quantity (MRC and UNEP, 1997). Analyses of relationships between floodplain fishery production and the habitat types and catchment features will aid the identification of the habitat preferences and spatial distributions for a specific targeted fish species. This information will help the Cambodians better locate proper protected areas for each particular targeted fish species and lead to better catchment environment management plans. The objectives in this study were: to examine and map the spatiotemporal distributions of floodplain fish species productivities and to identify the most variable habitat types and catchment features that most strongly influenced floodplain fish production in the TS Lake.

MATERIALS AND METHODS

Data Sources and Utilizations

The annual lot/floodplain fish catches at species level between 1995 and 1999 were recorded by the Mekong River Commission (MRC)/Danish International Development Agency (Danida) and the Cambodia Department of Fisheries (CDoF). Note that fishing lots in the TS Lake are located in five provinces, namely Kampong Chhnang, Battam Bang, Siem Reap, Kampong Thom and Pursat (Fig. 1). Of these, the lots in Kampong Chhnang typically locate in the river in the Lake delta (Fig. 1) were not taken into account in this study. Among 33 fishing lots locate in the floodplain area surrounding the lake, only 31 floodplain fishing lots, where the fish catches were fully recorded during 1995-1999, were taken into account for analysis in this study. The lot and species productivities were standardized by area (kg ha^{-1} year^{-1}) due to the heterogonous areas of the lots. Example, the largest was lot Bt2 (50,483 ha) in Battam Bang, while the smallest is lot Kt2 (2,455 ha) in Kampong Thom.

The fish catch data from these 31 fishing lots during 1995-1999 was used to analyze the temporal trends of lot and species productivities. The species productivities of 30 fishing lots were used to analyze the spatial distributions of fish productivities and their interactions to lot habitat types to identify fish species' habitat preferences. The lot Kt2 in Kampong Thom was not taken into account because it locates at the bottle neck position of receding channels where the floodwater outflow from the Lake to the TS River (Fig. 1). Fish species productivities of 12 relevant fishing lots and catchment features of eight associated sub-catchments were used to analyze the relationships between fish production and catchment environmental condition. The 12 relevant fishing lots and eight associated sub-catchments were selected based on their locations, where a lot would be possibly directly influenced by its associated sub-catchment. The pairs of selected lot and sub-catchment were as followings: Bt2 and Sangker; Bt7 and Battam Bang; Bt10 and Bt12 and Mongkol Borey; Kt1 and Sen; Kt4 and Staung; Ps1 and Dauntri; Ps4, Ps5 and Ps6 and Pursat and Sr4 and Sr5 and Siem Reap (Fig. 1). Noticeably, the small Sisophon sub-catchment was integrated in the Mongkol Borey sub-catchments. Additionally, the number of fishing gears of middle scale fisheries in the open lake analyzed in our previous research part (unpublished) was used to evaluate the influence of middle scale fishing practice on floodplain fish production.

Cambodia land use and soil type classifications and catchments' population census data in 1997 were provided by the MRC and CDoF. The annual discharge (m^3 sec^{-1}) and water runoff (mm) from 12 sub-catchments surrounding the lake between 1995 and 1999 were accessible in WUP-FIN (Water Utility Program-Finland) hydrological model.

The Cambodia land use Data in 1997 provided by the MRC was used to calculate: (1) habitat types by fishing lots based on six major land cover categories as followed: permanent water, inundated forest, inundated shrub, grass, agriculture and dry shrub lands and (2) land use types of 12 main sub-catchments around the TS Lake. The sub-catchments land use types were classified based on ten major groups including (dry) forest, inundated forest, (dry) wood and shrub, inundated wood and shrub, grassland, agriculture land, barren land, rocky, urban land and water.

The Cambodia soil type data provided by the MRC was used to calculate the sub-catchments soil types based on nine main soil types including acrisol, arenosol, cambisol, ferralsol, fluvisol, gleysol, leptosol, luvisol and plinthosol.

The data of water discharges (m^3 sec^{-1}) and the annual runoff (mm) from 12 sub-catchments (Fig. 1) during 1995-1999 provided by WUP-FIN (Finland Water Utilization Program) were used as the sub-catchments hydrological parameters. Finally, the Cambodia population data in 1998 provided by the MRC was used to calculate the 12 sub-catchments population sizes and densities.

Technical Application and Statistical Test

The main four tasks of the data analyses in this study were: (1) calculation of lot and species productivities (kg ha^{-1}) and habitat types and sub-catchment features, (2) identification of the most variable habitat types and catchment features/parameters, (3) analysis of the relationships between fish productivities and habitat types and/or catchment parameters and (4) mapping the spatial distributions of some dominant species. The schematic plan of data analysis and methodology of this study is shown in Fig. 2.

Geological Information System (GIS) technique was used to: (1) calculate area of habitat types for every fishing lots based on land use data, (2) calculate the area of catchment land cover for each of eight associated sub-catchment based on land use data and (3) calculate population, population density, and soil types for eight sub-catchment. Finally, GIS was employed to map the spatial distributions of lot and or species productivities based on their catches for the period 1995-1999.

Principal Component Analysis (PCA) is a multivariable analysis technique, a way of identifying patterns in data and expressing the data in such a way as to highlight their similarities and differences based on covariance. The other main advantage of PCA is that once you have found these patterns in the data and you compress the data i.e., by reducing the number of dimensions, without much loss of

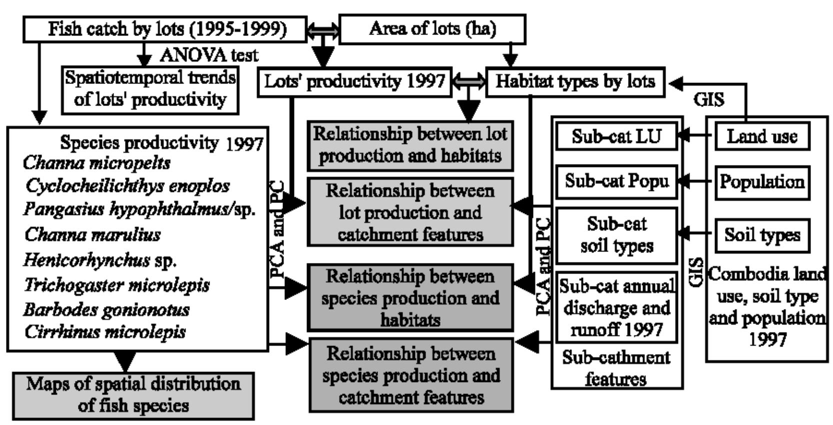

Fig. 2: Schematic data analyses of the relationships between lot fishery production and habitat and catchment features. Note: PCA was Principal Component Analysis, PC was Pearson correlation, LU was land use, GIS was geological information system

information (McGarigal *et al*., 2000; Smith, 2002). In this study, PCA was used to project the multi-relationships between fish species productivities and lot habitat types and or catchment environmental parameters based on data in 1997. On the two-dimensional ordination the most variable parameters that most strongly influenced fish production were identified.

Pearson correlations were used to explore: (1) the relationships between fish species productivity and habitat type and or catchment environmental features spatially and (2) the relationship between the number of fishing gears used in middle scale fishery and floodplain fish production during the period 1995-1999. ANOVA test was applied to check the variations of the temporal trends of fish productivities by lots to identify the lots where fish productivities varied positive, negative or no trends.

RESULTS

Spatiotemporal Spatial Distribution of Floodplain Fish Productivity

The annual fish catches of four provinces and the average productivities of 31 fishing lots of the TS Lake floodplain fishery during 1995-1999 are shown in Fig. 3a, b. The total annual lot catches were not much different (10,000-12,000 tons) from year to year during the sample period. The area of lots

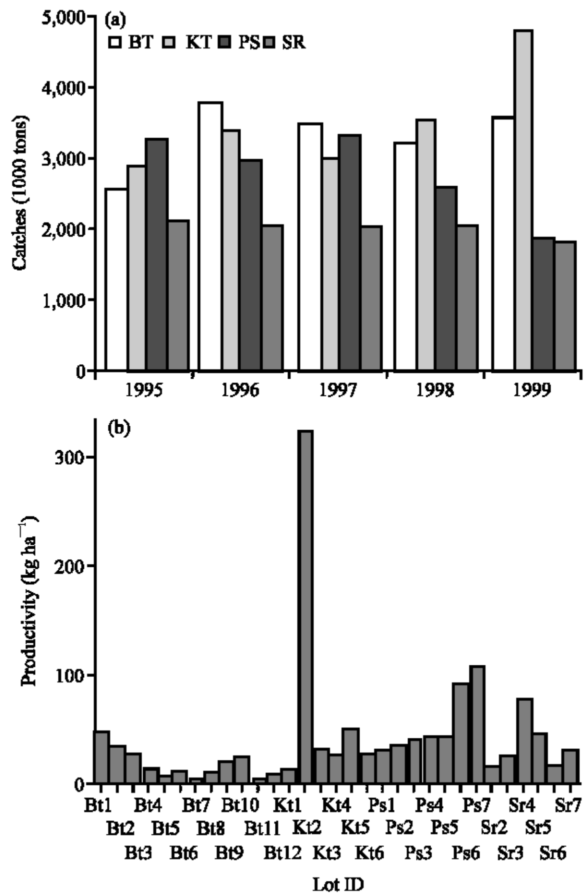

Fig. 3: (a) Tonle Sap floodplain annual catches in four provinces and (b) the average lot productivities (kg ha^{-1})

by provinces was 145,382 ha in Battam Bang; 100,439 ha in Kampong Thom; 73,124 ha in Siem Reap and 54,415 ha in Pursat. Battam Bang and Kampong Thom were the larger contributors to the total annual lot fishery catches; Siem Reap was the smallest contributor. Pursat lot fish catches were high during 1995-1997, but abruptly decreased in 1998 and 1999 (Fig. 3a). The average yearly lot productivities were low, between 31 to 35 kg ha^{-1} $year^{-1}$. In general, with exception of lot Kt2 (about 300 kg ha^{-1}), the average lot productivity was highest, from 30 to above 100 kg ha^{-1} $year^{-1}$, in Pursat province in the Southwest center of the lake, while the lowest fish productivity, from 4 to 45 kg ha^{-1} $year^{-1}$, in Battam Bang province in the Northwest of the lake (Fig. 3b). The significant ANOVA test ($p<0.000$) indicated the different temporal trends of productivities among 31 lots. The most variation (above 100 kg ha^{-1} $year^{-1}$ standard deviation) was lot Kt2, where the fish catches increased from about 200 to 500 kg ha^{-1} during 1995-1999. The next variations (20-40 kg ha^{-1} $year^{-1}$of standard deviations) were lots Ps6, Ps7 and Sr4. The productivities of lot Ps6 and Ps7 in Pursat province and lot Sr4 in Siem Reap province abruptly decreased from about 140 in 1995 to 40 kg ha^{-1} in 1999. The productivities of the remaining lots were slightly variable by years with standard deviation about 10 or less than 10 kg ha^{-1} $year^{-1}$. The productivities of lot Bt2 in Battam Bang slightly increased from about 20 to 40 kg ha^{-1} during the sample period. In Pursat province, the total annual lot catches decreased from about 3,000 in 1995 to 1,800 tons in 1999. Inversely, the numbers of active mobile gears (active gear pertaining to any type of gears being used in the fishing ground of the middle scale fishery in the open lake) increased from about 40,000 to 58,000 in the same period (Unpublished). There was a relatively high correlation between (Pearson correlation test: $r = -0.77$; $p = 0.064$) the numbers of middle scale fishing gears used and floodplain lot fishery catches annually in Pursat province. However, there were low correlations between numbers of active gears and lot catches in the other three provinces.

There were 70 fish species of 35 families taxonomically recorded from floodplain lot fishery catches during 1995-1999. The family Cyprinidae was the largest contributor (31%) to the lot catch, particularly *Cyclocheilichthys enoplos*, *Henicorhynchus* sp. and *Barbonymus gnionotus Cirrhinus microlepis* and *Osteochilus melanopleurus*, which contributed 6, 4 and 4%, 3.1 and 2.7% to the total lot catch respectively. The second contributor to the lot catch was the family Channidae (29%), particularly *Channa micropeltes* and *Channa murulius*, which contributed 19 and 10% to the catch respectively. Additionally, *Pangasius hypophthalmus*/sp. of Pangassidae family and *Trichogaster microlepis* of Osphronemidae family also contributed 7.2 and 8.1%, respectively to the lot catch. The spatial distribution mappings of these dominant species productivities by lots for the period 1995-1999 and the lot IDs by provinces are shown in Fig. 4. Spatially, the highest lot productivities were in lots Ps6, Ps7 and Sr4, while the lowest lot productivities were in lots Bt5, Bt6, Bt7, Bt8, Bt.11 and Bt12 in the Northern part floodplain (Fig. 4a). At single species, *Channa micropeltes*, *Channa marulius* and *Trichogaster microlepis* were more distributed in the floodplain area of the Northwest centre of the lake (Fig. 4b-d) and *Pangasius hypophthalmus* sp., *Cyclocheilichthys enoplos*, *Barbonymus gnionotus* and *Cirrhinus microlepis* were more distributed in the Southwest center floodplain of the lake (Fig. 4e-i). Noticeably, the percentage in each piece of Fig. 4 showed the proportion of that species in the total lot fish catch for the period 1995-1999.

Relationship Between Habitat Type, Catchment Environmental Feature and Fish Species Productivity

Fish species productivities in 1997 were very different among lots spatially and ranked between 0 and 25 kg ha^{-1}; with most less than 10 kg ha^{-1}. Seven dominant fish species productivities by lots are showed in Fig. 5. The higher productivities (18-25 kg ha^{-1}) of *Channa micropeltes* were at lots Bt1, Ps6 and Ps7 and Sr2. The higher productivities of *Cyclocheilichthys enoplos*, *Pangasius hypophthalmus*/sp. (13-18 kg ha^{-1}) and *Barbonymus gnionotus* (10 kg ha^{-1}) were at lots Sr5

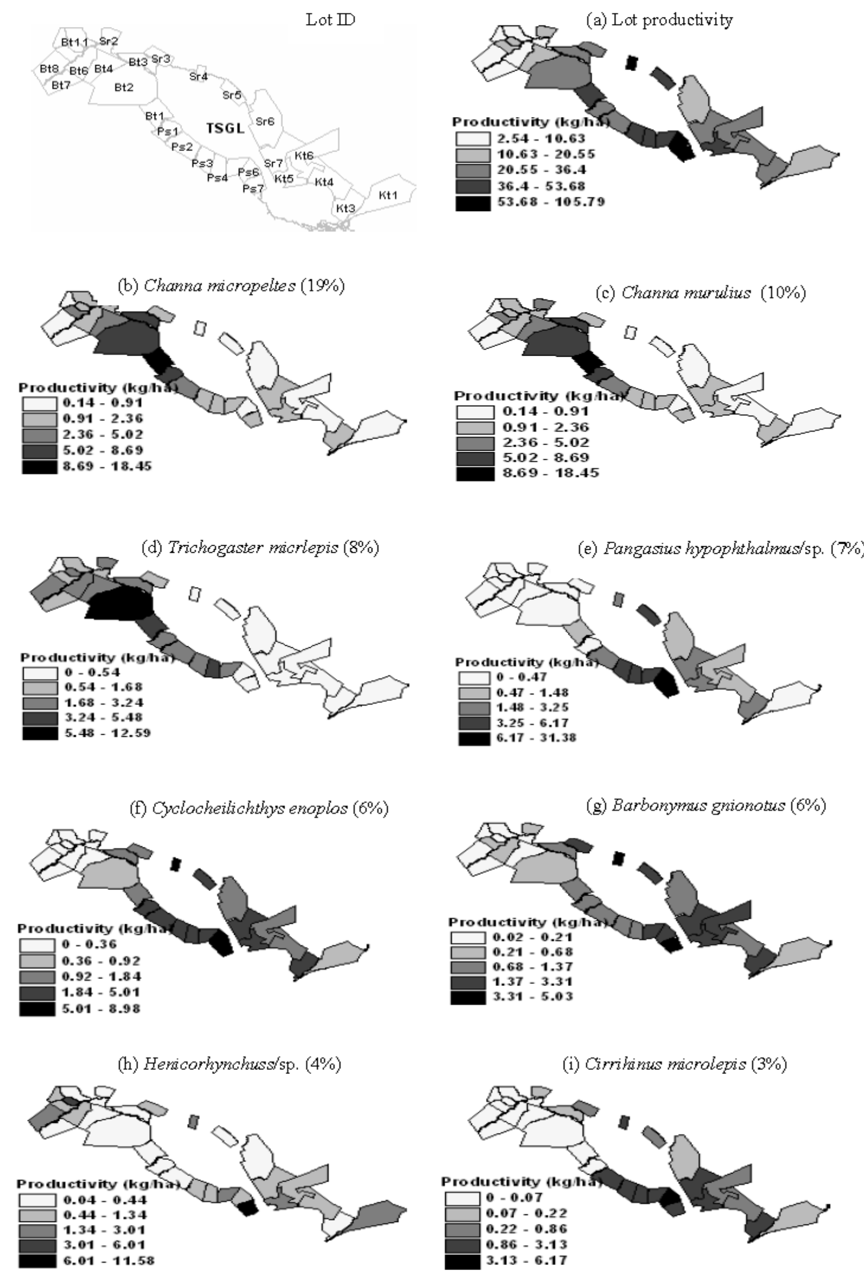

Fig. 4: Lot ID and the spatial patterns in harvest of eight dominant species in Tonle Sap lake, averaged for the period 1995-1999

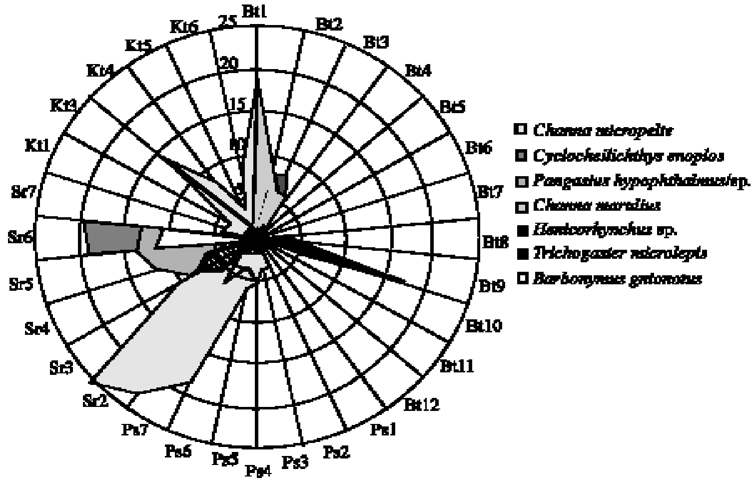

Fig. 5: Seven dominant fish species productivities in 1997 at 30 fishing lots

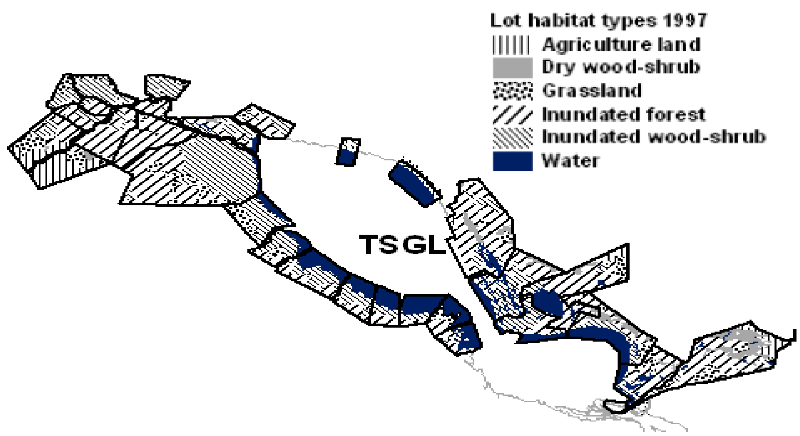

Fig. 6: Habitat types by six major land use categories in 1997 of 30 lots

and Sr6. The highest productivity (17 kg ha^{-1}) of *Channa marulius* was at lot Bt1. The productivity of *Henicorhynchus* sp. was highest (17 kg ha^{-1}) at lot Bt10 and the productivity of *Trichogaster microlepis* was highest (5-7 kg ha^{-1}) at lots Sr2, Sr3 and Sr4.

Six major habitat types, namely permanent water, inundated forest, dry shrub, inundated shrub, grass and agriculture land, of 30 fishing lots (excluding lot Kt2) calculated from of the Cambodia land use in 1997 are shown in Fig. 6. The highest percentages (70%) of inundated forest habitats were found in lots Bt4, Bt5, Bt6, Bt9 and Bt10 in Battam Bang; the next (50%) were in lot Kt3, Kt6 in Kampong Thom and Sr6 in Siem Reap. The highest percentages (50%) of shrub habitats were found in lots Bt1, Bt3, Bt11 and Bt12 in Battam Bang and Sr2 in Siem Reap; the next (40%) were lots Bt2, Kt5, Ps1, Ps3, Sr3 and Sr7. The highest percentage of grassland (34%) was found in Bt12. The dominant agricultural lands (70 and 30%) were found in lots Bt7 and then Bt8. The highest percentages of permanent water habitats (50%) were found in lots Ps5, Ps6, Ps7, Sr4 and Sr5. The next (30%) were lots Kt4, Ps2, Ps3 and Ps4, but there was no permanent water in eight lots (Bt5-Bt12) in Battam Bang.

Table 1: Area, population and hydrological features of eight sub-catchments selected

Sub-catchments	Total area (1000 ha)	Inhabitants	Population density (km^{-2})	Annual discharge ($10^9 m^3$)	Annual runoff (10^6 mm)	Associated fishing lots and sub-catchments
Sangker	237.8	47,451	20	3.3	561	Bt1
Battam bang	434.2	368,163	85	3.3	561	Bt7
Mongkol Borey	1,040.3	801,826	77	1.0	105	Bt10, Bt12
Sen	1,627.1	320,934	20	6.3	40	Kt1
Staung	437.2	148,822	34	0.5	149	Kt4
Dauntri	354.6	215,159	61	0.4	129	Ps1
Pursat	590.9	180,400	30	3.2	559	Ps4, Ps5, Ps6
Siem reap	306.1	360,185	118	1.3	433	Sr4, Sr5

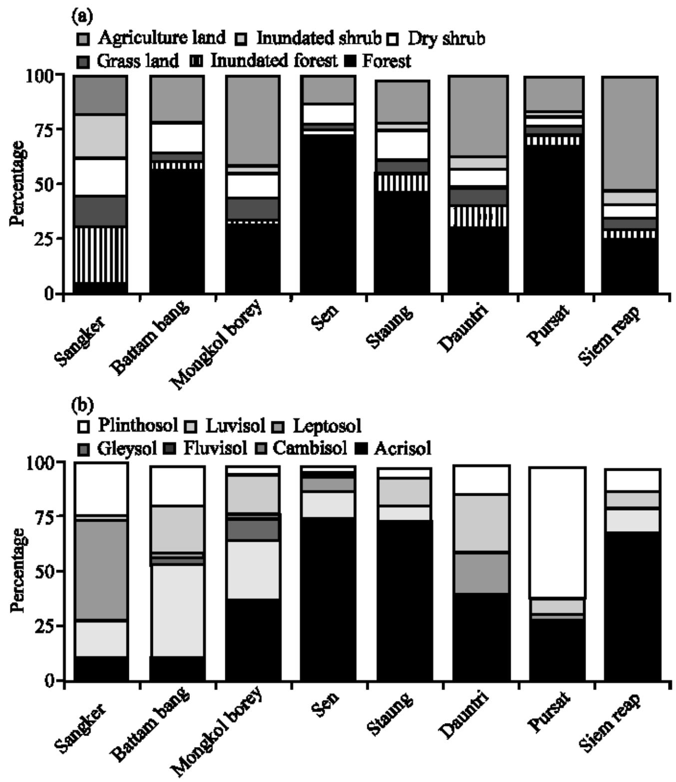

Fig. 7: Cumulative (%) of land use types (a) and soil types and (b) in 1997 of eight sub-catchments

The features of eight sub-catchments that were highly associated with 12 selected fishing lots are shown in Table 1. Of these, the largest sub-catchments were Sen (1,627,100 ha) and Mongkol Boery (1,040,300 ha), while the smallest were Sangker (237,800 ha) and Siem Reap (306,100 ha). In Table 1, the second smallest sub-catchment, Siem Reap, had the highest population density (118 individuals km^{-2}). The largest sub-catchment, Sen, had the lowest population density (20 individuals km^{-2}) and the lowest annual runoff (40×10^6 mm) and the highest annual discharge (6.3×10^9 m^3). While the smaller sub-catchments, included Sangker, Battam Bang and Pursat, had the largest volume of annual runoff (500×10^6 mm).

The cumulative percentages of six major land use types, namely forest, inundated forest, grass, dry shrub, inundated shrub and agriculture lands, of eight sub-catchments are shown in Fig. 7a. The highest percentage of forest cover (70%) was found in Sen and Pursat sub-catchments; the highest percentage cover of inundated forest (30%), grassland (10%), dry (20%) and inundated (20%) shrub were found in Sangker sub-catchment. The highest percentages of agriculture land were in Siem Reap (50%), Mongkol Borey and Dauntri (40%). The cumulative percentages of seven major soil types of eight sub-catchments are shown in Fig. 7b. Of these, Acrisol soil type was dominantly (70%) distributed in the highlands of Siem Reap, Sen and Staung sub-catchments in the Northeast of Lake catchment. Cambisol were most common (30%) in Mongkol Borey and Battam Bang sub-catchments in the Northwest. Gleysol was distributed in the inundated area around the lake and was most dominant in Sangker sub-catchment. Leptosol was more distributed in Pursat and Dauntri sub-catchments in the Southwest centre of lake catchment. Luvisol was more distributed in Mongkol Borey, Sangker and Battam Bang sub-catchments in the Northwest.

Lot productivity and seven dominant fish species productivities, the areas and percentages of five major lot habitat types in 1997 and total lot area of 30 fishing lots were projected by PCA (Fig. 8a). Note that the fish species name was shortly written; example *Channa micropeltes* was written as *C. micropeltes*, the lot production was shortly written as Lot_prod. The dark dots were the distributions of 30 fishing lots. The Fig. 8a showed the two-dimensional ordination illustrating the variable variation and inter-correlation among habitat types and fish species productivities. On PCA, the length of a variable, indicates the degree of the variation of that variable, i.e., the longer the axis, the more variation of that variable; while the correlation between any two variables is related to the cosine of the angle between their variable-axes. Two variables separated by small angle are highly positively correlated; two variables separated by a large angle are highly negatively correlated and two variables separated by a right angle are uncorrelated or independent. Then obviously, there were highly positive correlations among the variables including lot and species productivities of *Pangasius hypophthalmus* sp., *Cyclocheilichthys enoplos*, *Barbonymus gnionotus* and the large area and the high percentage of permanent water that grouped in the right-bottom quadrant. Similarly, there were highly positive correlations among the variables including lot area, the area and percentage of shrub land, forest and *Channa marulius* in the left-bottom quadrant. The PCA result showed five components with bigger than 1of Eigenvalue, the low correlation coefficients 27.97 and 16.00% of component 1 and 2, respectively resulted in less correlations of inter-relationship among species productivities and habitat types, less variations of all these variables and the centred distributions of 30 fishing lots on PCA. Among fish species productivities, *Pangasius hypophthalmus*/sp., *Cyclocheilichthys enoplos* and *Barbonymus gnionotus* had the high correlation coefficients (>0.70) on component 1. While the habitat types were generally low correlations, the highest was percentage of permanent water area (0.87), the next were grass land (-0.61) and permanent water area (0.59). However, on the component 2, the high correlation coefficients among lot habitat types were shrub land (-0.79) and agricultural land (0.53); while the high correlation coefficients among fish productivities were *Channa marulius* (-0.51) and then *Channa micropeltes* (-0.45). These high correlation coefficients indicate that these habitat types and species productivities are more varied among 30 fishing lots.

Similarly, productivities of lot and seven dominant fish species from 12 selected fishing lots and the eight land use and six soil types and population size and density, urban area and annual discharges and runoff from eight associated sub-catchments in 1997 were projected by PCA (Fig. 8b). Note that the dark dots in Fig. 8b were the distributions of 12 selected fishing lots; the abbreviations of Popu- and In- indicated the population and inundated meanings, respectively. Compared to the inter-correlation between fish productivities and habitat types, the higher correlation coefficients of component 1 and 2 (35.14 and 20.73%, respectively) on PCA indicate that the higher inter-correlation among fish species productivities and catchment features and the more variations of the catchment parameters among eight sub-catchments; resulting in the wider distribution of 12 fishing lots on PCA. On component 1 or 2; grass land, dry wood shrub and agricultural land of land use types, cambisol

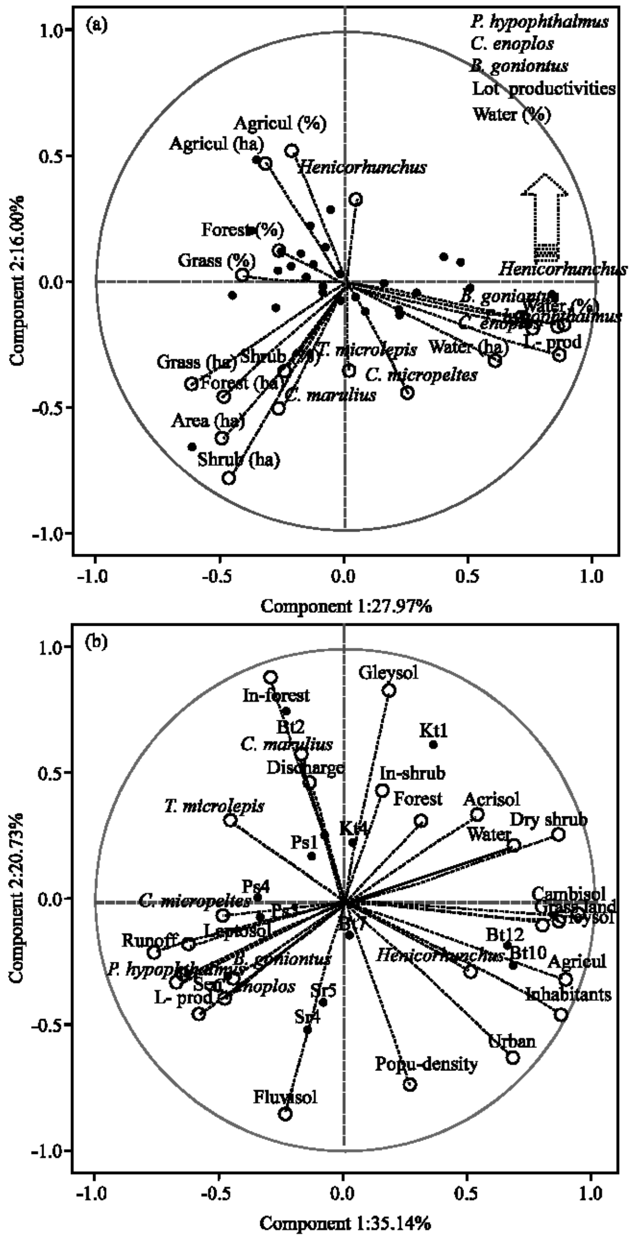

Fig. 8: Multi-relationships between (a) lot and fish species productivities and habitat types of 30 fishing lots and (b) catchment environmental features of 12 selected fishing lots and 8 associated sub-catchments

and luvisol soil types and population were high positive correlations (>0.70), while the annual water runoff was high negative correlation (<-0.70) on component 1. Inundated forest and gleysol soil were highly positively correlated, while the fluvisol soil and population density were negatively correlated on component 2. However, all fish species and lot productivities had low correlations on both component 1 and 2. Additionally, there were high positive correlations between annual runoff and

Table 2: Correlations between lot and fish species productivities and lot habitat types, catchment land use and soil types, population and annual runoff

		Lot and species productivities in 1997 (kg ha^{-1})						
	Parameters	Lot	*C. micropeltes*	*C. enoplos*	*P. hypophthalmus*/sp.	*C. marulius*	*Henicorhynchus* sp.	*B. gonionotus*
Lot habitat types	Shrub (ha)	-0.13	0.11	-0.14	-0.21	0.40*	-0.22	-0.14
	Grass (ha)	-0.28	-0.11	-0.17	-0.31	0.39*	-0.18	-0.14
	Water (ha)	0.42*	0.35	0.33	0.52*	-0.17	-0.16	0.34
	Water (%)	0.74*	0.39*	0.55*	0.76*	-0.21	-0.03	0.50*
Catchment land use types	Inundated forest (ha)	-0.09	0.18	-0.07	-0.11	0.76*	-0.34	-0.04
	Grassland (ha)	-0.31	-0.40	-0.31	-0.39	0.00	0.63*	-0.25
	Inundated wood-shrub (ha)	-0.04	0.16	-0.14	-0.36	0.77*	0.10	-0.14
	Agriculture (ha)	-0.25	-0.33	-0.25	-0.40	-0.22	0.62*	-0.24
	Cambisol (ha)	-0.55	-0.63*	-0.41	-0.55	-0.20	0.50	-0.35
Catchment soil types	Fluvisol (ha)	0.61*	0.19	0.37	0.52	-0.50	0.14	0.33
	Gleysol (ha)	-0.23	-0.06	-0.21	-0.32	0.65*	-0.05	-0.16
	Leptosol (ha)	0.51	0.15	0.36	0.90*	-0.13	-0.05	0.43
Other	Inhabitants/population	-0.28	-0.39	-0.25	-0.39	-0.33	0.60*	-0.25
	Annual runoff (mm)	0.46	0.17	0.31	0.60*	0.05	-0.26	0.36

*: Indicated the significant statistical test ($p<0.05$)

Pangasius hypophthalmus/sp., *Cyclocheilichthys enoplos* and *Barbonymus gnionotus* productivities within the group in the left-bottom quadrant while these were high positive correlation between *Henicorhynschus* sp. and cambisol soil, agricultural land, grass land, population and urban area within the group in the right-bottom quadrant. However, there were negative external correlations between the variables from these two groups because these two groups situated in the opposite orientations on component 1. Lots Ps4, Ps5 and Ps6 located in the area of the group in the left-bottom quadrant, lot Bt10 and Bt12 located in the area of the group in the right-bottom quadrant, while lot Bt2 located closely to the variables of inundated forest and *Channa marulius.*

The Pearson correlation test for each pair of variables (one species productivity and one habitat type or catchment parameter) is shown in Table 2. Lot productivity had positive correlations ($p<0.05$) with percentage and area of permanent water habitat and fluvisol soil. *Channa marulius* productivity was positively correlated with scrub and grass habitats and catchment inundated forest, shrub lands use types and gleysol soil; *Channa micropeltes* was positively correlated with large (%) area of water habitat and negatively correlated with Cambisol soil; *Pangasius hypophthalmus*/sp. had positive correlations with both percentage and area of permanent water habitat type, leptosol soil and annual runoff; *Cyclocheilichthys enoplos*, *Barbonymus gnionotus* had positive correlations with percentage of permanent water habitat; *Henicorhynchus* sp. was positively correlated with catchment grass and agriculture land use types.

DISCUSSION

Although there are about 70 fish species recorded from floodplain fisheries, the TSGL is typical a tropical ecosystem where the fish community are dominated by few species (Sverdrup-Jensen, 2002). The large contribution to total fish catch during 1995-1999 of *Channa micropeltes* (19%), *Channa marulius* (10%), *Pangasius hypophthalmus*/sp. (7%) and *Cyclocheilichthys enoplos* (6%)

indicate that the TSGL floodplain is very important habitat for these *k* species. A *k* species is large fish, slow-reproducing and growing species that produce few offspring and have a high energy demand (Chappman and Reiss, 2000). The TSGL floodplain was said as the important sheltering, spawning and feeding grounds for large species (Lamberts, 2001; Lim *et al*., 1999). Family Cyprinidae, the more longitudinal migratory and omnivorous species, contributes 31% to floodplain fish catches during 1995-1999 indicating that the TS floodplain is very important migration ground for migratory fish species. The 29% of floodplain fishery catch contributed by *Channidae* indicates that the floodplain is very important habitat for benthopelagic and more carnivorous species. *Channa micropeltes*, *Channa marulius* and *Trichogaster microlepis* are the lateral migrants (migration between the floodplain and open water), prefer standing or slowly flowing water and feed on fish, crustacean, aquatic insect and zooplankton (*Trichogaster microlepis*) (Froese and Pauly, 2006). Species distribution mapping results (Fig. 4) show that *Channa micropeltes*, *Channa marulius* and *Trichogaster microlepi* are more distributed in the inundated shrub habitat located in the North-west central floodplain. While, the lake coastal habitats in the Southwest of the Lake (lot Ps5, 6 and 7 in Pursat) are important visiting migration grounds along the migratory route of *Pangasius hypophthalmus*/sp., *Cyclocheilichthys enoplos*, *Barbonymus gnionotus* and *Osteochilus melanopleurus*, the typically longitudinal migratory (migration between floodplain, open water and the TS and Mekong Rivers) and more omnivorous species. The significantly positive correlations ($p<0.05$ Pearson correlation tests) between *Channa marulius* and shrub and grass habitats and between *Pangasius hypophthalmus*/sp. and the habitat of large permanent water area represent the habitat preferences of these two species. Similarly, Lim *et al*. (1999) and Lamberts (2001) found species feeding on benthic communities were more abundant in forest areas and the species feeding on phytoplankton and zooplankton were more common in the open lake and river habitats of the TS ecosystem. Obviously, these results would help Cambodians to better understand the critically important functions of floodplain habitats to maintain their fisheries resources. These results also support the Cambodian fisheries resource conservation programs to better identify specific important locations ecologically and then possibly to relocate the exiting fish sanctuaries (Fig. 1) to the proper locations for each targeted species.

The PCA analysis of the multi-correlation between the species productivities and habitat types (Fig. 8a) showed that the fish productivities had little variation among 30 fishing lots spatially; this may be caused by wide range of biological attributes and environments of the tropical fish species. Similarly, fish species productivities did not vary much in the multi-correlation analysis between fish productivities and catchment features (Fig. 8b). However, the large angle between the group of variables in the right-bottom quadrant and group of variables in the left-bottom quadrant (Fig. 8b) indicates the potential influences of these catchment features on these fish species production. These catchment features include grass, agriculture land uses, population size and urbanization. In particular, the catchment inundated forest and shrub are very important ecological functions related *Channa marulius* production due to the positive correlations ($p<0.05$) between these land use types and *Channa marulius* productivity (Table 2). Lamberts (2001) found the lowest fish production in rice and lotus field habitats, where diversity is actively reduced by agriculture activities in the TSGL ecosystem. Fitzpatrick *et al*. (2005) found the high scores of fish biological integrity index occurred in streams with less than 25% watershed urban land and the low scores of fish biological integrity index in the higher percent of watershed urban land among 45 streams in the Chicago. Therefore, this should be paid more attention in the TS ecosystem catchment land use management plan towards sustainable fishery resources. In relation to soil types, the correlations ($p<0.05$) between *Pangasius hypophthalmus*/sp. and leptosol, between *Channa micropeltes* and Cambisol and between *Channa marulius* and gleysol indicate that these soil types were influential factors on floodplain fish production in the TS ecosystem. However, the linkages between chemical and physical processes of these soil types and the biological process of fish growth and spawn should be studied further. There are positive correlations ($p<0.05$) between of *Henicorhynchus* sp. and grass, agriculture land use types and population size (Table 2). This may be because an opportunistic biological attribute of *Henicorhynchus* sp. (Van Zalinge *et al*., 2003) to adapt the changes of the environment condition to survive and recover population of this species. The strong positive correlation between catchment water runoff and *Pangasius hypophthalmus*/sp. productivity indicates that the importance of catchment water runoff (mm) to this species production. However, to understand better the influence of water runoff on this species' production, detailed studies on the synchronization between timing, duration and continuity of runoff water and life history such as spawning and nursing season and grounds of *Pangasius hypophthalmus*/sp. are necessary.

The average fish productivity in particular of 30 fishing lots in the floodplain area of the lake during 1995-1999 was low (31-35 kg ha^{-1} $year^{-1}$). This is similar to floodplain fish productivity 25-52 kg ha^{-1} $year^{-1}$ in Thailand (MRAG, 1994), but it is much lower than in Bangladesh, with a natural floodplain fish productivity of 104-130 kg ha^{-1} $year^{-1}$ (Hoggarth and Halls, 1997). This difference may be due to the different determinations of the floodplain area. Example, in this study, the floodplain was determined to the fine scale of lot fishery. While all the open water, floodplain and rice field of the TS Lake and TS River were determined as the TS floodplain (IFReDI, 2001). Floodplain fish production of the TS ecosystem was estimated between 139-190 kg ha^{-1} $year^{-1}$ by the expression between total annual fish catch of all types of fisheries and the area of surface water at 9.36 m high of water level (IFReDI, 2001). Note that the total fish catch used included lot fishery in the floodplain, bag net (Dai) fishery in the TS River, middle scale (mobile gears) in the open water of the lake and family scale in the open water of the lake and rice-fields. The total annual catches of lot fishery are not much different during the sample period; however the causes of gradually increasing fish productions in particular lot Bt2 in Battam Bang is unknown so far. The rapidly decrease of fish productions in particular lots Ps6 and Ps7 in Pursat are possibly because of the rapidly increasing of numbers of fishing gears of middle scale fishery in Pursat province. This important information would support Cambodian fisheries managers to improve exploitation policies. The further studies of environment, habitat and fishing technique that potentially influence fish production at these particular locations are necessary.

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