Journal of Environmental Engineering and Management, Vol. 16, No. 5, pp. 333-341 (2006)

A COMPARATIVE STUDY ON KEY FACTORS OF SUSTAINABLE DEVELOPMENT RELATED TO BIOMASS PRODUCTION IN THREE MAJOR RIVER BASINS IN TAIWAN

Chung-Fang Ho Chang,[1,*] Ping-Lun Huang,[2] Yi-Hung Chen[3] and Ching-Yuan Chang[2]

[1]Department of International Trade
Chung Yuan Christian University
Tao-Yuan 320, Taiwan
[2]Graduate Institute of Environmental Engineering
National Taiwan University
Taipei 106, Taiwan
[3]Department of Chemical and Material Engineering
National Kaohsiung University of Applied Sciences
Kaohsiung 807, Taiwan

Key Words: Biomass, biomass production, agricultural production, Choushui River Basin, Tamsui River Basin, Gaobing River Basin, Taiwan

ABSTRACT

This study analyzed the variations of the biomass (including crop, forestry, fishery and livestock) production in the Choushui River Basin in the middle Taiwan to establish the useful information and indicators. The material production of biomass materials (MPB) during 1987 to 2002 were computed from the available date and assessed. The results revealed that the contribution of rice planting in the Choushui River Basin had decreased recently. Accordingly, the contribution of rice production (M_R) in the Choushui River Basin for the whole rice product (M_{RTWN}) in Taiwan also reduced as well. The values of M_R/M_{RTWN} with the slight variation had the average value of 8.3% with the maximum and minimum values of 9.2% in 1988 and 6.9% in 1999, respectively. Furthermore, MPB in the Choushui River Basin generally increased before 1993 and after 1997, and had the lower value in 1994-1996 (968,670-1,020,550 tons). In overall, the values of MPB were 961,760 and 1,265,420 tons in 1987 and 2002 with average value of 1,143,850 tons. In addition, the variations of the ratio of farm to total populations (P_{Fa}/P_T) and cultivated land area (A_C) were addressed. The values of P_{Fa}/P_T and A_C were 54-64% and 54,070-58,770 ha with average values of 60% and 57,660 ha, respectively. The biomass production per employee of biomass industry in the Choushui River Basin exhibited gradually increasing trend whit minimum and maximum values of 9.3 tons/person in 1990 and 19.42 tons/person in 2002. The average value was 13.2 tons/person. It indicated an improvement of productivity of biomass by the employee of biomass industry. Further, the biomass production and key factors of sustainable development noted above in the Choushui River Basin were compared with those of the Tamsui and Gaobing river basins.

INTRODUCTION

Material flow analysis is essential to the study of industrial ecology [1]. Prior to 1980s, studies on the conservative and efficient usages of the national resources already had gained much attention regarding the sustainability of the economical development [2-4]. In the late 1980s, much interest had risen on the effects of resources consumption upon the environment. Those studies emphasized the need to analyze adequate data before making intelligent decisions on industrial policy [5]. The material flow database of Taiwan from 1986 to 1998 had been established by the previous studies [6-14]. However, information about various regions in Taiwan still needs to be investigated. It is beneficial to compare and assess the facts and conditions of resources utilization in various regions [15]. Based on the concept of input and output material balance, a system can be constructed to evaluate the productivity of industries in order to trace the uses of nature resources [16]. The information is also necessary for promoting the development in Tai-

*Corresponding author
Email: chunfang@cycu.edu.tw

wan [12]. Recently, Chang et al. [17,18] studied the trend of the biomass production in Tamsui and Gaobing river basins in Taiwan. The present study aimed at the analysis of the variations of biomass production (including crop, forestry, fishery and livestock) in the Choushui River Basin in the central Taiwan. Furthermore, biomass production in these three river basins was compared as well in this study.

Since 1986, Taiwan has strived to increase the level of competitiveness and to become a member of World Trade Organization. To setup useful information for assessing the key factors of sustainable development related to the material production of biomass (MPB), this study also analyzed yearly variations of the material productions, employees, population and other productivity items for the biomass of crop, forestry, fishery and livestock sectors in the Choushui River Basin. The data and information can then be used to compute useful indicators. The data about the material production and related information from the governmental statistics were collected for evaluating the material related indictors proposed by World Resources Institute [19]. In addition, some indicators related to the sustainable development reported by Ausubel [20] such as population were discussed in this study. The results can be referred to dealing with policy-making affairs, production efficiency and environmental consideration in the Choushui River Basin. The sustainable indicators of biomass production should, in principle, include all quantitative criteria reflecting high productivities, low loadings and less impacts. However, in practice, some essential or key indicators can be selected from the available data to reveal their significance. These indicators may include: biomass production of crop, forestry, fishery and livestock, land used, employees input, etc. The values of those criteria concerning biomass production of river basin are regional. Thus the key factors reported here can provide useful information for the sustainable development related to biomass production in the Choushui River Basin. Furthermore, the biomass production in the Choushui River Basin was compared with those in the Gaobing and Tamsui river basins.

METHODOLOGY

The data about biomass (including crop, forestry, fishery and livestock) production during 1987 to 2002 in the Choushui River Basin were collected from the Statistical Abstract and Agricultural Statistical Yearbook, which were published by the Statistics Agencies of Changhua [21], Nantou [22], Yunlin [23] and Chiayi [24] Counties, and the COAT [25]. The data used in the study are primary data from the above referred sources. The processes to treat these data are as follows**.** The administration districts (or areas) in the Choushui River Basin include 4 towns (or villages) of Changhua County, 8 towns (or villages) of Nantou County, 6 towns (or villages) of Yunlin County and 2 towns (or villages) of Chiayi County. The towns and villages in the Choushui River Basin are listed in Table 1. Those towns and cities in Table 1 have the main stream or branch of the Choushui River passing through them. None of them are in another river basin. The individual data about these districts were collected and summed for further investigation. The counting of the material production is based on the well defined functional parameters, which can provide the useful and standardized approach, assuring that the calculations of different kinds of materials are based on the same principles [19,26]. However, some data are not available in some districts. This study adopts the methodology of similarity and proportionality to estimate these unknown items from the known information as follows.

Table 1. Townships and cities in Choushui River Basin defined in this study

County	Township and city
Changhua	Dacheng, Jhutang, Sijhou, Ershuei, Tuanjhong
Nantou	Mingcgien, Jiji, Lugu, Jushan, Renai, Chungliao, Shueili, Hsinyi
Yunlin	Mailiao, Lunbei, Erlun, Siluo, Cihtong, Linei
Chiayi	Alishan, Meishan

The estimated unknown amount of material j of the specific towns of the county in the Choushui River Basin = total statistical amount of the entire county in the Choushui River Basin × $\sum_{i=1}^{N} \frac{\mathrm{Ri}}{\mathrm{N}}$ (1)

where R_i = the ratio of known amount of material i of the specific towns of the county in the Choushui River Basin to that of the entire county in the Choushui River Basin. N = total number of i. The applicable counties in the Choushui River Basin are Changhua, Nantou, Yunlin and Chiayi Counties. As illustrations, the estimations of some unknown items are listed as follows.

Case 1. Estimation of flowers, forage and green manure crops: N = 5, i = the products of rice, common crops, specific crops, vegetable and fruits.

Case 2. Estimation of hairy antlers, cow's milk, honey and royal jelly: N = 5, i = the yields of beef, pork, lamb, domestic fowls and egg.

Case 3. Estimation of wood, bamboo, forest by-product, afforestation area, tree felling and aquatic farm: N = 1, i = the land area.

Case 4. Estimation of pelagic, inshore and coastal fishing, sea farming and inland breed: N = 1, i = the fishery population.

The accuracy of the unknown amount estimated from Eq. 1 may decrease with the smaller value of R_i which would cause less reliability by the arithmetic methodology. Note that Eq. 1 is considered applicable for all cases in this study.

Furthermore, the statistics in the web sites of COAT [27], Changhua County Government [28], Nantou County Government [29], Yunlin County Government [30] and Chiayi County Government [31] were used to examine the reliability of data. The non-weight units of the data are converted to weight based on the Chinese National Standard of Taiwan. The calculation of hidden flows was not considered in this study because of the lack of such data.

RESULTS AND DISCUSSION

1. Biomass Production in Choushui River Basin

The time variations of employee (E_B) of agriculture including crop, forestry, fishery and livestock and the ratio of E_B to total population (P_T) are presented in Fig. 1a, while those of the ratios of farm to total populations (P_{Fa}/P_T) and of farm to total households (H_{Fa}/H_T) in the Choushui River Basin are shown in Fig. 1b. The circle, triangle, and square symbols in Fig. 1 represent the data in the Choushui, Gaobing, and Tamsui river basins, respectively. The results showed that E_B in general decreased gradually with time. For example, E_B in the Choushui River Basin decreased from 87,370 in 1998 to 65,140 employees in 2002 (average 89,420 employees). The E_B/P_T ratio in the Choushui River Basin with the average value of 15% had the similar trend as E_B. Recently, E_B/P_T gradually decreased from 18% in 1990 down to 11% in 2002.

For the Choushui River Basin, the P_{Fa}/P_T ratios varied slightly with time (maximum 64%, minimum 54% with an average 60%; Fig. 1b). The farm population (P_{Fa}) decreased about 8% from 332,830 persons in 1987 to 306,960 persons in 2002 (average 337,660 persons). The variation trend of H_{Fa}/H_T was similar to that of P_{Fa}/P_T. The ratio of average values of P_{Fa}/H_{Fa} to P_T/H_T was about 1.2. Therefore, the persons in the farm households were about 12% higher than those in the total households for all sectors in the area under consideration. The results indicated that the Choushui River Basin was changing toward industrialization, although its present status is mainly associated with agriculture.

The variations of cultivated land area (A_C), and A_C per farm household (A_C/H_{Fa}) and A_C per agricultural employee (A_C/E_B) with time are illustrated in Figs. 2a and 2b, respectively. The value of A_C ranged 54×10^3 to 59×10^3 ha over the period of 1987 to 2002. The average value of A_C/H_{Fa} was 0.82 ha/household. The maximum value of A_C/H_{Fa} was 0.93 ha/household in 2002 due to the significant decrease of the farm households in 2002 (H_{Fa} = 62,290 households). The value of A_C/E_B increased slightly with time because of the decreases in E_B. A_C/E_B had a maximum value of 0.89 ha/person (in 2002) with an

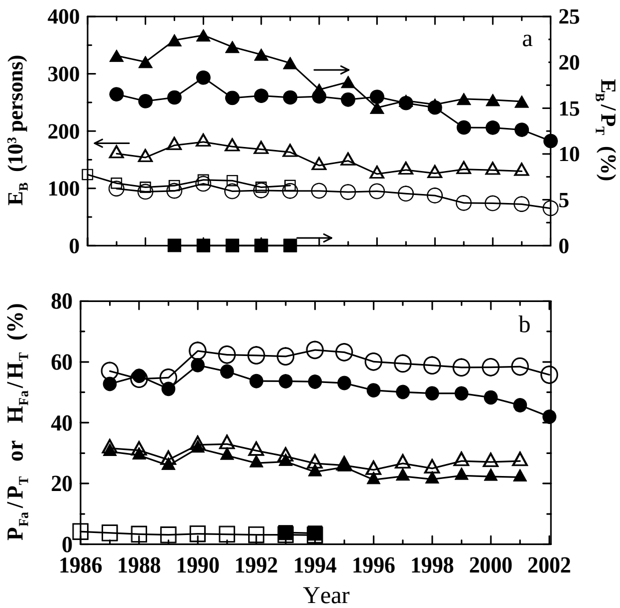

Fig. 1. Time variations of E_B, E_B/P_T, P_{Fa}/P_T and H_{Fa}/H_T in different river basins. The symbols for ○, △ and □ are for Choushui, Gaobing and Tamsui river basins, respectively. The solid symbols (●, ▲ and ■) refer to the parameter ratios of the respective basin. (a) E_B: employee of agriculture including crop, forestry, fishery and livestock; P_T: total population. (b) P_{Fa}: farm population; H_{Fa}: farm household; H_T: total household; ○, △ and □: P_{Fa}/P_T; ●, ▲ and ■: H_{Fa}/H_T.

increase of 63% comparing the minimum value of 0.55 ha/person (in 1990). The results pointed out that the capabilities of the farm household and agriculture employee in the Choushui River Basin were not well used, cultivating only small land area with values of A_C/H_{Fa} and A_C/E_B less than one.

The time variations of ratios of planted to cultivated land areas (A_P/A_C), and of regional to entire Taiwan rice productions (M_R/M_{RTWN}) and the rice production per harvested land area (M_R/A_H) in the Choushui River Basin are presented in Figs. 3a and 3b, respectively. The values of A_P/A_C with the average value of 77% had a maximum value of 98% (1988) with a minimum 66% (2001). It clearly revealed that the proportion of rice planting area became lower. This may be due to the fact that some crops with high economical value were planted instead of rice planting. The regional rice production M_R in the Choushui River Basin with average value of 173,590 tons showed a significant decrease of 27% from 219,900 tons in 1987 to 160,840 tons in 2002. Correspondingly, the values of M_R/M_{RTWN} of 9.2% and 8.9% in 1987 and 2002, respectively, indicated a slight decrease with time. Nevertheless, the M_R/A_H ratio, or M_R to harvested land area (A_H), showed a moderate variation (3.2-4.2 ton ha^{-1}).

The time variations of reforestation area per per-

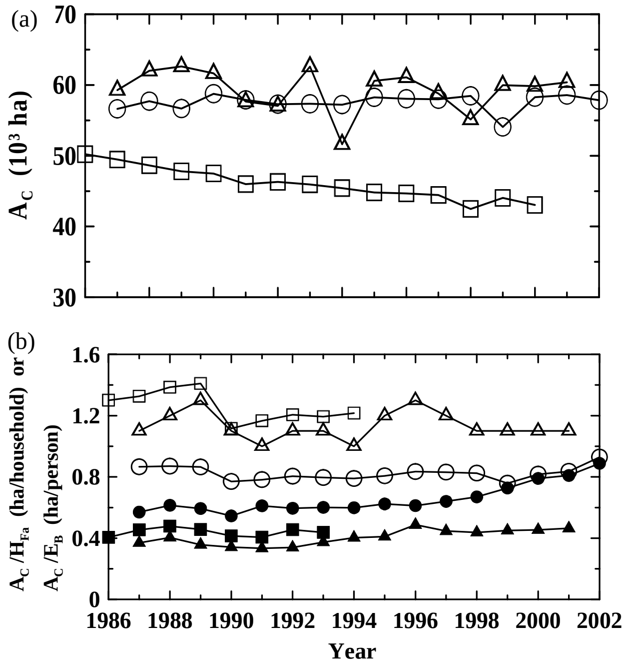

Fig. 2. Time variations of A_C, A_C/H_{Fa}, and A_C/E_B in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. E_B, P_T, P_{Fa}, H_{Fa} and H_T: as specified in Fig. 1. (a) A_C: cultivated land area. (b) ○, △ and □: A_C/H_{Fa}; ●, ▲ and ■: A_C/E_B.

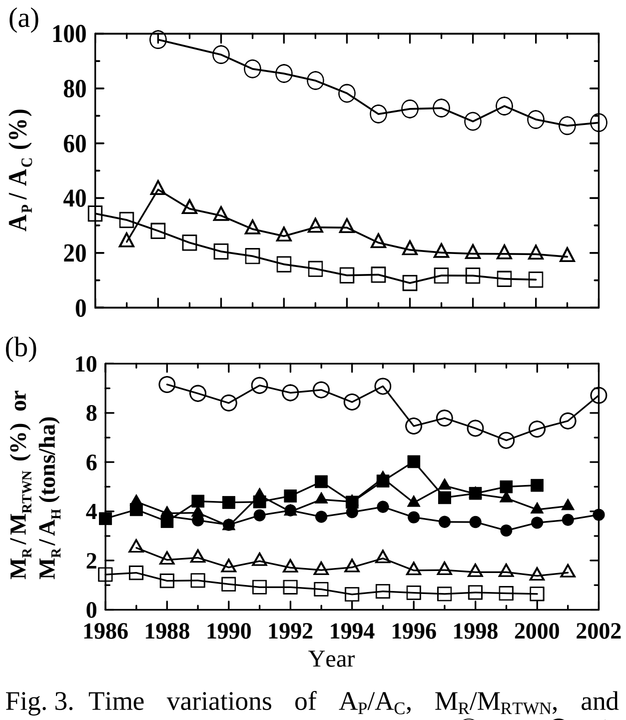

Fig. 3. Time variations of A_P/A_C, M_R/M_{RTWN}, and M_R/A_H in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. A_C: as specified in Fig. 2. (a) A_P/A_C; A_P: planted land area. (b) M_R: regional rice production; M_{RTWN}: whole rice production in Taiwan; A_H: harvested land area; ○, △ and □: M_R/M_{RTWN}; ●, ▲ and ■: M_R/A_H.

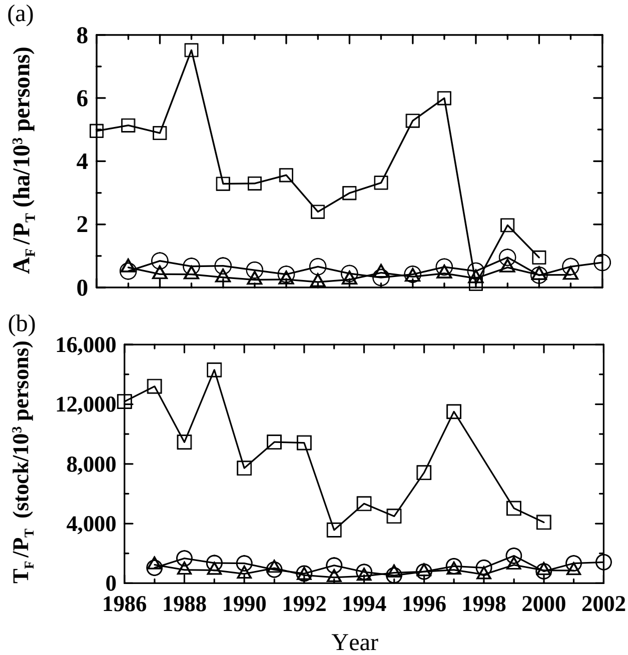

Fig. 4. Time variations of A_F/P_T and T_F/P_T in different river basins. ○ , △, and □: for Choushui, Gaobing, and Tamsui river basins, respectively. P_T: as specified in Fig. 1. (a) A_F/P_T; A_F: reforestation area. (b) T_F/P_T; T_F: reforestation trees.

son of total population (A_F/P_T) and reforestation tress per person of total population (T_F/P_T) in the Choushui River Basin are shown in Figs. 4a and 4b, respectively. The value of A_F/P_T initially varied with time with a maximum value of 0.95 ha/10^3 persons in 1999. Afterwards, A_F/P_T decreased to a minimum value of 0.39 ha/10^3 persons in 2000. Recently, the value of A_F/P_T gradually increased due to the encouragement of reforestation policies of the government aiming at protecting the environment. The variation trend of T_F/P_T was similar to that of A_F/P_T with maximum and minimum values of 1,840 and 520 stocks/10^3 persons, respectively. The average value of T_F/A_F was about 1855 stocks/ha during 1987-2002. Again, the recent increase of T_F/P_T was due to the environmental protection consciousness.

The variations of the ratio of fisherman to total households (H_{Fi}/H_T), and aquaculture land areas per fisherman household (A_{Fi}/H_{Fi}) and per person employed in fishery (A_{Fi}/E_{Fi}) are illustrated in Figs. 5a and 5b, respectively. The value of H_{Fi}/H_T ranged between 5.8-9.3% with a decreasing trend between 1996 and 2000. Note that H_{Fi} decreased from 13,220 households in 1996 to 9,290 households in 2001 indicating an apparent decrease of fisherman households in the Choushui River Basin. In 2002, however, H_{Fi} slightly increased to 11,480 fisherman households with H_{Fi}/H_T = 7.4. Moreover, A_{Fi}/H_{Fi} and A_{Fi}/E_{Fi} had higher values prior to 1992 and decreased in the following years due

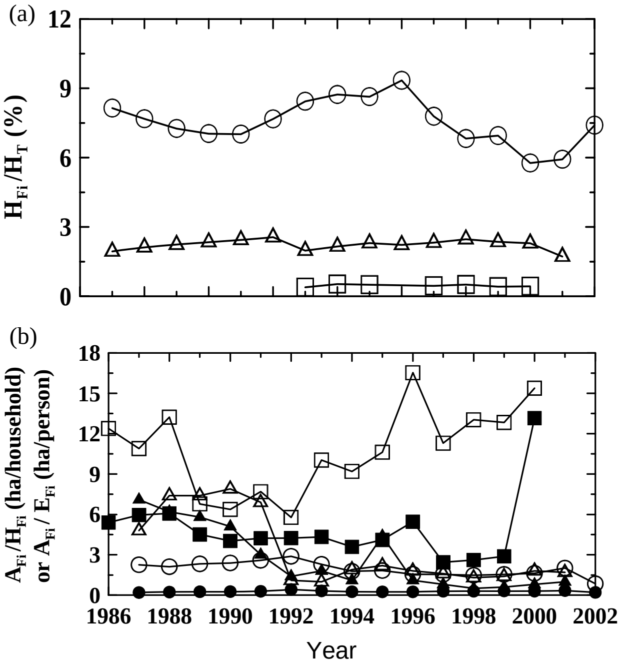

Fig. 5. Time variations of H_{Fi}/H_T, A_{Fi}/H_{Fi}, and A_{Fi}/E_{Fi} in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. H_T: as specified in Fig. 1. (a) H_{Fi}/H_T; H_{Fi}: fisherman household. (b) A_{Fi}: aquaculture land area; E_{Fi}: fishery employee; ○, △ and □: A_{Fi}/H_{Fi}; ●, ▲ and ■: A_{Fi}/E_{Fi}.

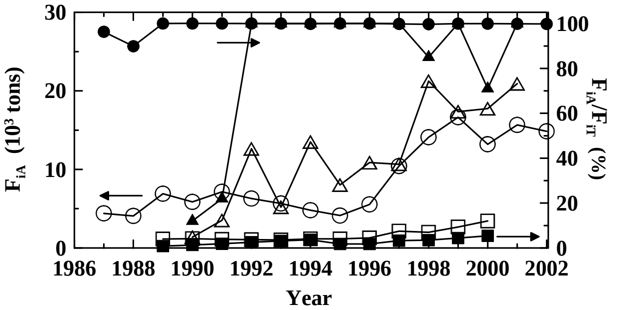

Fig. 6. Time variations of F_{iA} and F_{iA}/F_{iT} in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. F_{iA}: aquaculture fishery production. F_{iT}: total fishery productions. ○, △ and □: F_{iA}; ●, ▲ and ■: F_{iA}/F_{iT}.

to the increases of H_{Fi} and E_{Fi} during that period. The values of A_{Fi}/H_{Fi} and A_{Fi}/E_{Fi} after 1997 approached to the low values of 0.85-2.01 ha/household and 0.20-0.34 ha/person, respectively. Note that the lowest values of A_{Fi}/H_{Fi} and A_{Fi}/E_{Fi} occurred in 2002. Therefore, the balance between A_{Fi} and H_{Fi} (or E_{Fi}) in the future should attract high attention. The value of aquaculture fishery production (F_{iA}) increased about 168% from1996 to 2002. Also in Fig. 6, the time variation of the ratio of F_{iA} to total fishery production (F_{iT}) is presented. It is clear that the aquaculture fishery has be-

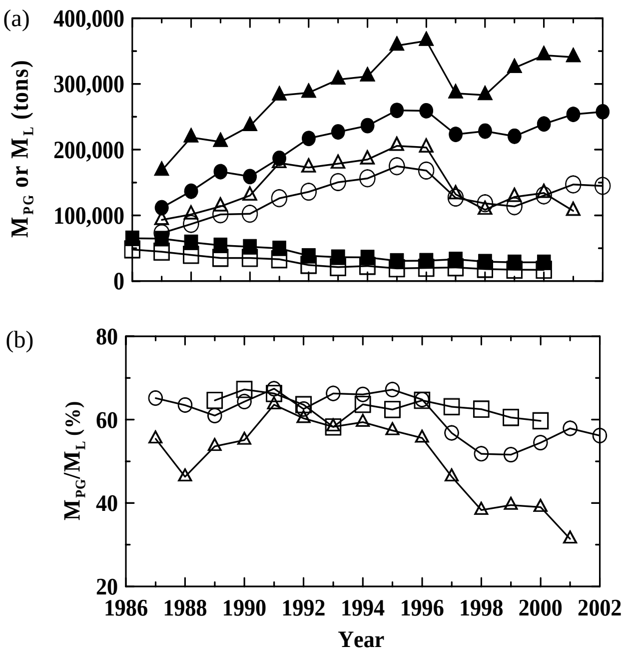

Fig. 7. Time variations of M_{PG}, M_L, and M_{PG}/M_L in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. (a) M_{PG}: weight of pig production; M_L: weight of livestock production; ○, △ and □: M_{PG}; ●, ▲ and ■: M_L. (b) M_{PG}/M_L.

come a major portion in the fishery industry due to its high economic benefit. The water used in the aquaculture fishery was mainly drawn from the groundwater. However, the environment had been seriously damaged resulting from the lack of proper design and operation for the use of groundwater. Some of the useful land had decreased in the region due to the overdrawing of groundwater resulting in a significant sink in some parts of the land.

The value of production of pigs (M_{PG}) was about 72,760 tons in 1987 and increased evidently with time until 1996 with an increase of 131% based on the estimation of 112 kg per pig [7] as shown in Fig. 7a. Afterwards, the value of M_{PG} began to decrease due to the eruption of foot and mouth disease in 1997. Note that Taiwan Environmental Protection Administration (TEPA) also promotes the policies to assist pig-raising households to transfer their occupations and encourage processing the drift fence of pig farm to reduce the number of pigs. The livestock (M_L) gradually increasing with time had the maximum and minimum values of 259,790 tons in 1995 and 111,650 tons in 1987, respectively. The average value of M_L was about 211,420 tons. The value of M_L of 257,660 tons in 2002 was the third highest during 1987-2002. As a result, it can be found that the weight ratio of the production of pigs to livestock (M_{PG}/M_L), which was greater than 60% before 1996, decreased below 60% from 1997 (Fig. 7b). The results demonstrated the

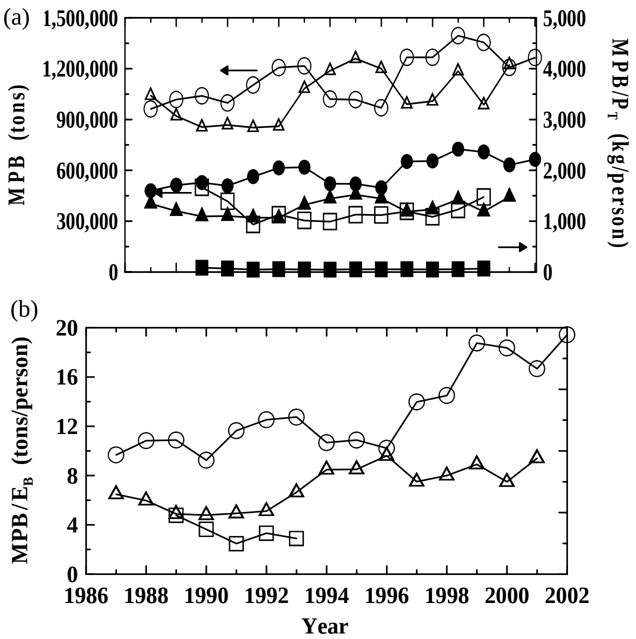

Fig. 8. Time variations of MPB, MPB/P_T, and MPB/E_B in different river basins. ○ and ●, △ and ▲, and □ and ■: for Choushui, Gaobing, and Tamsui river basins, respectively. P_T, E_B: as specified in Fig. 1. (a) MPB: material production of biomass; ○, △ and □: MPB; ●, ▲ and ■: MPB/P_T. (b) MPB/E_B.

good performance of TEPA in executing its policies.

The MPB, including crop, forestry, fishery and livestock, in the Choushui River Basin for 1987-2002 was computed. The items of crops consist of rice, common crop, special crops, vegetable, fruits, flowers, forage and green manure crops. As for the forestry, the items include beef, pork, lamb, domestic fowls, eggs, hairy antlers, cow's milk, honey and royal jelly. The fishery materials contain pelagic, inshore and coastal fishing, sea farming and inland breed. Finally, the items of livestock take into account for wood, bamboo and forest by-products. The variations of MPB and MPB per person of total population (MPB/P_T) in the Choushui River Basin are shown in Fig. 8. The value of MPB increased from 1987 of 961,760 tons to 1993 of 1,215,900 with an increase of 26%. It then began to decrease gradually during 1994 to 1996. However, MPB became more stable (1,206,890-1,394,410 tons) from 1997 onward. The major cause for the variation of MPB may be due to the variation of industrial structure in the Choushui River Basin. The value of MPB/P_T generally increased with time, giving the maximum and minimum values of 2,420 and 1,660 kg/person in 1999 and 1996, respectively. An increase of MPB/P_T indicated more requirement of biomass production per capita. Further, the average value of MPB/P_T in the Choushui River Basin was 1,960 kg/person. As shown in Fig. 8b, MPB/E_B in the Choushui River Basin gradually increased with time. The values of MPB/E_B had maximum and minimum values of 19.4 in 2002 and 9.3 tons/person in 1990, respectively, with the average value of 13.2 tons/person. Note that E_B stands for the employees producing the biomass. Thus, an increase of MPB/E_B indicated an enhancement of the productivity of biomass by its employees. Theses factors, reflecting the productivities and loadings, can provide the useful information for assessing the improvement of the sustainable development of biomass production in any particular river basin. Furthermore, the criteria of these factors for the sustainable development of biomass production may also be decided accordingly.

2. Comparison of Biomass Production in Three Major River Basins

The biomass production in the Choushui River Basin was further compared with those in the Gaobing and Tamsui river basins. The three river basins cover most of the agricultural lands in Taiwan. Among them, the Tamsui River Basin is in the northern Taiwan and well developed as a region for politics, business and high technology industries. The Choushui River Basin is located in the central part of Taiwan and the Gaobing River Basin southern Taiwan; both provide most of the needs of MPB. The Gaobing River Basin also has a significant development of industries. The data of Gaobing and Tamsui river basins were obtained from the studies of Chang et al. [17,18]. The value of E_B in the Choushui River Basin with the average value of 89,420 persons was lower than those in the Gaobing and Tamsui river basins with average values of 149,346 and 109,230 persons, respectively (Fig. 1a). However, the values of E_B/P_T in the Choushui and Gaobing river basins were higher than 10% and significantly greater than that in the Tamsui River Basin. The closer relation with biomass industry of the Choushui River Basin than the other two basins is also reflected in P_{Fa}/P_T and H_{Fa}/H_T (Fig. 1b). The values of P_{Fa}/P_T and H_{Fa}/H_T in the Choushui River Basin were about 2 and 16 times higher than those in the Gaobing and Tamsui river basins, respectively.

As shown in Fig. 2a, the values of A_C in the Choushui and Gaobing river basins were closer and more stable with time, while A_C in the Tamsui River Basin continuously decreased with time. The values of A_C/H_{Fa} and A_C/E_B in the Choushui River Basin were lower but greater than those in the Tamsui and Gaobing river basins (Fig. 2b), because of its higher H_{Fa} and lower E_B values. Moreover, A_C/E_B in the Choushui River Basin was about 150% of those in Tamsui and Gaobing river basins. The results indicated the need of beneficial help for the farm households in the Choushui River Basin, where its agriculture employees cultivated large Ac.

The value of A_P/A_C in the Choushui River Basin was apparently higher than those in the Tamsui and

Gaobing river basins (Fig. 3a). Thus, the cultivated land in the Choushui River Basin was well planted, yielding a highest rice production among the three basins. Also, the value of M_R/M_{RTWN} in the Choushui River Basin was about 4 times of those of the Tamsui and Gaobing river basins (Fig. 3b). However, the productivity of rice denoted as M_R/A_H in the Choushui River Basin was slightly lower compared with those of the other two river basins (Fig. 3b), indicating the need for improving the harvest in the Choushui River Basin.

As shown in Fig. 4a, A_F/P_T in the Tamsui River Basin had higher values before 1998 and significantly decreased in 1998. On the other hand, A_F/P_T only varied slightly in the Choushui and Gaobing river basins during 1987 to 2002. The variation trends of T_F/P_T in the three river basins were similar to those of A_F/P_T (Fig. 4b). The value of T_F/P_T in Tamsui River Basin is higher than those in the other two river basins. The results indicated that the people in the Tamsui River Basin paid more attention to reforestation than the other two basins.

As for the fishery, H_{Fi}/H_T in the Choushui River Basin with the average value of 7.5% was higher than those in the other two river basins (Fig. 5a). Because of the high fishery population, A_{Fi}/H_{Fi} and A_{Fi}/E_{Fi} in the Choushui River Basin were usually the lowest in the three river basins (Fig. 4b). From 1992, the aquaculture fishery production F_{iA} in the Gaobing River Basin became higher than that in the Choushui River Basin, with the lowest in the Tamsui River Basin during 1989 to 2000 (Fig. 6). Further, the total fishery production F_{iT} in the Choushui and Gaobing river basins from 1992 almost came from the aquaculture fishery production (Fig. 6). Oppositely, the aquaculture fishery contributed to only about 3% of F_{iT} in the Tamsui River Basin during 1989 to 2000. The results raised a great concern on land sinking in the Choushui and Gaobing river basins for the overdrawing of ground water.

Figure 7a compares the values of M_{PG} and M_L for the three basins. The values of M_{PG} in the Choushui and Gaobing river basins continuously increased from 1987 to 1996. Afterwards, M_{PG} began to decrease due to the eruption of foot and mouth disease in 1997. As noted in the previous section, the regulatory agency promotes the policies to help pig-raising households to transfer their occupation and processes the drift fence of pig farm to reduce the number of pigs. Thus, M_{PG} decreased to low values after 1997 in the Choushui and Gaobing river basins. Accordingly, the values of M_L in the Choushui and Gaobing river basins generally increased with time before 1997 while dropped significantly in 1997. On the other hand, M_{PG} and M_L decreased all the time in the Tamsui River Basin. As indicated in Fig. 7b, the values of M_{PG}/M_L in the three river basins remained higher before 1997 and generally decreased afterwards. The results also indicated that the performance of shifting the raising of pig to other livestocks in the Gaobing River Basin was better than those in the other two river basins.

The values of MPB in the Choushui and Gaobing river basins were two times greater than that in the Tamsui River Basin (Fig. 8a). In addition, the values of MPB/P_T, which were in the order of Choushui > Gaobing > Tamsui river basins, varied slightly with time in the three river basins. On the other hand, MPB/E_B in the Choushui River basin was the highest among the three river basins because of its fewer but very efficient and skilled agriculture employees E_B as indicated in Fig. 8b. All these results obtained for the comparison of biomass production and different environmental indicators (especially the environmental loadings) are useful for the policy-making of biomass industry. The results can be further linked to the possible environmental carrying capacity, providing the baseline for the decision-making of sustainable use of land. A further study concerning the relationship between environmental loading and environmental carrying capacity in different basins would be helpful to provide such baseline information.

CONCLUSIONS

The time variations of biomass production of crop, forestry, fishery and livestock in the Choushui River Basin provide useful information to assess the situation of the biomass industry. Results indicate that the agricultural employees E_B and the ratio of planted to cultivated land areas A_P/A_C were found to decrease with time. The importance of biomass industry in the Choushui River Basin gradually decreased due to the changes of the industrial and economic structures. On the other hand, the time variation of the cultivated land area was stable. Also, the aquaculture fishery production apparently became a major contribution in the recent fishery industry. Moreover, the production of pigs M_{PG} and the ratio of M_{PG} to livestock M_L (M_{PG}/M_L) significantly decreased because of the eruption of mouth and foot disease and the implement of the environmental policies promoted by the Taiwan government. Therefore, in order to improve the sustainable development, the government should consider how to use the agriculture area and set up the adequate polices of land development utilizing the available biomass resources.

Based on the comparison of the biomass production in the Choushui, Gaobing and Tamsui river basins, A_P/A_C, M_R/M_{RTWN} (regional to whole rice productions) and H_{Fi}/H_T (fisherman to total households) in the Choushui River Basin were the highest. The cultivated land areas per farm household A_C/H_{Fa} were the lowest, while A_C per agricultural employee (A_C/E_B) in the Choushui River Basin was the highest due to the high values of H_{Fa} and low values of E_B. Consequently, the transformation of agriculture development in the Choushui River Basin is important and necessary, aiming at reducing farm households while enhancing the contribution of other industrial sectors other than biomass industry for enhancing the gross domestic product.

ACKNOWLEDGMENTS

This study was supported by the National Science Council of Taiwan under Grant No. NSC 91-2621-Z-002-028.

NOMENCULTURE

Notation Referred to Choushui River Basin

A	agriculture, －
A_C	cultivated land area, ha
A_F	reforestation land area, ha
A_{Fi}	aquaculture land area, ha
A_H	harvested land area, ha
A_P	planted land area, ha
B	biomass including crop, forestry, fishery and livestock, －
C	crop, －
E_B	employee of agriculture including crop, forestry, fishery and livestock, person
E_{Fi}	fishery employee, person
F	forestry, －
Fi	fishery, －
F_{iA}	aquaculture fishery production, ton
F_{iT}	total fishery production, ton
H_{Fa}	farm household, household
H_{Fi}	fisherman household, household
H_T	total household, household
L	livestock, －
M_L	weight of livestock production, ton
MPB	material production of biomass, ton or kg
M_{PG}	weight of pig production, ton
M_R	regional rice production, ton
P_{Fa}	farm population, person
P_T	total population, person
PG	pig, －
T_F	reforestation tree, stock

Notation Referred to Other Regions

M_{RTWN}	whole rice production in Taiwan, ha
R_i	ratio of known amount of material i of the specific towns of the county in Choushui River Basin to that of the whole county in Choushui River Basin

REFERENCES

1. Erkman, S., Industrial ecology: An historical view. J. Clean. Prod., 5(1-2), 1-10 (1997).
2. Barnett, H.J., G.M. Van Muiswinkel and M. Schechter, Are minerals costing more? Int. Inst. Appl. Syst. Anal., Work Paper WP-81-20 II ASA, Luxemburg, Austria (1981).
3. Goeller, H.E. and A.M. Weinberg, The age of sustainability. Science, 191(4228), 638-89 (1976).
4. Grenon, M. and B. Lapillonne, The WELMM approach to energy strategies and options. Int. Inst. Appl. Syst. Anal., Research Report RR-76-19 II ASA, Luxemburg, Austria (1976).
5. Taylor, J., The challenge of sustainable development. Regulation, 17(1), 35-50 (1994).
6. Chang, C.F.H. and S.S. Lin, Material requirements of metals in Taiwan. J. Chinese Inst. Environ. Eng. (Taiwan), 12(2), 93-102 (2002).
7. Chang, C.F.H. and S.S. Lin, Material requirements of agricultural, forest and animal biomass industries in Taiwan. J. Chinese Inst. Environ. Eng. (Taiwan), 12(4), 315-324 (2002).
8. Chang, C.F.H. and S.S. Lin, Material flow analysis of industrial non-metal minerals in Taiwan. J. Chinese Inst. Environ. Eng. (Taiwan), 13(3), 183-190 (2003).
9. Chang, C.F.H., Y.C. Liu, C.Y. Chang, A.C. Chiang and S.S. Lin, Scenario analysis of material flow of steel and iron for the steel industry in Taiwan and international comparison of per capita of use and intensity of use. J. Chinese Inst. Environ. Eng. (Taiwan), 12(4), 325-335 (2002).
10. Hsiao, T.Y., Y.H. Yu and I.K. Wernick, A note on material flows of construction aggregates in Taiwan. Resour. Policy, 27(2), 135-137 (2001).
11. Hsiao, T.Y., Y.H. Yu and I.K. Wernick, Analyzing material flows for construction aggregates in Taiwan. J. Chinese Inst. Environ. Eng. (Taiwan), 12(2), 103-112 (2002).
12. Hsiao, T.Y., Y.T. Huang, Y.H. Yu and I.K. Wernick, Modeling material flow of waste concrete from construction and demolition waste in Taiwan. Resour. Policy, 28(1-2), 39-47 (2002).
13. Hsiao, T.Y., A Study on Industrial Ecology – Analyzing and Modeling Materials Flows for Construction Aggregates in Taiwan. Ph.D. Dissertation, Graduate Institute of Environmental Engineering, National Taiwan University, Taipei, Taiwan (2003).
14. Lin, S.S., Preliminary Study on Material Flow System and Its Establishment in Taiwan. Master Thesis, Department of International Trade, Chung Yuan Christian University, Taoyuan, Taiwan (2001).

15. Richards, D.J. and R.A. Frosc, Overview and perspectives. In D.J. Richards (Ed). The Industrial Green Game. National Academy Press, Washington, D.C. (1997).
16. Graedel, T.E. and B.R. Allenby, Industrial Ecology. 2nd Ed., Pearson Education, Inc., Upper Saddle River, NJ (2003).
17. Chang, C.F.H., I.H. Lee, J.L. Shie and C.Y. Chang, Estimation and trend analysis of biomass production in river basin in Taiwan: 1. Case in Tamsui River Basin. J. Chinese Inst. Environ. Eng. (Taiwan), 14(1), 1-8 (2004).
18. Chang, C.F.H., H.L. Lu, C.Y. Chang, H.W. Ma and Y.H. Chen, Estimation and trend analysis of biomass production in river basin in Taiwan: 2. Case in Gaobing River Basin. J. Chinese Inst. Environ. Eng. (Taiwan), 14(1), 9-16 (2004).
19. World Resource Institute (WRI), Wuppertal Institute, Spatial Planning and Environment of Netherlands Ministry of Housing and National Institute for Environmental Studies, Resource Flows: The Material Basis of Industrial Economies, WRI, Washington, D.C. (1997).
20. Ausubel, J.H., Resource and environment in the 21st century: Seeing past the phantoms. World Energy Council J., July, 8-16 (1998).
21. Statistics Agency of Changhua County, Statistical Abstract (1987-2002).
22. Statistics Agency of Nantou County, Statistical Abstract (1987-2002).
23. Statistics Agency of Yunlin County, Statistical Abstract (1987-2002).
24. Statistics Agency of Chiayi County, Statistical Abstract (1987-2002).
25. COAT (Council of Agriculture, Taiwan), Agriculture Statistics Yearbook (1987-2002).
26. Wernick, I. and J.H. Ausubel, National material flows and the environment. Annu. Rev. Energ. Env., 20, 463-492 (1995).
27. COAT, Statistical Data of Agriculture, http://www.coa.gov.tw/statistic/index.html (2003).
28. Changhua County Government Website, http://www.changhwa.gov.tw (2003).
29. Nantou County Government Website, http://www.nantou.gov.tw (2003).
30 Yunlin County Government Website, http://www.yunlin.gov.tw (2003).
31. Chiayi County Government Website, http://www.chiyai.gov.tw (2003).

Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-Chief within six months of publication.

Manuscript Received: November 15, 2005
Revision Received: February 17, 2006
and Accepted: February 20, 2006