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Evaluation of Productivity in Extensive Aquaculture Practices Using Interspatial TFP Index, Sulawesi, Indonesia

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Abstract

Various input factors contribute to the final output in extensive aquaculture systems. These include culture practices, skill level of the farmer, technology applied, species cultured, geographic location to market centers and environmental factors, among others. The evaluation of these factors in the context of Total Factor Productivity (TFP) analysis allows the comparison of specific characteristics of inputs in relation to their impact on outputs in the culture system which can assist in optimizing production under the conditions examined.

Total Factor Productivity (TFP) index, which is defined conceptually as the ratio of an index of total output to an index of all factor inputs, is adopted widely as the standard approach in measuring the total factor productivity. In this paper, we use a variant of the Tornquist Index, a TFP index, to examine the interspatial productivity differences of extensive farms in Indonesia practicing various forms of polyculture and milkfish monoculture. The data set comprises a total of 55 farms located at three different geographic and economic regions of Sulawesi. Polyculture farms carry out different combinations of crab (*Scylla serrata*), shrimp (*Penaeus monodon*), seaweed (*Gracilaria sp.*) and milkfish (*Chanos chanos*) cultures. TFP indexes are obtained from seed, labor, fertilizer, feed, and chemicals as variable inputs and the four different outputs (species cultured), adjusted by the input cost and output revenue shares for each farm. TFP indexes are then regressed against nine geographical locations, eight culture systems (seven different polycultures and the milkfish monoculture) and total pond area, in order to estimate the individual effects of these variables.

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Estimated TFP values range from 0.7 to 4.41 (μ= 1.52, σ= 0.819). Results of the regression show that polyculture plays a main role in achieving high TFP, particularly the inclusion of seaweed, a key species to increase productivity. A polyculture combination with *Gracilaria sp.* positively affected TFP ($p< 0.005$). From all other combinations of organisms under culture, only the polyculture of milkfish and crab has a positive effect on productivity. Total pond area is found to be inversely related to TFP ($p<0.05$). Geographical locations do not appear to affect TFP significantly. Finally, based on these results some considerations for aquacultural development policies are presented.

Introduction

The role of aquaculture as a foreign exchange earning activity took on a higher profile in Indonesia following Presidential Decree No. 39.1980 which banned trawl fishing activity in Indonesia and aimed to diversify revenue from non-oil and gas commodities. Shrimp production was targeted to double by the end of Pelita IV (fourth Five-year National Development Plan, 1985-90). With these objectives and a policy of "extensification and intensification" (expanding pond area and increasing production through intensive culture methods respectively) in the culture of shrimp, the tambak areas increased production by 35% over the 9-year period (1985-1994) to 326,910 ha. The National Shrimp project targeted 100,000 ha for tambak extensification and 120,000 ha for tambak intensification (Naamin, 1987). The current five-year plan (1997-2002) calls for further extensification and intensification of tambaks for shrimp by an additional 150,000 ha. This would be for extensive and semi-intensive culture.

Various input factors contribute to the final output in extensive aquaculture systems. These include culture practices, skill level of the farmer, technology applied, species cultured, geographic location to market centers and environmental factors, among a number of other factors. The evaluation of these factors in the context of the total factor of production can be helpful in comparing specific characteristics of inputs in relation to their impact on output in the culture system to assist in optimizing production under the conditions examined.

Description of tambak extensive system

The tambaks in the project site areas are characterized by small-scale family owned monoculture and polyculture extensive systems that are referred to as "traditional" and "traditional plus" (the latter includes limited addition of fertilizers and supplemental feed, also referred to as extensive plus) in Indonesia. The extensive system is characterized by major dependence on tidal water exchange, natural productivity, and natural stocking. Supplemental seedstock and fertilizer is used in traditional plus. The tambaks contribute to food security and the generation of foreign exchange as well as economic activity associated with the industry. Average production per unit area and income of the farms varied significantly among the project sites, as did the extent of tambak development area.

The majority of the production (milkfish) is for the domestic market and is produced under extensive culture technology. This is of significance in that the extensive method of aquaculture minimizes potential environmental impact from effluent, and is generally being considered as a sustainable aquaculture practice. In addition, the majority of production is used to meet the nutritional needs of the domestic population and contribute to the economy of Sulawesi through employment, purchase of farm inputs and the marketing process for the farm output. There are also a number of export revenue products that generate foreign exchange, thereby contributing to the national economy's growth and trade balance. These include shrimp (*Penaeus monodon*), seaweed (*Gracilaria sp.*), and mangrove crabs (*Scylla serrata*).

Reported analyses of polyculture systems are mostly for fish. Hulata, Milstein and Goldman (1993) evaluated the effect of management inputs on fish yields (or profits). Milstein, Alkon, Karplus, Kochba and Avnimelech (1995) analysed the effect of organic and inorganic fertilization and pellets feeding on fish performance and water quality. However, analysis of polyculture systems involving different aquatic organisms like fish, shrimp, seaweed and crab in the simultaneous culture were not found.

Materials and Methods

Economists commonly use partial productivity ratios such as output per worker and output per hectare to compare productivity of various agricultural production enterprises. The observed static differences in the partial productivity ratios are generally associated with differences in the use of modern industrial inputs as substitutes for land and labor. The dynamic or time differences of these ratios, on the other hand, provide a good indication of technological changes. However, economists recognized the inadequacy of these partial productivity ratios which can provide a misleading picture of productive performance and have subsequently developed a more comprehensive concept which compares outputs with the combined use of all inputs (resources). Total factor productivity (TFP) index, which is defined conceptually as the ratio of an index of total outputs to an index of all factor inputs, is adopted widely as the standard approach to the measurement of total factor productivity. Similar to the partial productivity ratios, TFP can also be used to measure productivity differences over time or across productive units. In this paper, we applied an interspatial TFP index to compare the productive performance of extensive farms in Indonesia practicing various forms of polyculture and milkfish monoculture.

TFP index is an index number that measures changes in a set of related variables and provides estimations of variation over time and/or space. Based on Diewert's earlier work (1976, 1978), Denny and Fuss (1983) developed the methodology for intertemporal and interspatial index determination and the resulting total factor productivity (TFP) analysis. This work was complemented by Caves, Christensen and Diewert (1982), who also worked on the methodology for input, output, and productivity measurement based on index numbers, developed from the Tornqvist-Theil index, a generalized version allowing for transitivity and multilateral cases.

In this work, we applied the multilateral generalization of the Tornqvist index for TFP determination. For binary comparisons, the Tornqvist TFP index for *s* and *t* time periods or enterprises is defined as:

$$\ln\frac{TFP_t}{TFP_s}=\ln\frac{TTOutputIndex}{TTInputIndex} \quad (1)$$

Since the binary Tornqvist Index will yield inconsistent results for multilateral comparisons due to the problem of transitivity, a generalized interspatial Tornqvist index is used to analyze productivity across farms in this work (Capalbo and Antle, 1988). TFP in this case evaluates a multi-factor, multi-output production process, allowing for comparison of productivity for each farm with the average farm. The interspatial TFP index is defined as follows:

$$TI_{iavg} = ½ \Sigma_m (\log Q_{mi} - \log Q_{mavg}) (s_{mi} + s_{mavg}) -½ \Sigma_k (s_{ki} + s_{kavg}) (\log X_{ki} - \log X_{kavg}) \quad (2)$$

where:

TI_{iavg} = Interspatial TFP measure
Q_{mi} = Output quantity of species m in the polyculture of farm i
Q_{avg} = Average output quantity of species m for the 55 farms
s_{mi} = mth species income share of farm i
X_{ki} = Quantity of input k in the production process of farm i
s_{ki} = ^{k}th input cost share of farm i

The exponentiation of TI_{iavg} gives the productivity difference between a farm and the average.

A primary advantage of using this index number in measuring TFP is the ease of computation, not requiring statistical estimation of parameters. Recent advances in index number theory have shown that the Tornqvist Index is exact for a homogeneous translog production or cost function. Therefore, the flexibility of this index is another desirable characteristic.

Once individual TFP values were obtained, a regression analysis was carried out to evaluate the effects of geographical location (Dd_j), culture system (Dcs_i) and total pond area (TPA) on TFP. Culture system (Dcs_i) is represented by a set of dummy variables with monoculture as the reference system as follows:

Dcs_1 = If seaweed polycultures with milkfish (G+M); 0 otherwise
Dcs_2 = If seaweed polycultures with milkfish and shrimp (G+M+S); 0 otherwise
Dcs_3 = If seaweed polycultures with milkfish, shrimp and crab (G+M+S+C); 0 otherwise
Dcs_4 = If milkfish polycultures with shrimp (S+M); 0 otherwise
Dcs_5 = If milkfish polycultures with crab (C+M); 0 otherwise
Dcs_6 = If shrimp polycultures with crab (S+C); 0 otherwise
Dcs_7 = If milkfish polycultures with shrimp and crab (S+C+M); 0 otherwise

Similarly, geographical location (Kecamatan) is represented by a set of dummy variables, Dd_j, where Kwandang is the reference location as follows:

Dd_1 = If Kecamatan is Walenrang in Luwu; 0 otherwise
Dd_2 = If Kecamatan is Malangke in Luwu; 0 otherwise
Dd_3 = If Kecamatan is Bone-bone in Luwu; 0 otherwise
Dd_4 = If Kecamatan is Buran in Luwu; 0 otherwise
Dd_5 = If Kecamatan is Wotu in Luwu; 0 otherwise
Dd_6 = If Kecamatan is Malili in Luwu; 0 otherwise
Dd_7 = If Kecamatan is Pasang Kayu in Lariang; 0 otherwise
Dd_8 = If Kecamatan is Budong-budong in Lariang; 0 otherwise

Data

Data on production and other contributing factors to evaluate production systems under extensive culture practices in Sulawesi, Indonesia were collected through farmer owner/operator interviews. Specific data collected through the interview questionnaire process were compiled for the individual project sites. This data was collected as part of the Mangrove Rehabilitation and Management Project in Sulawesi during 1996-97 (FitzGerald Jr. and Sutika, 1997). The data collected were divided into the following broad categories.

- Physical Characteristics
- Biological Characteristics
- Management Practices
- General Information
- Economic Information

In this study, three project sites were included in the analysis that represent different geographic and economic regions of Sulawesi. Luwu and Lariang are in the Southern Province; however, Luwu (six adjacent coastal sub-districts) is located in central Sulawesi in an economically established area while Lariang (two coastal sub-districts) is located along the northwest coast in a newly developing area. Kwandang (one coastal sub-district) is located in the Northern Province within a developing area.

For the estimation of costs and revenues, price information was provided for the different inputs and outputs. Even though this information was variable among species (for example seedstock cost for shrimp, crab, milkfish, seaweed; output prices for each of them), it is constant for the 55 farms. As there is no price differentiation (inputs and outputs) among farms, this excluded the possibility to carry out the dual cost index determination and analysis.

Results

Distribution of the TFP indexes for the 55 farms is as shown in Figure 1. The minimum TFP is 0.709, maximum is 4.41 and approximately 67% of all the farms have TFP values below the mean.

The Index Numbers obtained are presented in Table 1 on a geographical basis. Only in three of the nine sub-districts TFP (average) is above the total mean. By sub-district, the highest average TFP is obtained in the sub-district Walenrang, where only polyculture farms are established. For the three broad geographical and social regions, Luwu (1.67) presents the higher TFP compared with the average, followed by Kwandang (1.44) and Lariang (1.13). Values for mean Net Profit and mean Total Variable Costs are also included in Table 1. The TFP Index and Total Net Profits have a positive correlation of 0.645 (Pearson).

Table 2 shows the TFP values for the different production systems. TFP indexes for polyculture are higher in general, and in particular polyculture incorporating seaweed indicating that *Gracilaria sp.* is a significant factor in higher total factor productivity in these farms.

In this study, the highest TFP value (4.41) compared with the mean is achieved by polyculture systems of seaweed, milkfish and shrimp (G+M+S). As the interspatial TFP estimation works with logarithms, its exponentiation gives results in percentages as compared to the reference, which in this case is the mean of the 55 farms and represents the productivity differences. For example, a TFP index of 1.28 for the polyculture of milkfish and shrimp means that this system can achieve upto 28% more than the average revenue (output times the income share) of the 55 farms, for this particular combination of species and the inputs (quantity times input share) required in its culture. Hence, TFP variations reflect productivity differences with respect to the mean, for each particular farm.

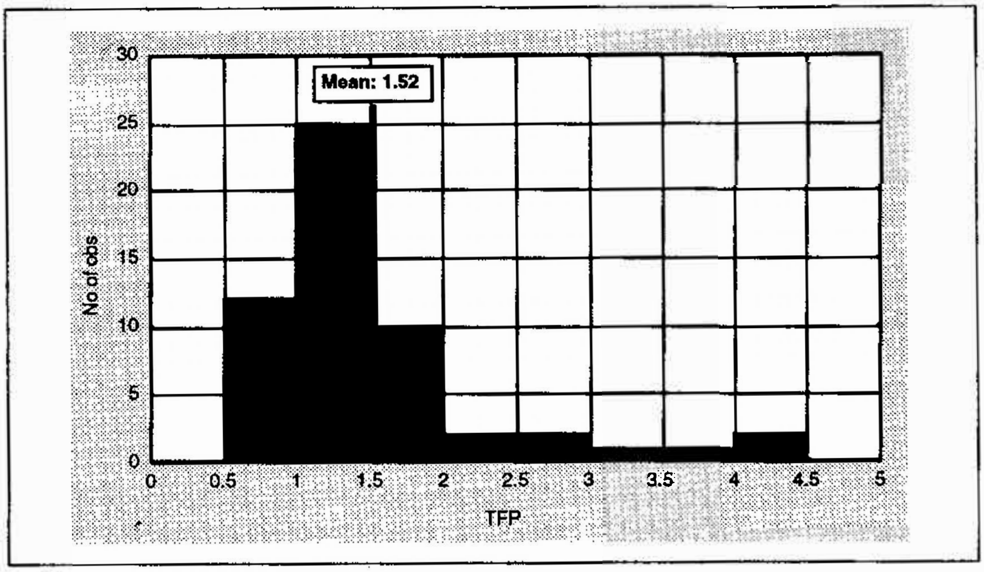

Fig. 1. Histogram of TFP (Tornqvist) Indexes for the 55 farms.

Table 1. Characterization of the culture systems by geographical location, including TFP indexes.

Kecamatan (sub-district)	No. of Farms	Mean Net Profit (Rp/yr)	Mean Pond Area (Has.)	Culture System	Mean Total Variable Costs	TFP (mean)
LUWU region						
Walenrang	7	3'763,009	5.71	7P	867,020	2.682
Malangke	5	3'415165	8	1M – 4P	1'080,635	1.656
Bone-bone	4	1'032,058	3.75	2M – 2P	1'160,167	1.126
Buran	4	2'076,207	3.61	2M – 2P	1'062,893	2.089
Wotu	4	650,811	3.77	3M – 1P	473,289	1.213
Malili	6	2'050,552	3.58	6P	1'140,048	1.236
KWANDANG region						
Kwandang	10	6'488,249	3.8	4M – 6P	1'955,302	1.4423
LARIANG region						
Pasang Kayu	9	1'761,098	3.66	2M - 7P	316,637	1.187
Budong-budong	6	1'264,400	3.66	2M – 4P	369,367	1.074

M= Monoculture P= Polyculture.

Table 2. TFP indexes by culture system.

Culture System	Mean TFP
Monoculture	1.2308
Polyculture with seaweed	3.2644
G + M	3.3213
G + M + S	4.4157
G + M + S + C	2.4927
Polyculture without seaweed	1.3945
S + M	1.2821
C + M	3.566
S + C	1.133
S + C + M	1.2133

S=shrimp, G= Seaweed, M=Milkfish, C=Crab

The result of regressing TFP as a function of nine different geographical locations, eight different culture systems (for culture combination) and total pond area is:

$$TFP = 1.4190 + 2.4\ Dcs_1 + 3.37\ Dcs_2 + 1.54\ Dcs_3 + 0.32\ Dcs_4 + 1.79\ Dcs_5$$

(7.69) (5.06) (4.64)* (2.98)* (1.86) (2.95)**

$$- 0.209\ Dcs_6 + 0.091\ Dcs_7 - 0.049\ TPA - 0.278\ Dd_1 + 0.449\ Dd_2 - 0.27\ Dd3$$

(-0.42) (0.12) (-2.34) (-0.48) (0.98) (-0.98)*

$$+ 0.178\ Dd4 - 0.1\ Dd5 - 0.33\ Dd6 - 0.3\ Dd7 - 0.393\ Dd8$$

(0.59) (-0.35) (-1.32) (-1.40) (-1.6)

R^2= 0.6793

In parenthesis are t values.

(*) significant at 95%

From the signs of the significant coefficients we can interpret that all culture systems incorporating seaweed have a significant positive effect on TFP ($p < 0.005$), this is, significantly higher than the reference system which is the monoculture. Without seaweed, the culture system with crab and milkfish is also significant for TFP higher values. On the other hand, total pond area is inversely related to TFP. Finally, geographical location doesn't exert a significant effect on TFP values.

Figures 2 and 3 show the share of total variable costs for the different inputs and the share of revenues from the different species for the polyculture systems that have significant positive effect on TFP values from the regression analysis. Labor and seed are the two main variable operation costs in these extensive systems. The polyculture which has a stronger positive effect on TFP (G+M+S) has a small share of costs for seed and around 70% of the total costs in labor. The revenue from the seaweed culture represents for this best scenario upto 61% of the total. In general, as shown in Figure 3, the incorporation of seaweed in the production system represents upto 40%, 60% and 70% of the total revenue for the polycultures G+M+S+C, G+M+S and G+M respectively.

Considering that for this study prices are fixed (input and output), the incorporation of seaweed, which has relatively low impact for the main variable cost (seed) but represents the biggest share in revenues, is a good production strategy. These relationships are reflected in the positive impact on TFP.

Discussion

From the analysis, three areas were identified to be significant in the TFP regression. These were as follows.

- Polyculture practices had a positive impact on TFP
- Addition of seaweed (*Gracilaria sp.*) to polyculture had a positive impact on TFP
- Pond area had an inverse impact on TFP.

The results indicate that the application of polyculture practice result to greater production than that obtained from the monoculture system for the species considered in the extensive culture systems. This is a logical conclusion, since the use of a multiple species stocking strategy allows for the fuller utilization of the pond's niches and resources. However, determination of what combination of species is most productive is critical in optimizing the use of the resources. The culture parameters of the major species used in tambaks (e.g., shrimp, milkfish, mangrove crab, and *Gracilaria sp.*) are established, particularly for shrimp and milkfish. However, the use of various polyculture mixes of these species should be explored to optimize production. In addition, other potential species should be considered (e.g., mullet, sea bass, shellfish, and hybrid red tilapia) to meet local preferences and market opportunities.

Of the various polyculture systems used at the project sites examined in this study, those that included seaweed culture were the most productive. The addition of seaweed to the polyculture species had a significant impact on the

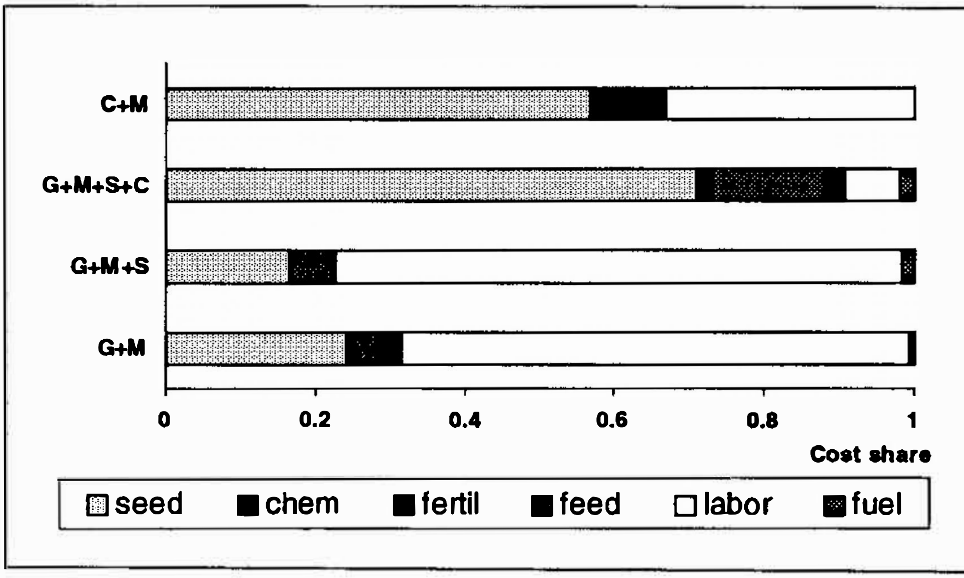

Fig. 2. Input cost shares for the polycultures with significant higher TFP indexes. (Polycultures: C+M: crab and milkfish; G+M+S+C: seaweed, milkfish, shrimp and crab; G+M+S: seaweed, milkfish and shrimp; G+M: seaweed and milkfish).

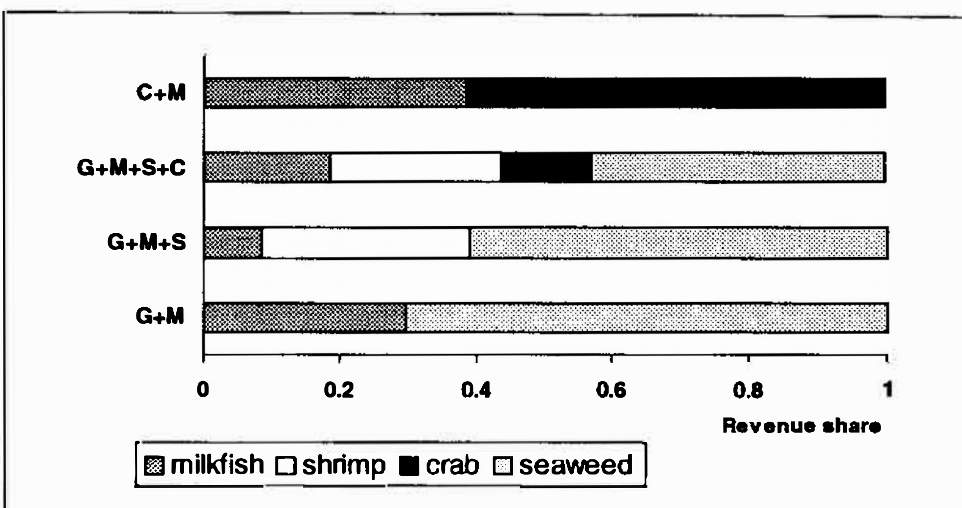

Fig. 3. Revenue shares of the different species for the polycultures with significant higher TFP indexes. (Polycultures: C+M: crab and milkfish; G+M+S+C: seaweed, milkfish, shrimp and crab; G+M+S: seaweed, milkfish and shrimp; G+M: seaweed and milkfish).

TFP. Figure 3 indicates that seaweed was the major contributor to production revenue in all polyculture systems when utilized as one of the cultured species. Seaweed provides for the fuller utilization of the culture pond and utilizes the natural production capacity of the pond by filling a trophic level that is not utilized by the other species. The management of seaweed culture requires additional technical skill and does increase the labor input; however, the additional product produced offsets these increased costs.

The inverse relationship of pond area and TFP is indicative of small family owned/operated farms, since the labor resource is mainly based on family members and as the area under management increases, the level of labor devoted per unit area decreases. With a decrease in labor per unit area and a corresponding reduction in management applied, the consequence is a reduced production per unit area. Skill level would also play a role in this relationship, since the skill requirement to properly manage a farm increases with the size of the farm.

The application of culture practices that approach the upper limits of a specific aquaculture system (e.g., extensive) is important for a number of reasons.

- First of all, it is to maximize the economic benefit to the owner/operator.
- Second is to fully utilize the natural productivity capacity of the system.
- Third, in extensive systems the fuller utilization of production capacity of the pond by utilizing a combination of species that occupy different trophic levels and niches will allow for the fuller use of these production factors and also minimizes potential negative environmental impacts from pond effluents. That is, it would reduce the nutrient load in the system by converting a greater amount of the nutrients into a biomass of the products harvested.
- Fourth, this information is of value to the development of fisheries policy for the aquaculture industry and its practical use in fisheries extension programs that are to assist farmers in the operation and management of their farms.

In extensive polyculture systems in this study, farmers are often limited in the quantity of seedstock purchased by their financial resources. The cost associated with seedstock, particularly for shrimp and milkfish, limits the purchase of adequate seedstock to fully stock their ponds for extensive plus culture practices. Similar constraints were cited by Konphalindo (1996). Figure 2 shows that polyculture utilizing G+M and G+M+S, the major cost of production is in labor which is not a limiting factor in this study (in the case of labor intensive harvesting and processing of seaweed, labor is often temporarily hired and paid based on the quantity processed). However, in the G+M+S+C and C+M the major cost of production is in seedstock, which requires cash that often poses a constraint. With limited financial resources, this results in stocking density, particularly of shrimp and milkfish, being less than optimal, which would have a negative impact on potential production.

As major production declines in various countries over the past decade due to improperly designed or operated systems that have exceeded the environmental carrying capacity, a sustainable aquaculture industry has become an issue. The manifestation of environmental degradation affects pond water quality and increases disease problems and subsequently negatively impacts production. Therefore, the determination of sustainable aquaculture systems is a widely debated and crucial point from both environmental and economic perspectives. Under monoculture conditions, Posadas (1987) compared the profitability of extensive, semi-intensive and intensive shrimp cultures and found all three to be profitable under stable market conditions. However, with a 20% fluctuation in input costs, market price or both, only the semi-intensive farms remained profitable (Csavas, 1988, 1990; Primavera, 1994). Primavera (1991) concluded that only semi-intensive culture practices in shrimp aquaculture would be sustainable when all three criteria of economics, ecology, and social concern were addressed. Konphalindo (1996) reviewed five culture systems (silvofisheries or mixed mangrove and aquaculture, traditional, traditional plus, semi-intensive, and intensive) and concluded that a single sustainable model could not be identified for all locations, since it is highly site specific as well as subject to other local conditions that influence a system's sustainability.

Land for aquaculture in developing countries was frequently treated as an unconstrained input factor. The conversion of mangrove forest areas, which in the past had been considered to be of "little or no value" by governments, has provided a low cost land resource for aquaculture development. Therefore, extensive culture practices and inefficient use of the coastal resource was unimpeded by land availability. However, this has changed in recent years with the growing limitation of land resources and the realization of the environmental value of mangroves and the broader issues of environmental degradation. This shift in policy is characterized by the Indonesian aquaculture development objective of obtaining sustainable levels of production by optimizing use of natural resources and the application of appropriate technology within environmentally sound practices (Nurdjana, 1997). Extensive systems under certain conditions may be the most appropriate system and will continue to play a major role in the overall Indonesian aquaculture industry due to limitation of various input resources including seedstock, capital and skilled manpower. Therefore, efforts to better utilize current aquaculture ponds within realistic limitations should be a consideration in fisheries policy development and implementation. The method put forth in this study of TFP analysis is a means of contributing to the identification of practices for increasing the output efficiency of aquaculture ponds within the constraints of the input and operational system as part of a broader integrated sustainable coastal resource management program.

Research on optimization of both extensive and semi-intensive pond culture under polyculture systems should focus on optimizing production within limiting system constraints. Researches that aim to identify low cost local inputs that can substitute for some of the major inputs (e.g., feed, fertilizer) should be examined. The objective should be to develop an efficient culture system utilizing readily available lower cost local inputs and optimize output under the given conditions within appropriate technology levels. This would also be limited by skill level, sustainability of the system, and compliance with "codes of practice" and "best management practices".

The implication of TFP analysis is that it can play an important role in the refinement of culture systems and in the design of a sustainable aquaculture industry. TFP analysis can also contribute to the process of developing appropriate policies based on applied analytical results.

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