Life Cycle Assessment of Fish Culture in Thailand: Case Study of Nile Tilapia and Striped Catfish

Patcharaporn Pongpat and Rungnapa Tongpool

***Abstract*—This study was aimed to assess environmental impacts of fish culturing in Thailand using life cycle assessment (LCA) method. The scope was a cradle-to-gate study of red nile tilapia (*Oreochromis niloticus*) and striped catfish (*Pangasianodon hypophthalmus*). The impact assessment method of CML Baseline 2000 was applied to evaluate the impacts in the categories of abiotic depletion, acidification and global warming. The impacts of red nile tilapia were 3-4 times higher than those of striped catfish. The global warming potential of red nile tilapia was 2.96 kg CO_2 eq, where as that of striped catfish was 1.01 kg CO_2 eq. The feeds, especially fish meal, were the main impact contributors. Small replacement of fish meal with soybean meal while maintaining the growth rate of the fish was possible. This leaded to slightly decrease in the environmental impacts. The environmental performance of fish meal itself should be improved in order to reduce the impacts from fish culture.**

***Index Terms*—Fish culture, LCA, Nile tilapia, striped catfish.**

I. Introduction

Aquaculture is the fastest growing food-producing sector in the world [1]. Aquaculture plays an increasingly important role in food security and the economy of Thailand [2]. Freshwater aquaculture is mainly for domestic consumption. Small-scale freshwater aquaculture is important in providing high quality protein food for rural poor people. Freshwater aquaculture produces medium-value products for export. In 2010, total production from freshwater aquaculture was 496,599 tons as shown in Fig. 1. The main freshwater fish cultured were nile tilapia (*Oreochromis niloticus*), walking catfish (*Clarias batrachus*), snakedskin gourami (*Trichogaster pectoralis*) and striped catfish (*Pangasianodon hypophthalmus*). The production of freshwater culture in Thailand has been the same from 2005 to 2010 and some have been the same for more than ten years (Fig. 2). The improvement of fish culture should be paid attention to meet up with an increasing demand of the world.

The striped catfish from Thailand is called 'tropical white fish' in Europe. The term 'tropical white fish' is commonly used to designate the fish with white flesh, such as cod, hake, Alaska Pollock, which are common in European [4]. This sector has to overcome trade embargoes and related restrictions that are imposed by certain importing countries [5]. Currently, such barriers on the striped catfish from Thailand do not exist in most importing countries. However, food safety and food quality standards are still enforced. Concerns on fish quality and environment of farming system have been raised.

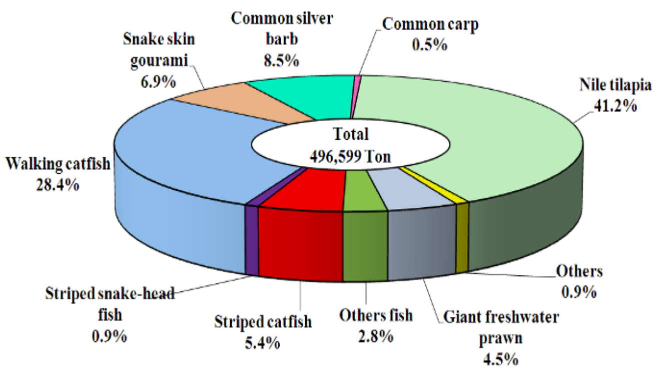

Fig. 1. Production of freshwater culture by species in 2010 [3].

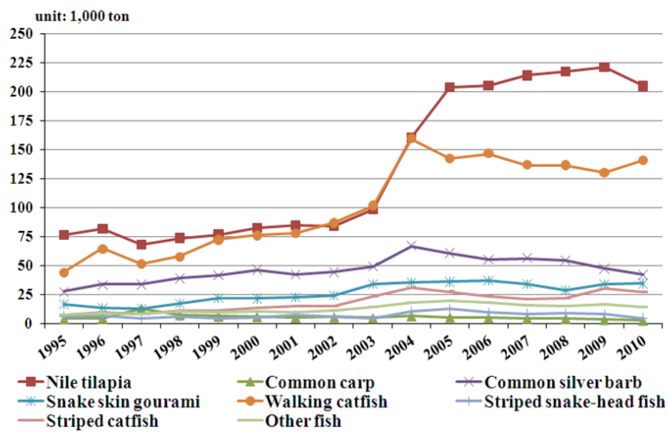

Fig. 2. Production of freshwater culture by species, 1991-2010 [3].

As mentioned above that nile tilapia and striped catfish are important in the fish industry of Thailand. The resource used and emissions from the cultures affects environment status of the country. This study was aimed to evaluate the environmental impacts from the production of these two fish using life cycle assessment (LCA) method and to identify of environmental hot spots (activities contributing large impacts). The result of this study will be beneficial for farmers to see possible approaches in improving the management and practices in the farms. This will subsequently reduce the environmental impacts of the fish and increase their competitiveness in the world and domestic market.

Manuscript received April 25, 2013; revised June 25, 2013. This work was supported in part by the National Science and Technology Development Agency (NSDTA) Thailand, under the Thailand National LCI Database Project.

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DOI: 10.7763/IJESD.2013.V4.423

II. Methodology

LCA is a comprehensive environmental accounting tool with well-established procedures and international standard [6]. There are four steps in LCA, which are goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation. LCA has been used to evaluate environmental performance of fishery and seafood products [7].

A. Goal

The goal of this study was to evaluate environmental impacts of nile tilapia and striped catfish using LCA and CML Baseline 2000 assessment method. The result of this study could be helpful for the stakeholders of fishery industry and policy-makers in Thailand in order to understand the problem of fishery production, providing scientific proof on environmental impacts in several categories.

B. Scope

The scope of this study is shown in Fig. 3. The culture system of nile tilapia and striped catfish included preparation of pond and floating basket (cage), as well as feeding fish and harvesting. Natural resources used and emissions from the production of chemicals and feeds are included, i.e., a cradle-to-gate study. Transportation data was excluded.

There are two main types of nile tilapia; Chitralada strain (normal tilapia) and Tabtim strain (red nile tilapia). They can be cultured in cages and in ponds [8] as shown in Fig. 4. In this work, red nile tilapia was studied. In Thailand, most of the red nile tilapia is cultured in fish cages and striped catfish (known as "Sa-Wai" in Thai) is cultured in ponds.

Various substances and energy used in each process were included in the inventories. The background data of certain processes and chemicals could not be found, and thus they were excluded from the scope of this study. The total exclusion was less than 1% by weight.

The functional unit (FU) was defined as 1 kg of fish.

C. Life Cycle Inventory Analysis

The gate-to-gate inventory data were obtained from the project "Development of National Life Cycle Inventory Database of Food and Agriculture" by National Metal and Materials Technology Center and University of Payao under the Thai National Life Cycle Inventory Database Development Project, carried out according to ISO 14040 [9]. Data collection was obtained from the fish farm in Thailand in 2012.

The inventories of the nile tilapia and striped catfish included all inputs, e.g., feeds, chemicals, fuel, as well as all outputs, e.g., product, air emission, solid waste and dead fish. Water supply for the farms was obtained from river, streams and canals. Harvesting was done using seine nets after draining 60–80% of the water in the pond.

Amount of CO_2 CH_4 and N2O from fuel combustion was calculated using emission factors of IPCC 2006 [10]. Data on emissions of CO, SO_2, NOx, NMVOC and PM10 were calculated using emission factors from EMEP/EEA air pollutant emission inventory guidebook 2009 [11]. The background data of each input was chosen from Ecoinvent database to obtain cradle-to-gate inventory.

D. Life Cycle Impact Assessment (LCIA)

The impact assessment method of CML Baseline 2000 was used via SimaPro 7.3 software [12]. The impact categories of interest were abiotic depletion (ABD) (unit: kg Sb eq), acidification potential (ACD) (unit: kg SO2 eq), global warming potential (GWP100) (unit: kg CO2 eq) [12]. This method provides summation of the environmental impacts occurred throughout the scope of this study. Global warming potential, acidification and abiotic depletion have been typically included as impact categories in LCA studies of seafood products [1].

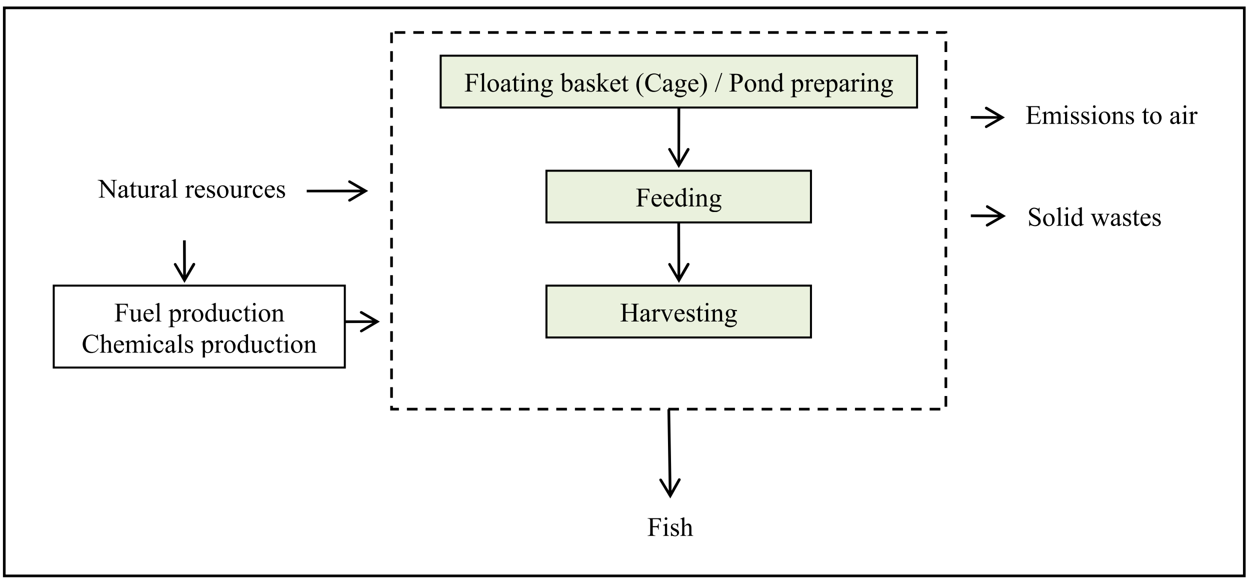

Fig. 3. Product systems of fish culture under LCA study.

(a) Floating basket (Cage) (b) Pond

Fig. 4. Common types of fish culture in Thailand

III. Results and Discussion

The environmental impacts of the fish are shown in Table I. It can be seen that the red nile tilapia had higher environmental impacts than the striped catfish in all categories. The sources contributing to the environmental impacts, shown in Fig. 5, were categorized as (i) impacts from farming (shown as Farm), (ii) fish meal, (iii) soybean meal, (iv) rice bran, (v) maize starch, (vi) vegetable oil and (vii) vitamin C. Fish meals shared large contributions in all categories. Maize starch shows relatively high impact in the category of abiotic depletion. Contributions from soybean meal played important role in the categories of abiotic depletion and global warming potential.

The environmental impacts of striped catfish are shown in Fig. 6. Fish meal was also the main impact contributors in all categories. Soybean meal played important role in the categories of abiotic depletion and global warming. Rice bran shows relatively large contribution in global warming.

The CML Baseline 2000 assessment method has been used to study environmental impacts of seafood [12]-[14]. Table II shows the environmental impacts of trout and salmonid, produced by common technology and assessed within the same scope as the red nile tilapia and striped catfish. It can be seen that striped catfish had the lowest impact. This is because the striped catfish was fed with left over agricultural products such as chicken intestine and swine dung which had no environmental burden. The use of swine dung generated planktons which were eaten by the striped catfish.

TABLE I: Environmental Impacts of 1 Kg of Nile Tilapia and Striped Catfish.

Impact category	Unit	Red Nile Tilapia	Striped Catfish
Abiotic depletion	kg Sb eq	0.0024	0.0006
Acidification	kg SO2 eq	0.0408	0.0093
Global warming	kg CO2 eq	2.9600	1.0142

TABLE II: The Impact on Global Warming from the Production of 1 Kg Fish

Impact category	Unit	Trout [13]	Salmonid [14]
Abiotic depletion	kg Sb eq	Not available	0.0109
Acidification	kg SO2 eq	0.0105	0.0166
Global warming	kg CO2 eq	2.1561	1.4379

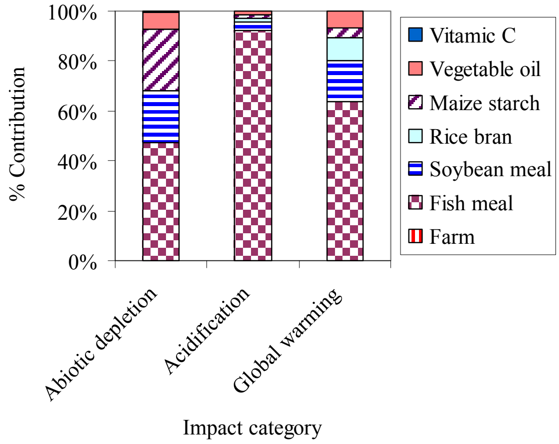

Fig. 5. Impact contributions from the components used to produce 1 kg of red nile tilapia.

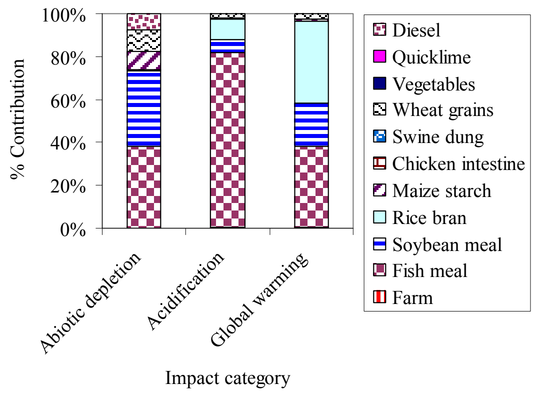

Fig. 6. Impact contributions from the components used to produce 1 kg of striped catfish.

It can be seen that the impact of red nile tilapia are higher than trout, salmonid and striped catfish. Therefore farmers should find alternative feed sources that would not interrupt the growth rate of fish. It was reported that when 30% of fish meal protein was replaced by soybean meal for the feeds containing 32% protein, the growth rate of nile tilapia was changed [15]. However when the feeds contained 24 % protein, the 30% replacement gave the same result as the control group (no fish meal replacement).

The scenario was modeled in this study and find out how much the environmental impact can be reduced. One fifth of fish meal protein was replaced by soybean meal, giving the feeds the same protein content. The environmental impacts of the scenario are shown in Table III. It can be seen that the impact reduction in the category of acidification for the red nile tilapia and striped catfish was 17.6 and 15.6%, respectively. The reductions in the other two categories were relatively low. If the ratio of fish meal was further decreased, the grow rate of fish could be reduced. Therefore the impact of fish meal itself should be paid attention.

Table IV shows environmental impacts of 1 kg of fish meal produced from trash fish [16]. The impact in the category of global warming was as high as 5.7 kg CO_2 eq/kg. Environmental performance of fish meal should be improved.

TABLE III: ENVIRONMENTAL IMPACTS OF 1 KG OF RED NILE TILAPIA AND STRIPED CATFISH ACCORDING TO THE SCENARIO.

Impact category	Unit	NILE TILAPIA		STRIPED CATFISH	
		Scenario	% Reduction	Scenario	% Reduction
Abiotic depletion	kg Sb eq	0.0023	3.9	0.0006	3.2
Acidification	kg SO_2 eq	0.0336	17.6	0.0079	15.6
Global warming	kg CO_2 eq	2.7127	8.4	0.9643	4.9

TABLE IV: THE ENVIROMENTAL IMPACTS FROM THE PRODUCTION OF 1 KG FISH MEAL FROM TRASH FISH.

Impact category	Unit	Impact
Abiotic depletion	kg Sb eq	0.0035
Acidification	kg SO2 eq	0.1139
Global warming	kg CO2 eq	5.6921

IV. CONCLUSIONS

Life cycle assessment was used to evaluate the environmental impact of red nile tilapia and striped catfish culture and to identify environmental hot spots. The results revealed that the feeds, especially fish meal, were the biggest impact contributor. Small replacement of fish meal with soybean meal while maintaining the growth rate of fish was possible. This leaded to the environmental impact reduction in the category of acidification. The impacts in the categories of abiotic depletion and global warming were slightly changed. Therefore the environmental performance of fish meal itself should be improved.

ACKNOWLEDGMENT

The authors acknowledge the funding support from National Science and Technology Development Agency (NSTDA), Thailand. We appreciate University of Payao for LCI data collection of this study. We also acknowledge Assoc. Prof. Dr. Thumrongrut Mungcharoen and Ms. Chantana Yuvaniyama, the experts at National Science and Development Agency (NSTDA), for the advice on the Thai National Life Cycle Inventory Database Development Project.

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Dr. Tongpool achieved gold medal from Agriculture-Horticulture-Gardening Section, 34th International Exhibition of Inventions, New Techniques and Products, Geneva, in 2006, on her invention “zip-lock paper bag”. She wrote the book “Establishment of Thai National Life Cycle Inventory Database, Pathumthani, NSTDA, 2012 (ISBN: 978-616-12-0176-0) according to her experience on LCI and LCA. Her recent article is “Improvement of the environmental performance of broiler feeds: a study via life cycle assessment”, published in Journal of Cleaner Production, 2012.