Journal of Integrated Field Science

Vol. 10

March. 2013

Field Science Center
Graduate School of Agricultural Science
Tohoku University

Journal of Integrated Field Science (JIFS)

Office : Field Science Center,
Graduate School of Agricultural Science,
Tohoku University,
1-1 Tsutsumidori-Amamiyamachi, Sendai,
Miyagi, 981-8555, Japan

Printed by Meirin-sha Company, Ltd., Sendai, Japan

Contents

Effects of Environmental Moisture on Twig Litter Decomposition by Fungal Colonizers

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Keywords: Acid-unhydrolyzable residue (AUR), beech, holocellulose, humus accumulation, twig decay

Received 7 December 2012; accepted 12 February 2013

Abstract

The effects of variations in environmental moisture on fungal decomposition of the chemical components in Japanese beech (*Fagus crenata*) twigs were examined using a pure culture test with two ascomycetes (*Phomopsis* sp. and *Xylaria* sp.) and two basidiomycetes (*Mycena polygramma* and *Phanerochaete filamentosa*). Moisture did not significantly affect the weight loss of the twigs after a 6-month incubation, but it significantly altered the decay preferences of each fungus for different wood components. *Phanerochaete filamentosa* shifted from being a selective decomposer of acid-unhydrolyzable residue (AUR) with high moisture to being a selective decomposer of holocellulose with low moisture. *Xylaria* sp. shifted from being a simultaneous decomposer of AUR and holocellulose with high moisture to being a selective decomposer of holocellulose with low moisture. Thus, our findings indicate that dry conditions stimulate AUR accumulation in twig litter.

Introduction

The decomposition of woody litter is an important factor controlling soil humus formation in forest ecosystems (Swift et al. 1979). Woody litters are mainly composed of acid-unhydrolyzable residues (AUR, formerly referred to as lignin) and holocellulose (Eriksson et al. 1990). AUR is the main precursor of humus (Stevenson 1982), so the decay ratio of AUR to holocellulose is crucial in determining the accumulation of soil organic matter and humus formation in forests (Osono 2007).

Fungi have a central role in the process of decomposition of woody litter (Boddy 1991); abiotic conditions such as moisture are primary agents that indirectly affect litter decomposition processes mediated by microbial activity (Prescott 2010). Fine woody litters such as twigs and branches are particularly affected by environmental moisture because moisture conditions differ depending on weather they are attached, hanging in the air, or lying on the ground (Boddy and Swift 1983). Drier conditions usually delay the litter decay rate by reducing mycelial activity (Swift et al. 1976; Erickson et al. 1985; Osono et al. 2003b), but the appropriate moisture range for mycelial growth and decay activity varies among fungal species (Griffin 1972). For example, fungi living in dry places, such as attached dead twigs, usually have a lower optimal moisture level (Boddy et al. 1985; Chapela and Boddy 1988a) whereas soil-borne fungi have a higher optimal moisture level (Griffin 1972). Thus, it is hypothesized that the effect of moisture on fungal decay of AUR and holocellulose will differ among fungal species. However, little is known about the effects of moisture on fungal preferences for litter chemical components during decay processes.

In this study, we focused on the effect of moisture on the abilities of fungi to decay beech twig litter and its chemical components. Fungi associated with beech twigs include *Phomopsis* sp. (anamorph of *Di-*

aporthe) and *Xylaria* sp. (anamorph) as the dominant endophyte ascomycetes on healthy Japanese beech twigs (Sahashi et al. 1999; Osono and Mori 2003) and they act as primary colonizers of twig litter (Griffith and Boddy 1990). *Mycena polygramma* (Bull. Fr.) S.F. Gray and *Phanerochaete filamentosa* (Berk. et Curt.) Burdsall are basidiomycetes that are found on beech forest floors in Japan (Osono 2002; Fukasawa et al. 2009a). These four fungal species were used in pure culture decay experiments with two different environmental moisture levels, i.e., low (50%) and high (100%), which replicated the moisture conditions in an attached dead twig (Griffith and Boddy 1991) and the soil at our study site (Hishi et al. 2004), respectively. The results for the high moisture level have already been published (Fukasawa et al. 2009b) according to which *P. filamentosa* is AUR-selective, *Phomopsis* sp. is holocellulose-selective, and *Xylaria* sp. and *M. polygramma* are simultaneous decomposers of AUR and holocellulose.

Materials and methods

Source of fungi and twig litters

Four isolates in four fungal species were used in this experiment. *Phomopsis* sp. (Code Phom397) and *Xylaria* sp. (Code Xyl470) were isolated from surface-sterilized healthy twigs (diameter < 0.5 cm) of Japanese beech collected from a crown of recently-fallen beech tree in a cool temperate deciduous forest in the Ashiu Experimental Forest of Kyoto University, Kyoto, Japan in October 2004. *Mycena polygramma* (Code NBRC33011) was obtained from the culture collection (NBRC, Tokyo, Japan). *Phanerochaete filamentosa* (Code 1070506) was isolated from a basidiocarp collected at the Ashiu Experimental Forest in July 2001. These two basidiomycetes were used in *in vitro* decomposition tests to determine their ability to decompose leaf litter (Osono and Takeda 2002; Osono et al. 2003a) and wood block (Fukasawa et al. 2005). The fungi were maintained on 2% (w/v) malt extract agar medium [MA: malt extract (Nacalai Tesque, Kyoto, Japan) 20 g, agar 15 g, and distilled water 1000 ml] until the tests started.

Beech twigs (diameter < 0.5 cm) used in the decomposition tests were collected from recently fallen beech trees in October 2004 at the Ashiu Experimental Forest. Twigs were oven-dried for 1 week at 40 °C and cut into short lengths of 500 mg each (approximately 5 cm in length), and sterilized with ethylene oxide gas at 60 °C for 3 h. The sterilized twigs were used for decomposition experiments.

Twig decomposition experiment

Experimental set up followed Fukasawa et al. (2009b). Glass jars (110 ml) were filled with 10 g air-dried perlite (a naturally occurring, processed volcanic glass; Koyoen, Japan) and sterilized for 1 h at 180 °C. Sterilized distilled water (5 ml or 10 ml) was added to each jar to achieve a 50% moisture reproducing the conditions of attached dead twigs that is the habitat of endophytic ascomycetes (Griffith and Boddy 1991) or 100% moisture reproducing the conditions of the soil of the Ashiu Experimental Forest (Hishi et al. 2004) where saprobic basidiomycetes inhabit, respectively. Each of these two levels of water contents was referred to as low and high moisture level, respectively.

One twig sterilized with ethylene oxide gas was buried in each jar using sterilized forceps. An inoculum of one of the four fungal species was cut out from the actively growing margin of 2-week-old cultures on 2% MA plate using sterilized cork borer (5 mm in diameter) and inoculated into each jar. The jars were capped and sealed by parafilm to prevent evaporation, and incubated in the dark at 20 °C for 3 or 6 months. Sterilized twigs inoculated with agar plugs without fungi were set as control. Three replicate jars were prepared for each treatment. After the incubation, the twigs were retrieve, dried to a constant mass at 40 °C and weighed.

Chemical analysis

The dried twigs were ground in a laboratory mill (0.5 mm screen). The amount of AUR in the sample was estimated gravimetrically using hot sulfuric acid digestion (King and Heath 1967). Total carbohydrate was analyzed with the phenol-sulfuric acid method (Dubois et al. 1956). Details of chemical analyses were described in Fukasawa et al. (2009b). The mass of holocellulose (insoluble carbohydrate) was calculated as the difference between total carbohydrates and soluble carbohydrates. Initial mass of AUR and holocellulose within 500 mg healthy beech twig were 171.0 and 221.3 mg, respectively (Fukasawa et al. 2009b).

The AUR/weight loss ratio (AUR/W) is a useful index of the substrate utilization pattern of each fungal species (L/W in Osono and Takeda 2002). The AUR/

W was calculated according to the following equations:

AUR/W = weight loss of AUR (% of original AUR weight) / weight loss of twig (% original weight)

Weight loss of the twigs and AUR were determined as the difference from the weight loss of control, expressed as a percentage of the original weight.

Data presentation and statistical analysis

Data are presented with the standard error of the mean (SE). We referred to Fukasawa et al. (2009b) for the weight loss data in high moisture level to compare with the data in low moisture level obtained in this study. Weight losses of twig, AUR and holocellulose, and AUR/W were compared among fungal species and between moisture levels, using two-way ANOVA. Where indicated, Tukey-Kramer's honestly significant difference (HSD) test was performed. Percentage weight loss data were all arcsine transformed before the analysis. All statistical analyses were performed with JMP version 5.1.1 (SAS Institute 2004).

Results

Weight loss of the twigs ranged from 0.6% to 4.6% at 3 month, and from 8.0% to 12.0% at 6 months (Fig. 1). Neither moisture level nor fungal species significantly affected weight loss of the twigs (2-way ANOVA) for both incubation periods. After 6 months incubation, the chemical components of the twigs were analyzed.

Weight loss of AUR and AUR/W were significantly affected by both moisture and fungal species (Table 1). The weight loss of holocellulose was affected by fungal species but not by moisture. Significant interactions between the effects of moisture and fungal species were observed for weight losses of AUR and holocellulose, and AUR/W.

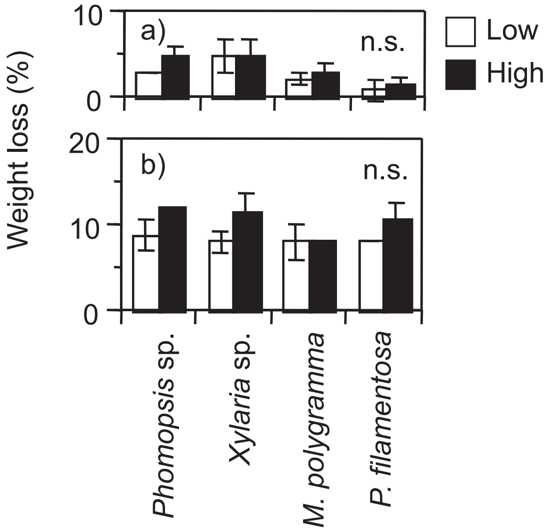

Fig. 1. Wight loss of beech twigs after a) 3 months and b) 6 months incubation period. Open bars, low moisture level (50% water content); Closed bars, high moisture level (100% water content). Error bars, SE. Data of high moisture were from Fukasawa et al. (2009b)

The weight loss of AUR ranged from –0.4% to 19.7% (Fig. 2), and was highest for *P. filamentosa* at high moisture level. Weight losses of AUR for *Xylaria* sp. and *P. filamentosa* were significantly lower at low moisture level compared to high moisture level. The weight loss of holocellulose ranged from 3.3% to 24.3%, and was highest for *Phomopsis* sp. at high moisture level. Weight loss of holocellulose for *P. filamentosa* was significantly higher at low moisture level compared to high moisture level.

AUR/W ranged from –0.1 to 1.9 (Fig. 3), highest in *P. filamentosa* at high moisture level and lowest in Phomopsis sp. at low moisture level. L/W for *Xylaria* sp. and *P. filamentosa* were significantly lower at low moisture level compared to high moisture level.

Table 1. Results of two-way ANOVA comparing weight losses (%) of AUR and holocellulose, and AUR/W after 6 months incubation period

	Moisture level			Fungi			Moisture × Fungi		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
AUR	1	27.08	0.0001	3	20.18	< 0.0001	3	11.91	0.0003
Holocellulose	1	1.17	0.2962	3	17.70	< 0.0001	3	14.38	0.0001
AUR/W	1	28.91	< 0.0001	3	36.65	< 0.0001	3	15.39	< 0.0001

AUR, acid unhydrolyzable residue.
AUR/W = weight loss of AUR / weight loss of twig.

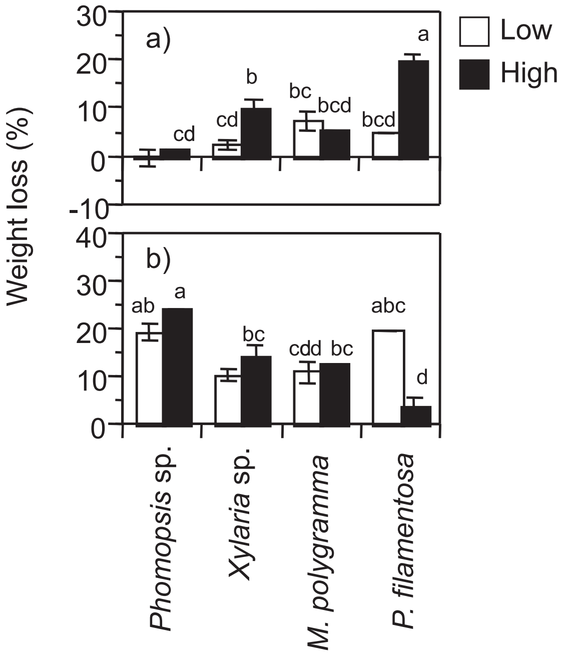

Fig. 2. Weight losses of chemical components of beech twigs after 6 months incubation period. a) acid-unhydrolyzable residue (AUR), b) holocellulose. Bars as for Fig. 1. Same letters above bars indicate no significant difference. Data of high moisture level were from Fukasawa et al. (2009b)

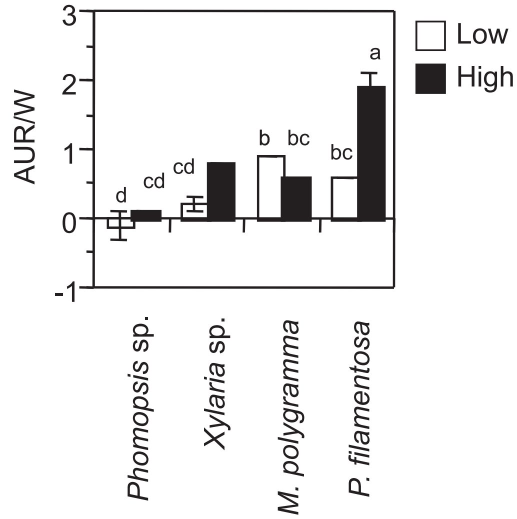

Fig. 3. AUR/W of beech twigs after 6 months incubation period. Bars as for Fig. 1. Same letters above bars indicate no significant difference. Data of high moisture level were from Fukasawa et al. (2009b)

Discussion

The present study demonstrates the effects of variations in environmental moisture on twig decomposition by fungi. The weight loss of twigs did not differ between the low and high moisture levels, but significant effects of moisture were observed on the fungal preference for decomposition of different chemical components of the twigs. With the high moisture level, *Phomopsis* sp. selectively decayed holocellulose, *Xylaria* sp. and *M. polygramma* simultaneously decayed AUR and holocellulose, whereas *P. filamentosa* selectively decayed AUR as described in Fukasawa et al. (2009b). In contrast, with the low moisture level, the AUR/W for the three fungal species were less than 1, with the exception of *M. polygramma*, suggesting their preference for holocellulose. It was surprising that the preference of *P. filamentosa*, known to be a highly selective decomposer of AUR, shifted to holocellulose-selective in dry conditions. *Xylaria* sp. also shifted to holocellulose selective decomposition under dry conditions. In contrast, the AUR/W for *Phomopsis* sp. and *M. polygramma* did not vary with moisture levels. These results suggest that the effect of moisture conditions on the decay preferences of fungi for different twig components depends on the fungal species, although there were no similarities in the moisture responses within each fungal ecological strategy such as endophytes (*Phomopsis* sp. and *Xylaria* sp.) and saprophytes (*M. polygramma* and *P. filamentosa*)

There have been few studies on the implications of moisture on AUR decomposition (e.g., ligninase activities, Bastos and Magan 2009), but high water potential may facilitate AUR decomposition when the reaction occur as hydrolysis (Thomsen et al. 2007). The reason why holocellulose decomposition by *P. filamentosa* was more stimulated at the low moisture level compared to the high moisture level is unclear. Previous reports indicate a higher decomposition rate of holocellulose under high water potential conditions (Summerell and Burgess 1989; Thomsen et al. 2007). Nevertheless, these results suggest that dry conditions could stimulate AUR accumulation in twig litter, which may retard subsequent decay processes (Berg and McClaugherty 2003). Further researches are essential to determine the effects of moisture on the litter decay abilities of a greater variety of fungi, and its subsequent decay processes.

Acknowledgements

We thank Dr. Chisato Kobayashi and Mr. Yasunori Baba for invaluable comments. Financial support for this study was provided in part by the Research Fellowship Division, Japan Society for the Promotion of Science for the first author.

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Environmental Impacts of Methane Fermentation System Using Hot Springs

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Keywords: cost analysis, hot spring, life cycle assessment, methane fermentation.

Received 5 December 2012; accepted 12 February 2013

Abstract

For establishing one of effective biomass-using system on hilly and mountainous regions in Japan, we developed the small methane fermentation system for garbage using hot spring. This study evaluated the environmental impacts and cost in the system. We used life cycle assessment methods using the actual data from our system and the inventory data. Energy consumption and global greenhouse gas emissions were used as the indicators of environmental impacts. In these results, the environmental impacts of initial material inputs (67.9 GJ, 4.96 t CO_2) were much larger than ones of operations (2.24 GJ / year, 0.361 t CO_2 / year). The balances between the environmental impacts of the initial and operations and the alternative effects such as methane utilization, slurry utilization, using garbage treatment and using hot spring were minus except for the balance between only inputs and methane utilization. It is suggested that our proposed system has the reduction effect of environmental impacts. In comparison with the centralized large-scale methane fermentation system, the cost of our system was cheaper than the centralized system. Assuming the introduction of our system to Naruko area, located on hilly and mountainous regions in northern part of Japan, the total cost of our system was half of the centralized system. The balances of energy consumptions and global greenhouse gas emissions were -347 GJ and -2.50 t CO_2 per year in our system and 216 GJ and 41.1 t CO_2 per year in the centralized system. This proposed system should be the key technique of the reduction of environmental impacts using bioenergy in hilly and mountainous regions.

Introduction

The various bioenergy production systems, which are expected to contribute to Japan's energy security and induce a lower climate change potential, have recently been receiving high attention (Gnansounou et al. 2009). Especially in organic waste from livestock and human, the methane fermentation system was expected because organic wastes generally have the high water contents and are unsuited for use in burning. On-farm methane fermentation system has been wide-spreading for livestock waste treatment in Japan (e.g. Hishinuma et al. 2002, 2008, Ishikawa et al. 2006) as well as Europe (Collet et al. 2011). On the other hand, the centralized methane fermentation system, which typically has larger-scale than on-farm system, could be suitable for human waste but the system has been underused (reviewed in Nakamura 2011). If the well-developed transportation network, the large population and the wide space enough to built a plants exist in the system-produced area, the centralized large-scale methane fermentation system may have economical and environmental benefits: but, even in this case, the problem of slurry treatment from the system may be remained (Nakamura 2011). It is difficult to build such a large-scale methane fermentation plant in hilly and mountainous regions, which occupy about 70 % of total land area in Japan. In such regions, there are a lot of resort areas in Japan. In these areas, three times garbage per capita is producedbecause many dishes are served based on Japanese traditional hospitality in accommodations (personal communication with Naruko Machi-zukuri, a community facilitation company in Naruko area). The effective treatment and usage of the garbage in such an area are urgently needed in Japan.

We are thinking one of potential energy source in the resort areas is hot spring that Japanese most resort areas have. Most hot springs have been used for only bathing activity but have a numerous thermal energy. Recently, some communities in the resort areas have been using this energy (Okumura et al. 2010). In the case using hot springs as energy, most are directly used as a thermal energy, e.g. central heating. as well as Iceland. We considered to use this thermal energy for methane fermentation. The thermal energy of hot springs is more suitable than energy from fossil fuel because the thermal energy for methane fermentation is too low to produce using fossil energy. There are two suitable temperature zones for methane fermentation: 35 °C and 55 °C (reviewed in Nakamura 2011). Choosing which 35 °C-fermented or 55 °C-fermented system uses depends on plants. More methane is produced by higher degree fermentation (55 °C) but the 55 °C-fermented system requires a lot of energy for heating fermentation tank. Thus, smaller plants are inefficient using the higher degree zones (reviewed in Nakamura 2011, Ogawa et al. 2003). Even in lower fermentation (35 °C), the smaller plant should have lower energy efficiency than larger one. Here, we have been trying to build small methane fermentation system using a thermal energy of hot spring in Naruko area, which is one of the famous resort areas in Japan. It has already been confirmed that the methane was produced in this system (Suzuki et al. 2012). In addition, the digested slurry from methane fermentation can be used as fertilizer of crops because there are many arable lands in Naruko area. Now this pilot plants are being tested (Suzuki et al. 2012).

For improving our proposed system, we should know how environmental impacts and cost including both initial inputs and operations are in comparison with the centralized methane fermentation system in hilly and mountainous. However, such a system, even similar-type methane fermentation system, has never existed. Thus, we cannot use the data of already-existed plants for our system and we must perform the estimation based on our results. For estimating both of environmental impacts, life cycle assessment (LCA) method has been widely used (Center for Environmental Information Service 1998, Jury et al. 2010, Roy et al. 2009). Within the methodological framework of LCA, environmental impacts will be carried out based on inventory of emissions and resources consumption. In addition, LCA method is suitable to evaluate the environmental impacts of an innovative technology (Jury et al. 2010).

In this study, the energy consumptions and global greenhouse gas (GHG) emissions of initial inputs and operations were estimated in the small methane fermentation system using hot spring. Both are useful as indicators of environmental impacts (Koga and Tajima 2011). And we also evaluated the costs of this system. The data of them were compared with that of the centralized methane fermentation system, assuming the introduction in such hilly and mountainous regions. We considered the effect of reduction of environmental impacts in hilly and mountainous regions.

Materials and Methods

2.1. Outline of our system

Fig. 1 illustrates outline of our proposed system and boundary of LCA. Garbage is taken into paper bag and brought to the methane fermentation plant by walk. Thus, we don't add environmental impacts and cost in transport of garbage to the estimation. Methane fermentation plant was heated up by hot spring. Methane produced by our system is used by gas lamp through desulfuration system. The slurry from methane fermentation is reserved in the tank for 1-3 days. After that, the slurry is transported in small truck and used as fertilizer. Evaluated energy consumptions and GHG emissions were drawn up in Fig. 1. We didn't count the energy and GHG that are used for production process on small track and broadcasting machine because these machineries are not only for our system.

2. Energy consumptions and GHG emissions from fuel and electricity consumptions

The consumption of fuel and electricity for operations in methane fermentation system such as transporting and broadcasting the slurry (see Fig. 1) were taken into account for energy consumptions and CO_2-equivalent GHG emissions. Total energy consumptions and GHG emissions were calculated using the index of energy consumptions and CO_2 equivalent GHG emissions (Table 1). In transport of the slurry, total gasoline consumption was estimated using fuel efficiency (8 km / L), load capacity (350 kg) and mean loading ratio (50 %) of small track and the assumed one-way distance (1 km). In broadcasting, total diesel consumption was estimated using fuel

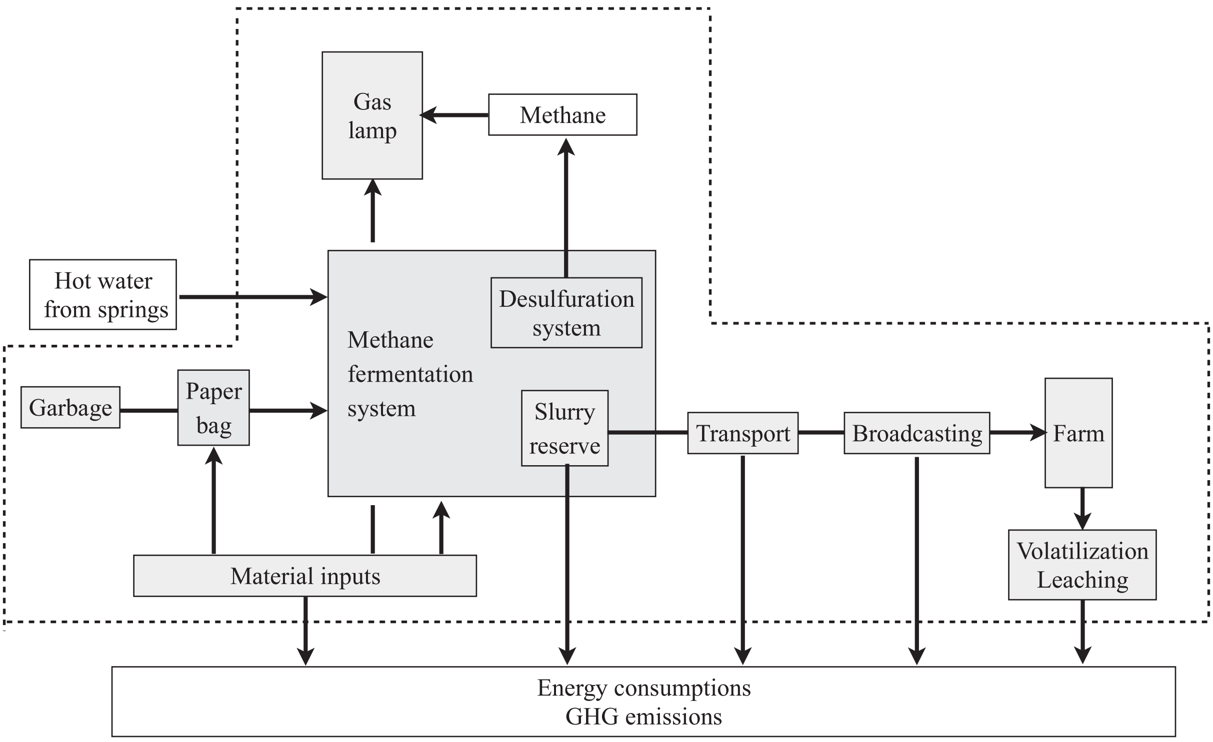

Fig. 1. Outline of the input-output flows of materials, energy and GHG emissions. Boundary is enclosed by dash lines.

Table 1. Equivalents for energy inputs and CO_2 emissions of fuels.

Fuels	Energy consumption	GHG emission
	MJ / L, kWh	kg CO_2 / L, kWh
Diesel	37.8	2.59
Gasoline	34.6	2.32
LNG	54.6	2.70
Electricity	3.60	0.555

Means of 2004-2006. Data cited from Greenhouse Gas Inventory Office of Japan (2008).

efficiency (7.1 t slurry-broadcasting / L) and total broadcasting volume (60 L / day).

3. Energy consumptions and GHG emissions from input materials

Energy consumptions and GHG emissions from input materials such as desulfuration system, the tank for slurry, methane fermenter, gas lamp, monitoring device, balloon for methane storage and paper bag for garbage (Table 2) were estimated using energy and emission intensity data from Center for Global Environmental Research (2007). These intensity data derived from Japanese Input-Output tables (equivalent to a million yen). The actual expenditure for each material in our system was used for the estimations.

4. CH_4 emission from slurry reserve and volatilization and leaching from field.

CH_4 emission from slurry reserve was estimated using 0.0156 L CH_4 / kg-VS / day and 0.04 kg-VS / kg-slurry. To calculate total N_2O emissions from slurry-used field including indirect emissions from NH3 volatilization and NO_3 leaching, we used 0.0155 kg N_2O / kg-N applied as fertilizer (Greenhouse Gas

Table 2. Equivalents for energy inputs and CO_2 emissions of materials.

Materials	Material names on database	Energy consumption MJ / 10^3 yen	GHG emission kg x CO_2 / 10^3 yen
Desulfuration system	General machinery	47.4	3.66
Tank	Plastic products	44.9	2.79
Methane fermenter	Cast iron products	129	10.5
Gas lamp	General products	27.6	1.88
Monitoring device	Analyzer and measuring apparatus	21.5	1.39
Balloon	Tires and rubber	44.1	2.86
Paper bag	General paper products	41.8	2.42

Center for Global Environmental Research (2007).

Inventory Office of Japan 2008). The rate of N applied as fertilizer for the spinach cultivation was 90 kg N/ha. To sum up GHG emissions, global warming potentials factors of 1, 21 and 310 were used for CO_2, CH_4 and N_2O, respectively (Greenhouse Gas Inventory Office of Japan 2008).

5. Estimation of alternative effects of the system

Reduced energy consumptions and GHG emissions were evaluated by using methane and slurry from this system and garbage and hot springs. Methane produced in this system was evaluated as using instead of LNG. We used the actual data (produced methane: 0.3 m^3 / day) and energy consumption and GHG emission of using LNG (Table 1). Using of slurry as fertilizer reduces using chemical fertilizer that has energy consumptions and GHG emissions in the production and transport process. The slurry contains the nutrition components: 0.2 % N, 0.01 % P_2O_5, 0.15 % K_2O (w/v) from actual measurement data. The environmental impacts of reduced chemical fertilizer were estimated (150 MJ / kg, 10.5 kg CO_2 / kg using Center for Global Environmental Research 2007). Garbage typically was burned in Japan. The burning process has energy consumptions and GHG emissions. We assumed using garbage for methane fermentation reduces the electricity for burning. The environmental impacts of burning garbage are 0.643 GJ / t-garbage and 99.1 kg CO_2 / t-garbage. Using hot springs reduces fuel for heating methane fermenter in boiler (fuel efficiency 4 L diesel /h).

6. Estimation of costs in methane fermentation systems.

We evaluated the costs for our proposed methane fermentation plant and centralized larger-scale methane fermentation plant using the value in the report of Institute of Applied Energy (2006). The initial material input cost of materials of our proposed system was 750 thousand yen. Whereas, that of centralized methane fermentation plant is assumed as 70 million yen. Both construction costs are assumed as 20 % of initial costs and the depreciation periods in plants are assumed as 15 years. The maintenance costs of both plants are assumed as 5 thousand yen / t-garbage. The operation, repair and insurance costs per a year are assumed as 1, 3, 0.4 % of the initial material input costs, respectively. The staff cost is assumed as 3.5 million yen and the general administration cost is assumed as 80 % of it. In the centralized methane fermentation plant, at least three full-time staffs are needed but, in our system, no staff is needed because the manager of the hot spring can check system.

7. Evaluation of the introduction to the actual area

We evaluated our proposed system introduced in Naruko area in comparison with the centralized larger-scale methane fermentation system in same area. Naruko area, which has many hot springs located in Northern Japan, is one of famous resort areas. Naruko area is separated to five subareas and each area has many accommodations. Table 3 shows capacities of accommodation in the five areas. The total number of overnight guests per year is 230 thousands in Naruko area (personal communication with Naruko Machi-zukuri). It is suggested that 40 % of total capacity is used in Naruko area. It is assumed that one guest produces 300 g-garbage / day. In this evaluation, the centralized methane fermentation system is assumed as building nearby the already-existing disposal plants. The distances between each subarea and disposal site are also shown in Table 3.

Results

Energy consumptions, GHG emissions and costs in initial material inputs are shown in Table 4. The total cost of making our proposed system was about 1.6 million yen and gas lamp for using produced methane accounted for about half of this cost. Total energy consumption and GHG emission were 67.9 GJ and

Table 3. Capacity, amount of garbage and distance of five subareas in Naruko area.

Area	Capacity of accommodations	Amount of Garbage	Distance from disposal site
	pearsons / day	t / year	km
Kawatabi	448	20	9
Higashinaruko	855	37	12
Naruko	3339	146	15
Nakayamadaira	681	30	20
Onikobe	489	21	30
Total	5812	254	

Amount of garbage was estimated using 40 % of capacity of accommodations and garbage produced per a person (300 g/day).

Table 4. Costs and Environmental impacts of material inputs.

Fuels and Materials	Cost	Energy consumption	GHG emission
	10^3 yen	GJ	t CO_2
Desulfuration system	100	4.74	0.366
Tank	50	2.25	0.140
Methane fermenter	200	2.58	2.10
Gas lamp	800	2.21	1.50
Monitoring device	200	4.29	0.278
Balloon	200	8.81	0.573
Total	1,550	24.9	4.96

Costs were actual data. Environmental impacts were estimated using costs and the values of Table 2.

Table 5. Environmental impacts of operations in the proposed system.

Fuels and Materials	Fuel	Energy consumption	GHG emission	Energy consumption	GHG emission
		GJ / year	t CO_2 / year	GJ / t	t CO_2 / t
Paper bag	-	1.04	0.0606	0.476	0.0280
Slurry reserve	-	-	0.000599	-	0.000273
Transport	Gasoline	1.08	0.0810	0.498	0.0370
Broadcasting	Diesel	0.116	0.00715	0.053	0.00327
Volatilization and leaching	-	-	0.212	-	0.097
Total		2.24	0.361	1.03	0.165

Environmental impacts were estimated using the values of Table 1 and 2.

4.96 t CO_2, respectively. Balloon for the storage of methane has the highest values in both energy consumptions and GHG emissions.

Energy consumptions and GHG emissions in operating our system are shown in Table 5. The environmental impacts of paper bag were estimated using the values of Table 2. In slurry reserve and volatilization and leaching from field, only GHG emissions occurred. Total Energy consumption and GHG emission per a year were 2.24 GJ and 0.36 t CO_2, respectively and total Energy consumption and GHG emission per ton-garbage were 1.03 GJ and 0.165 t CO_2, respectively. Each value of operations is small because this system does not need the energy for heating methane fermenter using hot spring.

The summarized results from Table 4, 5 and the four alternative effects are illustrated in Fig. 2. The environmental impacts of initial material inputs (67.9 GJ, 4.96 t CO_2) were much larger than ones of operations per a year (2.24 GJ / year, 0.361 t CO_2 / year). The environmental impacts of four alternative reduced effects were evaluated to a large extent: e.g. 1.41-1290 GJ / year. The effects without using boiler for heating methane fermenter were extremely large (1290 GJ / year, 87.2 t CO_2 / year and 588 GJ / t-input, 39.8 t CO_2 / t-input).

Table 6 summarizes the alternative effects from Fig. 2. Both energy consumption and GHG emission of initial materials inputs were divided by 15 years because the depreciation period of this system is assumed as 15 years. Concerning the balances between the environmental impacts of initial and operations and the four alternative effects in energy consumptions and GHG emissions, the balances became minus except for the balance between inputs and only methane utilization (0.1 GJ / year, 0.504 t CO_2 / year). It is suggested that our system has the reduction effect of environmental impacts.

The costs of our proposed system and centralized larger-scale methane fermentation system are shown in Table 7. As well as energy consumptions and GHG emissions, the costs of initial inputs were divided by 15 years. Our system did not need full-time staff and electricity for plants. On the other hand, the centralized system was assumed to need two full-time staffs and the electricity. The differences in them were critical. The difference in total cost is extremely large. The garbage input capacities are different in 2 t / year of our system and 300 t / year of centralized methane emission but, in the costs per ton-garbage, our system was cheaper than the centralized system. The difference is about 30,000 yen.

The results from evaluation of the introduction of the system to Naruko area were shown in Table

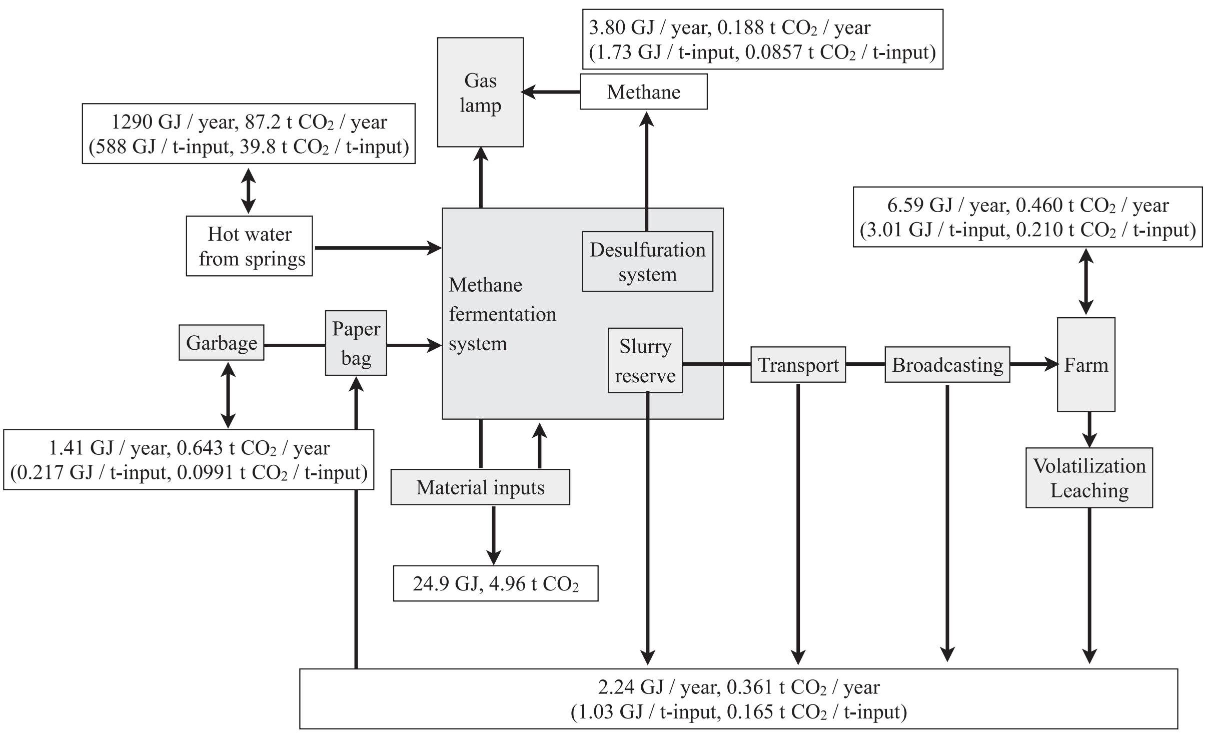

Fig. 2. Energy consumptions and GHG emissions and alternative effects.

8. Using the capacities of accommodations and the value of 300 g-garbage / person day, it was assumed that 254 t-garbage per year were treated by methane fermentation systems (Table 3). The number of our system needed 69 plants. The cost per one plant is much lower than the centralized system (Table 7) but, in the cost in the total area, the cost of our system was half of the centralized system. We assumed the centralized methane system has a cogenerating system from methane to electricity. The apparent values of electricity have already reduced the amount of electricity from methane. Thus, the value of methane utilization of the centralized system was zero. In addition, there are energy consumption and GHG emission in the slurry treatment. The balances in energy consumptions and GHG emissions are -347 GJ, -2.50 t CO_2 / year of our proposed system and 216 GJ, 41.1 t CO_2 / year of centralized system.

Discussion

In this study, we evaluated the environmental impacts and cost of our proposed methane fermentation system using hot spring in hilly and mountainous regions. And those data of them were compared with that of the conventional larger-scale methane fermentation system. We used LCA methods, which are suitable to evaluate an innovative technology, using the data from our system and the inventory data. We evaluated the environmental impacts of initial inputs (67.9 GJ, 4.96 t CO_2) and ones of operations (2.24 GJ / year, 0.361 t CO_2 / year) in this system. Using methane and slurry from methane fermentation system using hot spring without fuel for heating up, our proposed system has a potential of significant reduction of environmental impacts. Assuming the actual area on hilly and mountainous regions, not only the environmental impacts but costs were more reduced than the centralized methane. It has been considered that

Table 6. Environmental impacts of initial, operation and alternative effects.

	Energy consumption GJ / year	GHG emission t CO_2 / year
Initial	4.53 (67.9 GJ)	0.331 (4.96 t CO_2)
Operations (including slurry-using process)	2.24	0.361
Methane utilization	-3.80	-0.188
Slurry utilization (without using chemical fertilizer)	-6.59	-0.460
Using Garbage (without burning using electricity)	-1.41	-0.643
Using Hot springs (without using boiler)	-1290	-87.2

Environmental impacts of initial were divided by 15 years. Total impacts are noted in brackets.

Table 7. Costs of the proposed system and centralized system.

Costs	Proposed system 10^3 yen	Centralized System 10^3 yen
Initial	60 (750)	5600 (70000)
Maintenance	10	1500
Labor	0	7000
Electricity	0	1450
Others	30	8400
Total	100	23950
per t-input	50	80

Costs of initial were divided by 15 years. Total costs are noted in brackets.

Table 8. Evaluation of introduction of two methane fermentation systems to Naruko area.

	Proposed methane fermentation system	Centralized methane fermentation system
	10^3 yen, GJ, t CO_2 / year	10^3 yen, GJ, t CO_2 / year
Number of required systems	69	1
Costs	12,700	20,320
Energy consumption		
Initial	312	114
Collection	0	6.98
Running	0	7.25
Methane utilization	-262	0
Slurry treatment	-397	87.3
Balance	-347	216
GHG emission		
Initial	23.0	8.33
Collection	0	0.489
Running	0	1.02
Methane utilization	-13.0	0
Slurry treatment	-12.5	31.3
Balance	-2.50	41.1

Environmental impacts and Costs of initial were divided by 15 years.

to establish any bioenergy system is difficult in hilly and mountainous regions in Japan (Hong et al. 2009, Roy et al. 2009) but our proposed system could be an effective system in such areas.

We consider the reason why these positive effects of reduction in environmental impacts are four things: 1) using hot spring for heating methane fermenter, 2) on-site plants (the distance of garbage transport is zero), 3) using methane as fuel directly, 4) using slurry as fertilizer. Concerning environmental impacts and cost, most papers of methane fermentation system have reported the key of reduction in environmental impacts and cost is to build large-scale plants (Hong et al. 2009, Roy et al. 2009). However, based on our results, small-scale methane fermentation system should be an effective system for both environmental impacts and cost.

In our research, we evaluated the significant reduction of environmental impacts and cost in comparison with the centralized system but we validated the effects to introduce our system in only Naruko area. It is not directly suggested that the environmental impacts and cost are reduced using our system in the other resort areas. However, Naruko area is typically Japanese traditional resort area. The similar resort areas, which have hot spring located in hilly and mountainous regions, were abundant in Japan. In such areas, the effects on reductions may be similar to this estimation.

The centralized methane fermentation system assumed in this research is relatively small in large-scale plants. We considered it is difficult to build the much larger-scale plants in hilly and mountainous regions such as Naruko area but, if the garbage was collected from the larger area, the centralized system should be more effective on the reduction of both environmental impacts and cost. Furthermore, we must consider how size our proposed system is effective. We should accumulate the more data for sensitive analysis for this.

In conclusion, it has been considered that to introduce any bioenergy system is difficult in hilly and mountainous regions in Japan but our proposed methane fermentation system using hot spring could be an effective system in such regions. These results should facilitate to rethink about the establishment of small biomass use system and our proposed system should be one of key techniques in the reduction of environmental impacts using biomass in hilly and mountainous regions.

Acknowledgement

This work was financially supported by Funds for the Overall Promotion of Environmental Research from the Ministry of the Environment.

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Restoration of Coastal Ecosystems and Fisheries in Thailand after Northern Sumatra Earthquake and Tsunami Disasters

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Keywords: Participatory approach, fishing industry, coastal aquaculture, seagrass,coastal habitats, compensation

Received 22 March 2013; accepted 10 May 2013

Abstract

The 2004 Indian Ocean tsunami on 26 December severely affected six provinces (Ranong, Phang-nga, Phuket, Krabi, Trang and Satun) on the Andaman sea coast of Thailand. This paper presents the impact of the tsunami in the fishery and aquaculture sectors including the post rehabilitation. The immediate result of the tsunami was nearly the destruction of the local economy. The economic disaster was such that it led to a 0.8% reduction in the Thai national gross domestic product (GDP) growth rate for the year 2005. It was estimated that the total impact of the tsunami in the fishery and aquaculture sectors of the affected provinces is 6,481 million Baht, 40% of which (2,560 million) is the damage to assets and the remaining 60% (3,882 million) is the losses in production for the rest of the year. The livelihoods of many coastal fishery communities in Thailand were completely or partially destroyed by the tsunami. Economy at the community level was severely affected, which led to even deeper poverty. Preliminary assessment (after the tsunami attacked) reveals that the fishery resources decline by half. The price of marine animal also dropped within 3 months after the tsunami. There were more than 5,000 large and small boats damaged and sunk by the tsunami. In aquaculture, there are about 27,000 fish cage culture operators damaged by the tsunami impact, covering a total cage area of some 112 ha. The approved compensation rates are 20,000 and 14,000 baht for registered and nonregistered cage farms, respectively.

It was found that the assistance by compensation package in the monitory term was far from desirable. The way in which compensation was given caused serious problems, which led to serious conflicts within communities and among communities in tsunami-affected areas. Three main critical issues have to be solved, i.e. illegal fishing, democratization management, and constraint and need in continuing rehabilitation. In addition, lessons learned in the fishery rehabilitation phase for Thailand reveal several future sustainable works, such as creating supplementary income, training programs, marketing system development, financial support, strategic approach need, self-help focus, conflict management, and participatory approach.

1. Introduction

Southern Thailand, also known as Peninsular Thailand, lies between latitudes 50 and 110 N, and longitudes 980 and 1020 E. It covers an area of 7,153,917 ha and has over 2,705 km of shoreline, with the western coastline facing the Andaman sea and the eastern coastline facing the Gulf of Thailand (see Fig. 1). Due to rapid economic growth of tourism and fishing industry, the mangrove and beach forest along the coastal shores have been replaced by human-built infrastructures, such as aquaculture industries and tourist resorts (UNEP, 2006). As a consequence of no green belt, the coastal areas of southern Thailand have become particularly vulnerable to natural disasters, such as coastal erosion, tsunamis, storm surges, etc.

The earthquake that caused the tsunami was the world's fifth largest, with a magnitude of 9.3 on the Richter scale. It occurred at 00:58:53 (GMT) on Sunday, 26 December, 2004, with the epicenter at a depth of 30 km, just off the west coast of North Sumatera, Indonesia. The sudden vertical rise of the seabed by several meters during the quake displaced massive

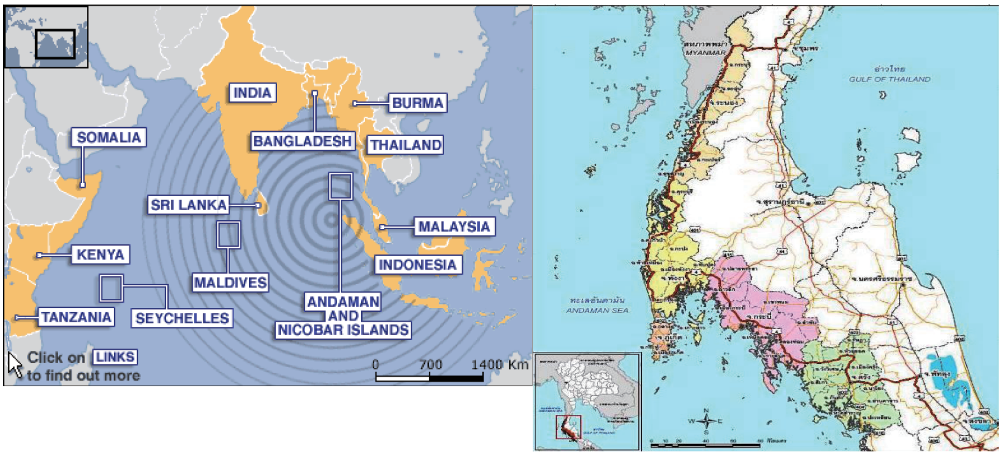

Fig. 1. Affected countries and provinces in Thailand

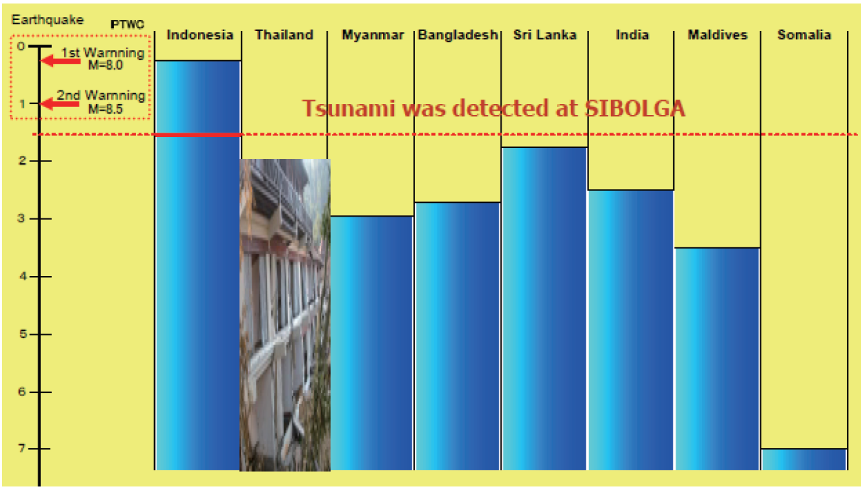

Fig. 2. The 2004 Indian Ocean tsunami time line

volumes of water, resulting in a devastating tsunami. This seismic sea wave traveled thousands of kilometres across the Indian Ocean, and ravaged the Andaman coast of southern Thailand at 10.00 am local time. The tsunami time line is shown in Fig. 2.

Thailand has been suffered from the 2004 Indian Ocean Tsunami in 6 provinces along the Andaman coastline. Immediately after the event, the Thai-Japanese tsunami expert group made a detailed survey on tsunami behavior. Due to the offshore bathymetry, the tsunami height varied by nearly a factor of 3-4 times with the maximum height of 19.6 m at Ban Tung Dap in Prathong island, 15 m at the popular Khao Lak resort area, and 5-6 m at the Patong beach in Phuket. The tsunami heights are shown in Fig. 3a). Unfortunately, since the tsunami arrived at high tide, it rode on top of the elevated tidal level (see Fig. 3b)) , causing more severity.

In Damaged areas, the number of deaths, missing and property damage is summarized by the DDPM (2005) and TEC (2005) in Table 1 and 2. As expected, many resorts in Kho Lak area with its low-lying coastal plane experienced serious destruction while several buildings with sliding glass doors or windows facing the sea suffered little structural damage. This is because the tsunami force broke through all the openings. In addition, most of the engineering-design reinforcement of concrete buildings with the good foundation could survive the wave attack. Due to the maximum attack wave height, Phang Nga had the largest number of fatalities or missing (more than 65 %) and also property damage (about 50 %).

2. Impact on fisheries, aquacultures and coastal habitats

The total estimated impact of the tsunami in the fishery and aquaculture sectors of the affected provinces is 6,481 million Baht, 40% of which (2,560 mil-

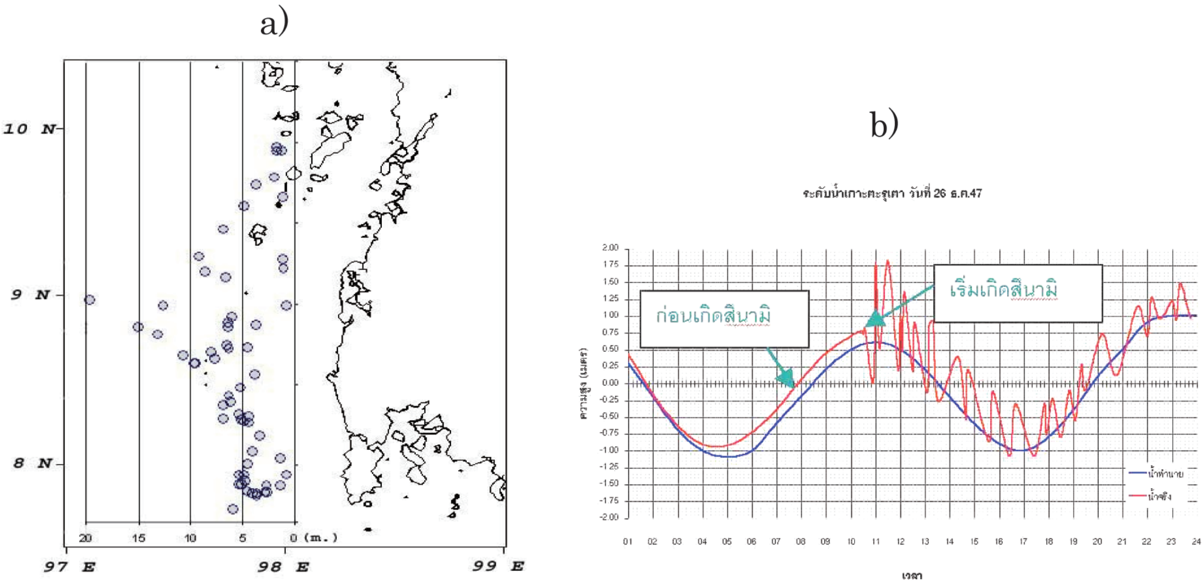

Fig. 3. Surveyed tsunami heights and tidal record

Table 1. Damage in case areas and people affected from Indian Ocean tsunami

No.	Province	Devastated Area			House Damage		Number of affected	
		District	Tambon	Village	Partly	Totally	Person	Household
1	Phang Nga	6	19	69	1641	626	19,509	4,394
2	Krabi	5	22	112	1343	357	15,812	2,759
3	Phuket	3	14	58	601	393	13,065	2,616
4	Ranong	3	10	47	111	255	5,942	1,509
5	Trang	4	13	51	156	33	1,302	1,123
6	Satun	4	17	70	69	102	2,920	414
Total		25	95	407	3921	1766	58,550	12,815

Table 2. Number of death, injured, missing and property damage

No.	Province	Number of affected people			Property Damage, US Dollar			
		Death	Injured	Missing	Fishery	Livestock	Agricult.	Business Establish
1	Phang Nga	4,225	5,597	1,655	22,830,462	341,515	61,466	161,402,125
2	Krabi	721	1,376	544	4,792,413	8,131	8,572	67,091,295
3	Phuket	279	1,111	608	8,622,779	7,591	4,603	98,852,073
4	Ranong	159	246	9	4,268,450	76,228	15,902	20,750
5	Trang	5	112	1	374,500	1,085	45,967	165,000
6	Satun	6	15	-	2,984,843	6,090	29,125	-
Total		5,395	8,457	2,817	43,873,447	440,640	165,635	327,531,243

lion) is the damage to assets and the remaining 60% (3,882 million) is the losses in production for the rest of the year. Detailed impacts are given as follows.

2.1 Impact on fisheries

The most seriously affected economic sectors were tourism and coastal fisheries. (Tanyaros and Crokall, 2011). The immediate economic impact of the tsunami was felt most acutely in the tourist industry, and to a lesser extent in the fishery sector. Prior to the 2004 tsunami, the tourism and fishing industries provided most of the livelihoods in the affected areas along the Thai Andaman coast. The immediate result of the tsunami was nearly the destruction of the local economy. The economic disaster was such that it led to a 0.8% reduction in the Thai national gross domestic product (GDP) growth rate for the year 2005, compared to the rate that would have existed without the tsunami (Israngkura, 2005).

The tsunami caused major losses in the fishing industry and coastal aquacultures in terms of fishing boats and gear, culture ponds, cages and shrimp hatcheries. Seventy-four affected sub-districts and 386 villages reported losses for fisheries and aquacultures (DoF, 2005). The estimated damage, as reported by the Fisheries Rescue Coordination Centre is summarized in Table 3 (FAO-MOAC, 2005).

Fishing and aquaculture, although popular at present, were marginal activities some 30 years ago. Fishing developed steadily and tourism grew exponentially in the years leading up to the tsunami. In the fishery sector, artisanal fishers as a group earn the lowest income (Silvestre et al. 2003). The livelihoods of many coastal fishery communities in Thailand were completely or partially destroyed by the tsunami. Economy at the community level was severely affected, which caused 19,968 already poor fishers to fall into even deeper poverty (Paton et al., 2008). The small-scale and artisanal fishers are very vulnerable to coastal disasters such as the 2004 Indian Ocean tsunami.

2.1.1 Damage or loss of fishing boats

There are 5,431 fishing boats either damaged or totally wrecked, 93% of which were small-scale and artisanal fishing crafts and 7% commercial fishing ships. It was estimated that 2,923 fishery households were affected. Damage to fisheries alone amounted to 16.6 M USD (DoF, 2005). Table 4 shows the number of damaged fishing boats in each provinces. It was found that Phuket suffered the greatest losses for large boats, while small boats losses were largest in

Table 3. Damage (in units) caused by 2004 Indian Ocean tsunami

Damaged type	Numbers
1 Small fishing boats	3,174
2 Large fishing boats	1,199
3 Ecotourism boats	554
4 Public habours & pies	83
5 Fish & Shellfish cage farms	47,063
6 Shrimp farms	6,063
7 Hatcheries	573
8 Shellfish concession plots	17

Table 4. Number of damaged and sunk fishing boats

Provinces	Large boat		Small boats		Losses (USD)
	Damaged	Sunk	Damaged	Sunk	
Ranong	204	13	414	27	12,331
Phang-nga	322	124	754	46	915,546
Phuket	490	157	642	41	1,884,618
Krabi	147	1	808	54	19,269
Trang	1	-	648	-	-
Satul	35	6	552	49	20,520
Total	1,199	301	3,714	217	2,852,284

Krabi. The small fishing boats are most vulnerable.

2.1.2 Damage or loss of fishing gear

In practice, it is extremely difficult to make assessment on the loss of fishing gear. After the tsunami, vessels and fishing gear were assumed to have been lost together. Gear replacement is a lower-cost item, but its compensation can help them to return to their normal lives. It is assumed that they are able to repair damaged vessels themselves. In such circumstances, gear provision is likely to be significantly less costly than expenses for boat repair.

2.1.3 Impact on fishery resources

From 1976 to 2003, the DoF monitored the implementation of measures to conserve marine resources during seasons of fish spawning and nursing young fish along the Andaman

coast. This was to identify study areas and periods in order to implement conservation measures for spawning and breeding of mature economic shallow-water fishes and marine shrimps. Surveys were conducted and reported an abundance of marine fishes and shrimps in several study sites along the Andaman coast (DoF, 2005). Preliminary assessment, in early January 2005, of fishery resources along the Andaman Coast indicated declination by half in some areas after the tsunami (Bueno, 2005). It was also found that the price of marine animals dropped within three months after the tsunami, and then gradually climbed back to the normal level.

The DoF also reported that the density of marine resources decreased during the: month following the tsunami. However, if only economic fish species were counted, the density around Phang-nga Bay and adjacent areas decreased compared with a similar pre-tsunami period. In the two provinces of Trang and Satun, which were less severely hit by the tsunami, the catch increased (ONEP, 2006). The marine fish catch off the west coast of Phang-nga and Phuket Provinces decreased after the tsunami attack (pre-tsunami 72.69 kg/hr; post-tsunami 34.92 kg/hr). The juvenile fish catch increased after the tsunami attack; similar results were found in a fish larvae survey (Nootmorn, 2006). One of the main reasons for these differences is the change in the physical effect of water movement. The tsunami waves caused a huge undercurrent with massive movement of water, disturbing sediments at the sea bottom and stirring a water mass rich in nutrients at the pycnocline level in the deep sea, bringing them up towards the continental shelf. In this way, the tsunami moved great amounts of nutrients from the Sundra trench and water mass from the deep sea up to fishery areas along the Andaman coast. The food chain was thus impacted, with links from water movement through plankton and young marine animals to increased juvenile fish catch. Whanpetch et al. (2010) have shown that the patterns of temporal change in abundance and diversity of macrofaunal assemblages before and after the tsunami varied greatly from site to site, and that the degree of temporal changes in assemblage structure was not solely related to the magnitude of the tsunami. More importantly, the presence or absence of seagrass vegetation altered the patterns of temporal change in macrofaunal assemblages and recovery processes after a tsunami.

2.2 Impact on aquacultures

The Andaman coast of Thailand has significant amounts of coastal aquaculture based in and around mangrove areas, especially in the creeks and delta mouths. Several types of aquaculture were affected by the tsunami, e.g. fish cages, shrimp ponds, hatcheries and shellfish.

2.2.1 Cage culture

In the pre-tsunami period, the system of cage culture was like open access. Whoever came to set cage first could reserve that place. They normally set up their cages near their houses. After the Tsunami, some fishers could start to set up cage culture with their own money earlier than other fishers who did not have enough money. However, according to the consensus among people, they set up their cages at the same place as it was before to avoid conflict with others.

Cage culture was one of the primary occupations for those living in the coastal communities devastated by the December 2004 tsunami. The typically fragile construction of cages made them particularly vulnerable to the tsunami, which resulted in the breakup of cages and escape of the stocks (see Fig.6). Some 5,568 cage culture farms, covering a total cage area of some 112 ha, were reportedly affected by the tsunami, with a total of 15,802 cages damaged (Table 5). The government (DOF, 2005) estimated losses from aquaculture cages to be 20 M USD.

Fig. 6. Damaged cage culture farms (Tanyaros and Crokall, 2011)

Table 5. Damage to aquaculture (DOF, 2005)

Province	Fish cage farms	Shrimp pond (ha)	Hatchery farms	Shellfish (ha)
Ranong	677	1. 61	-	3.41
Phangnga	3,008	16.88	180	64
Phuket	315	5.84	209	58.02
Krabi	389	18.24	-	4.86
Trang	243	-	144	0.84
Satun	966	-	40	-
Total	5,568	42.57	573	131.13

2.2.2 Shrimp farm

Though many shrimp farms exist on the Andaman coast, little damage to shrimp farm operations has been reported. This is due to the smaller number of farms located near the coast, as compared with the Gulf of Thailand coast. The DoF (2005) reported that only 42.56 ha of shrimp ponds in four provinces were totally damaged by the tsunami. The most damaged farms were located in the immediate vicinity of the shore in low-lying area.

2.2.3 Fish and shrimp hatcheries

Only one private fish hatchery was reported to have been damaged, while the government stations were reported not to have incurred any significant damage. However, destruction of shrimp hatcheries considerably reduced production. The six affected provinces are the main areas in Thailand for marine shrimp fry production. The 573 shrimp hatcheries damaged accounted for a 30% loss in seed production, which translates into 70,000 metric tons of cultured shrimp for only one crop (Bueno, 2005). It was estimated that it would take at least six months to get most of the hatcheries back into operation. The industry speculated that this would be an additional lost opportunity of more than 28 M USD and would inevitably lead to shrimp seed scarcity and its higher price.

2.2.4 Shellfish concessions

Shellfish consist principally of cockle beds, green mussels, oyster and land-based abalone operations, all of which suffered some damages.

2.3 Impact on coastal habitats

The coastal habitat and environment were impacted in various ways. In some coastal areas,coral reefs and seagrass beds were damaged or destroyed, greatly degrading fisheries resources and thus fishers' livelihoods. Both coral reefs and seagrass have been able to recover to a certain extent. From a rapid assessment (3 weeks after the event), only about 13% of the coral reefs in the Andaman sea were found to be severely damaged (>50% of corals destroyed), while almost 40% showed no measurable impact by the tsunami (DMCR, 2005; Brown, 2005; Wilkinson et al. 2006). A study on coral recruitment and recovery after the 2004 tsunami by Sawall et al. (2009) near the Phi Phi Islands (Krabi Province) and Phuket found rapid recovery to be the norm, suggesting that the duration of disturbance, degree of sorting and hence stability of coral rubble are key determinants of recruitment success. The tsunami-impacted coral reefs have now revived to a certain degree as a result of rehabilitation activities instituted by government agencies, private groups, communities and NGOs.

Seagrass shows a similar picture. Only some 5% of seagrass beds and 321.6 ha of mangrove forests were damaged or destroyed (ONEP, 2006). A comparative analysis (Nakaoka et al., 2007) of seagrass biomass and coverage before and after the tsunami revealed that seagrass beds were severely affected by the tsunami. A broad-scale coastal census after the tsunami showed that the effects on seagrass beds were spatially variable; some seagrass beds disappeared completely, whereas others were only negligibly impacted. The ecology of seagrass beds in all areas hit by the tsunami was able to survive and regain to a previous level within a year without replanting (DMCR, 2005).

3. Post rehabilitation

After the tsunami, several Thai government agencies, the private sector, NGOs and international organizations set up a wide range of projects for emergency assistance and long-term rehabilitation, in both fisheries and aquaculture sectors, with the aim of enhancing the quality of life for all victims. It appears that local people were satisfied with the level of resilience of natural resources, such as mangrove forests, beach forests, seagrass beds and coral reefs. Local perception, gathered from personal interaction, is that the rehabilitation of coral reefs was successful to a certain extent. People thus requested continued efforts to restore the natural resources back to the original state of abundance (ONEP, 2006).

3.1 Fisheries sector

A first step in the assistance plan was swiftly implemented by the DoF; its primary goal was to establish a Fisheries Rescue Centre (FRC). The centre coordinated and collected of damage and loss information from the six affected provinces. Damage was caused down to the affected villages, and it was possible to identify significant losses at sub-district and even village levels. This data set can therefore be used as an indicator to assist in identifying the most affected areas.

The second stage of the DoF emergency plan was to compensate the victims in cash for their losses or damaged boats, fishing gear and aquafarms. This compensation aims to assist victims to start up their fishing and aquafarming activities as soon s possible and to restore their livelihoods. The full Cabinet of the Thai Government approved a tsunami response budget of 5,252 M THB. Out of this budget, 1,343 M THB was allocated to assist 27,828 fishermen. This included the repair of 3,426 small fishing boats (under 10 metres in length) and 544 larger fishing boats (DoF, 2005). Boat owners (registered) were required to inform the loss within 15 days in the area. The Provincial Fisheries Office (or District Fisheries Office) had to collect the documents and check for accuracy before sending to the DOF within 120 days. Typical documentary evidence required for compensation was the vessel registration or permission to fish document (with date). Since the majority of vessels that were damaged or lost were in the small-scale category, very few actually had registration documents.

3.1.1 Compensation for fishing vessels

Table 6 shows damaged categories and compensation package for fishing vessels. These aim to support the recovery of a vessel (i.e., re-floatation, or movement of the vessel, as many had been swept some distance inland), support repairs of a damaged vessel, and compensate for loss or damage beyond repair.

Table 6. Compensation (THB) package for fishing vessels (DoF, 2005)

Type	Compensation per vessel	
	< 10 m	> 10 m
Retrieval	10,000	25,000
Repair	20,000	70,000
Vessel lost	66,000	200,000

3.1.2 Compensation for fishing gear loss

Vessels and fishing gear are assumed to have been lost together. Small-scale artisanal gear may be reconstructed (such as fish and crab traps). Larger gear such as nets, require purchase. Loss of fishing gear was compensated at a relatively low rate (about 3,000 THB per case). Table 7 shows the government compensation for the loss of fishing gear.

3.2 Aquaculture sector

Loss or damage of aquaculture facilities was compensated by the Royal Thai Government to assist the farmers to re-start their farming activities. Two broad targets for compensation were aquaculture holdings and fish cage culture operations.

3.2.1 Compensation for aquaculture holdings

Information regarding loss from aquaculture holdings does not appear to have been announced, however the document made available to the mission containing the dates of compensation also included rates for aquaculture. Compensation was payable in the case of:

1) Loss of fish stocks, 1,400 baht per rai (for a total area not exceeding 5 rai).

2) Loss of shrimps and crabs, 3,800 baht per rai (for a total area not exceeding 5 rai).

3.2.2 Compensation for fish cage culture operations

Compensation was payable in the cases of fish culture in a cage, cement tanks or other

(e.g. aquarium fish, frogs, soft-shelled turtle). The rate was 150 baht per square metre of production up to an area not exceeding 80 square metres. The Thai government provided funding of over 111.6 M THB through the DoF to restore the cage farms on the coast of the Andaman sea after the tsunami (DoF 2005). Several types of assistance were provided from private sectors (NGOs and philanthropic foundations) for the cage farmers, including provision of cash funds, materials for cage re-construction and fish seed. The loss of aquaculture operation systems was supported through emergency assistance from the government as illustrated in Table 8.

It was found that 69.7% of the main financial sources supporting the farmers in the affected areas came from government organizations. Non-governmental organizations, at the Thai national and international levels, also played an important role in assisting the affected farmers. About 31.3% of the farmers received assistance, and each of those obtained 30,000 baht from these organizations (Anantasuk et al., 2008). The DoF was the main body supporting aid to the farmers; more than half of the farmers received

Table 7. Budget for emergency assistance for the fishery sector (DoF, 2005)

Type	Unit	Total USD budget	Max. USD compensation /victim		
			Retrieval	Repair	Replacement
Small fishing boat	3,426 boats	6,676,308	256	512	1,692
Large fishing boats	1,222 boats	7,050,000	641	1,795	5,128
Bamboo trap (legal)	421 fisherman	107,949	-	-	256
Other traps	13,690 fisherman	3,510,256	-	-	256
Nets	1,871 fisherman	479,734	-	-	256
Total		17,824,247			

Table 8. Budget for emergency assistance for the aquaculture sector (DoF, 2005)

Type	No. of farmer	Total USD budget	Max. repair & seed for restocking / farmer
Cage	27,828	14,270,769	513 (cage & seed)
Shrimp pond	42	21,538	513 (pond & post larval)
Hatchery	573	293,846	513
Shellfish farm	80	40,770	-
Total	28,523	14,626,923	

Table 9. Source of materials support (Anantasuk et al., 2008)

Target	Source percentages	
	DoF	NGOs
Material for cage construction	55.6	47.6
Seed	11.1	18.3
Fishing gear	31.1	13.4
Fishing boats	2.2	20.7
Total	100%	100%
Proportion from each source	57.1%	42.9%

materials for cage re-construction, seeds, fishing gear, and boats. Table 9 gives the percentage of farmers who obtained materials from the DoF and various NGOs.

4. Conclusions and future recommendations

The Andaman Sea coast has seen a substantial decline in fisheries resources. The tsunami event of December 2004, the fuel crisis, the violation of regulations and illegal fishing all have impacted fisheries negatively. This situation will not only cause an increasing problem for the fishers but it will also lead to serious degradation of all marine resources, thus threatening the sustainable management and health of the Andaman sea as a whole.

It was estimated that the total impact of the tsunami in the fishery and aquaculture sector of the affected provinces is 6,481 million Baht, 40% of which (2,560 million) is damage to assets

and the remaining 60% (3,882 million) is the losses in production for the rest of the year.

The livelihoods of many coastal fishery communities in Thailand were completely or partially destroyed by the tsunami. Economies at the community level were severely affected, which led to even deeper poverty. However, there are difficulties involved in the estimation of replacement values of boats and fishing gear since no comprehensive registries are available. The number of boats and gear used in the estimation of damage only represents the number of units that the fishermen reported in order to obtain compensation from their authorities. Since compensation rates are low, some fishermen did not bother to report their loss of assets, and some large boats went also unreported because they have private insurance arrangements. For the estimation in the aquaculture sector, the same difficulty arises again in that the owners only reported their damage bearing in mind possible compensation from the authorities, and not all aquaculture facilities are duly registered with full information as to size and capacity.

So far we have mentioned only the assistance by compensation package in the monitory terms. However, on the ground, the results of money compensation were far from desirable – due to both internal and external factors. Internal factors include greed and family structure; external include distribution methods. Several constraints have to be solved and we should make suggestions as to how they may be alleviated, for the benefit of all and in such a manner as to avoid hardship on those who must give way to better, even best, practices. The way in which compensation was given and monitored directly or indirectly caused serious problems, which in turn led to serious conflicts within communities and among communities in tsunami-affected areas. Three main critical issues have to be solved, i.e. illegal fishing, democratization management, and constraint and need in continuing rehabilitation. In addition, lessons learned in the fishery rehabilitation phase for Thailand reveal several future sustainable works, such as creating supplementary income, training programs, marketing system development, financial support, strategic approach need, self-help focus, conflict management, and participatory approach.

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The 10th International Symposium on Integrated Field Science

Restoration of Coastal Ecosystems and Fisheries in Tohoku District: Lessons from Northern Sumatra Earthquake and Tsunami Disasters

March 23-24, 2013
Graduate School of Agricultural Science (Amamiya Campus), Tohoku University, Sendai, Japan

Objective

The Great East Japan Earthquake on 11 March 2011 resulted in a major tsunami that brought destruction along the Pacific coastline of Tohoku district (Japan's northern islands). The coastal ecosystems also suffered more than a little damage and the fisheries were destroyed. To restore the coastal ecosystems and fisheries in Tohoku district, Tohoku Ecosystem-Associated Marine Science Project (TEAMS) was established in 2012. Many marine biologists and oceanographers in Japan gathered together under this program and have monitored the ecosystem after the tsunami for restoration of fisheries. However, to construct feasible plans for the restoration, we have to learn from the experience with a similar recent past case, i.e. Northern Sumatra Earthquake and Tsunami Disasters. This symposium has two primary objectives: 1) To compare the damage situation between two disasters; 2) To build relationships, share knowledge and encourage long term thinking including restoration process about coastal ecosystems and fisheries damaged by tsunami disasters.

Program

Day 1

Saturday, March 23 (Venue: The 1st lecture room in Amamiya Campus)

Session

12:00	Registration
	Chair: Minoru Ikeda (Tohoku University, Japan)
13:00-13:05	Masanori Saito (Tohoku University, Japan) *Opening Address*
13:05-13:15	Akihiro Kijima (Tohoku University, Japan) *Outline of Symposium and Introduction of Invited Speakers*
13:15-13:45	Motoyuki Hara (Tohoku University, Japan) *Introduction of Tohoku Ecosystem-Associated Marine Science Project*
13:45-14:15	Masakazu Aoki (Tohoku University, Japan) *Dynamics of the Rocky Subtidal Ecosystem after the Tohoku Pacific Earthquake*
14:15-14:45	Subandono Diposaptono (Ministry of Marine Affairs and Fisheries, Indonesia) *Tsunami Disaster Mitigation in Fisheries Sector, Indonesian Experience*
14:45-15:00	Coffee Break
15:00-15:30	Anil Premaratne (Ministry of Defense and Urban Development, Sri Lanka) *Restoration Rehabilitation and of Coastal Resources and Ecosystems after 2004 Tsunami Disaster in Sri Lanka*
15:30-16:00	Zulfigar Yasin (University of Science, Malaysia) *The Short and Intermediate Term Impacts of the Indian Ocean Tsunami 2004 on the Malaysian Fisheries and Some Associated Marine Habitats in the Straits of Malacca*
16:00-16:30	Seree Supratid (Rangsit University, Thailand) *Restoration of Coastal Ecosystems and Fisheries in Thailand after Northern Sumatra Earthquake and Tsunami Disasters*
16:30-16:40	Coffee Break
16:40-17:10	Panel Discussion/Open Discussion
18:00-20:00	Banquet (Kita-no-Kazoku)

Day 2
Sunday, March 24
Excursion to afflicted areas

8:45	Gathering in Graduate School of Agricultural Science, Tohoku University (Amamiya Campus)
9:00	Starting on chartered bus to Onagawa Town (by way of Higashi-matsushima City and Ishinomaki City)
11:00	Arrive Onagawa Field Center
11:00-15:00	Inspection afflicted areas (including lunch and attending Onagawa Renaissance Festival)
17:00	Arrive Amamiya Campus

Organizing committee

Akihiro Kijima	Project Leader of Tohoku Ecosystem-Associated Marine Science, Professor, Tohoku University, Japan
Motoyuki Hara	General Manager of Tohoku Ecosystem-Associated Marine Science, Project Professor, Tohoku University, Japan
Minoru Ikeda	Associate Professor, Tohoku University, Japan

Introduction of Tohoku Ecosystem-Associated Marine Science (TEAMS) Project

Motoyuki Hara

Mareine Sceience Restration Support Section,
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The mega earthquake, which occurred on March 11th in 2011, caused high-intensity ground shaking and a massive tsunami, resulting in a disaster of a scale unprecedented in the history of Japan. Therefore, it is totally unknown how seriously the marine ecosystems and environment have been affected by the pile-up of a large amount of debris, loss of seaweed beds and tidelands, which serve as habitats for aquatic organisms, sand and mud deposited on reefs, destruction of transitional zones between land and sea due to ground subsidence, and spread of heavy oil and radioactive substances. To achieve recovery and reconstruction of the fishing ground and industry of the affected area, it is essential to conduct surveys to identify the damage and launch new industries. The TEAMS project is mainly constructed with Tohoku University as its representative, the University of Tokyo's Atmosphere and Ocean Research Institute and the Japan Agency for Marine-Earth Science and Technology as deputy representatives. Under the collaboration of these research institutes, the four research projects were planned to survey the impacts of the disaster on the marine environment and ecosystem, and Tohoku Univ. has conducted the project "Elucidation of the process of change in the fishery environment". I would like to introduce the outline and current results of the TEAMS project.

Motoyuki Hara (e-mail: mhara@m.tohoku.ac. jp)
Project Professor. My research fields are conservation genetics and breeding science genetics of Pacific saury, Japanese flounder and Pacific abalone using genetic markers. The study of population structure and close species relations of Pacific abalone was effective in genetic management of the wild resources carried out in reproduction. Also, as basically genetic data, linkage maps for Pacific abalone with microsatellite DNA markers were constructed in order to perform efficient breeding. Now, I have worked as a coordinator of Tohoku Marine Science Project.

Dynamics of the Rocky Subtidal Ecosystem after the Tohoku Pacific Earthquake

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The rocky subtidal benthos communities at three localities have been monitored regularly since three months after the earthquake as a contribution to evaluateing the dynamic effects of the Tohoku Pacific Earthquake on the coastal ecosystems of Miyagi Prefecture. In Shizugawa Bay, new recruits of the sea urchin *Strongylocentrotus nudus* appeared from September 2012. Tsunami had a seriously damaging effect on *Eisenia bicyclis* kelp beds, particulary, at innermost of the bay. The juvenile kelps grew at closer areas from shore in comparison to those prior to the earthquake, where they matured into adult plants. However, those settled in the deeper zones grew slowly and weakly, and died off at the deepest site. Similar trends have also been observed in the *E. bicyclis* population on the west coast of the Oshika Peninsula. The unusually high water temperature in the summer of 2012 evoked additional negative effects at these sites. The poor growth of *E. bicyclis* at deeper sites may be caused by the lack of light, with lower transparency probably due to subsidence (approx. 1 m) along the coast following the earthquake, and the disturbance and deposition of large quantities of mud in the off-shore zone as a result of the tsunami. In Onagawa Bay, analysis of the relationships between environmental factors and the distribution of algae and benthic animals shows that mud deposition at more sheltered sites has had a negative effect on the distribution of algae, abalones and sea urchins. Overviewing the results, the deposition of mud after the earthquake seems to have had profound effects on the rocky shore communities along the coast of Miyagi Prefecture.

Masakazu Aoki (e-mail: m-aoki@m.tohoku.ac.jp)
Associate Professor. The main focus of my interest has been the ecological aspects of coastal marine benthos, in particular the interactions between marine algae and herbivores. My interests have also included taxonomic and systematic studies of caprellid and gammarid amphipods; and, concerning plants, the seasonal dynamics of *Sargassum* species as habitats for epiphytic meso-grazers. I am currently engaged in studies on the population responses of kelp species such as *Eisenia bicyclis* and *Ecklonia cava* to herbivorous animals.

Tsunami Disaster Mitigation in Fisheries Sector Indonesian Experience

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Indonesia has long been affected by Tsunami. There are records of more than 100 such events over the last 400 years. These records indicate that between 1600 and September 2012 there have been 110 tsunamis. From 1960 - 2012 there have been 23 significant tsunamis. This indicates that the frequency of tsunamis is around one in every two years .

Some of Indonesian coastal areas of highest potential risk by tsunami include: the West coast of Sumatra, South coast of Java, South coast of Bali, North and South coast of Nusa Tenggara, islands of Maluku, North coast of Papua, and most of Sulawesi (Celebes) coast.

To reduce the impact of coastal disasters in Indonesia, nationally we always improve our capabilities to mitigate these events. The Ministry of Marine Affairs and Fisheries (MoMAF), Republic of Indonesia is also pro active in minimizing the impact of coastal disaster on coastal communities and on aquaculture activities. The program emphasized the implementation of Integrated Coastal Zone Management (ICZM). In ICZM we will try to make a balance between the natural ecosystem, human utilization, and disaster mitigation aspects.

The Indonesian coastal ecosystem has suffered severe degradation which leads to increase the vurnerability of the coastal area. In this regards, ecosystem rehabilitation is very important in order to reduce the vurnerability. The objective of the ecosystem rehabilitation is to increase the coastal environment capacity to provide its services for livelihood and protection from coastal hazards.

Restoration and Rehabilitation of the Coastal resources and Coastal Ecosystems after 2004 Tsunami Disaster in Sri Lanka

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The Sri Lanka's Coastal areas have 67 Assistant Government Agents areas and these areas contain;

- 24 percent of the land area and 32 percent of the population;
- About 65 percent of the urbanized land area;
- Approximately 80 percent of the Sri Lanka's hotel rooms;
- 80 percent of the annual fish production;
- About 67 percent of the nation's industrial facilities;
- Habitats critical to the sustained production of fisheries, the maintenance of good water quality, and scenic values important to both residents and tourists; and
- Rich biodiversity reserves including coral reefs, sea grass beds and mangroves

Most of these resources have been destroyed by the Tsunami in 2004 and killed 35,322 people, displaced 100,000 persons and affected over two thirds of the island's coastline and outlying 13 districts. Besides the tremendous loss of life and injuries, the tsunami caused extensive damage to property and disruptions of fisheries and other livelihood activities and business assets. Social networks also were severely disrupted. In many cases lives became complicated due to the loss of legal documents. The socio-economic impacts were of greater consequence as the tsunami compounded previously existing vulnerabilities. Assets were destroyed and water and electricity supplies were severely affected. Remote coastal areas were not accessible for several days. The risk of a sizable death toll from possible deterioration of sanitary conditions, lack of clean drinking water and shelter, and delayed access to medical aid was strong, but did not occur.

In this background, it was an enormous challenge for Sri Lanka's authorities to address the multifaceted problem of providing immediate relief and facilitating recovery and reconstruction. The demonstration of human solidarity and kindness in the immediate aftermath in this endeavor in Sri Lanka was exemplary.

This paper will discuss and critically evaluate the experiences received by the Sri Lankan authorities through the implementation of the recovery and reconstructions process of the coastal resources and ecosystems under the following categories;

- Emergency response and relief
- Funding for recovery and reconstruction process
- Getting people back to their homes

- Restoring livelihoods (specially fisheries)
- Health education and social protection
- Upgrading national infrastructure
- Cross cutting issues
- Guiding principles
- Micro economy
- Environmental and habitat rehabilitation and restoration
- Institutional arrangements

Experiences gained through the implementation of the activities under each of the above sub hedging will be explained inthe paper and lesson learning from the Sri Lanka may be replicated in other countries as well.

Anil Premaratne (e-mail: premaratnaanil@yahoo.com)
Director General Coast Conservation and Coastal Resources Management. My main field area is Coastal Resources Management. I am also engaging in Integrate coastal area planning and management. I am currently engaged in spatial coastal and marine area management as well.

The Short and Intermediate Term Impacts of the Indian Ocean Tsunami 2004 on the Malaysian Fisheries and Some Associated Marine Habitats in the Straits of Malacca

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Human communities living along the coasts were greatly affected by the tsunami of 26 December 2004. Apart from the lost of life and property the detrimental effects of the tsunami came about from the direct losses as a result of damage to natural coastal ecosystems. These were the source of their livelihood. We have categorized the damage caused by the tsunami into immediate damage (damage seen after from hour to a period of weeks following the tsunami), short term (one to two months following the tsunami) and intermediate term damage (from two months to more than a year). Damage in the long term will be duly assessed. The degree of damage to the coastal ecosystems is non-uniform and is a function of the severity of the wave and the status of the ecosystem before the wave hit. Impacts can also be direct (as a result of the wave energy and/or sea water inundation on non salt-tolerant species and/or introduction of foreign material into the coastal habitat). Indirect impacts resulted from changes intermediated through biological channels such as changes in the food chain, living environment and maybe even changes in the living community components. The offshore reefs and islands showed damages unlike that of large storm damage. Erosion was recorded on the reef tops, especially the reef edge. Sediment resuspension and physical damages had caused severe damages to fragile coral skeletons. The shallow and intertidal reefs were most affected, followed by evidence of secondary effects of tsunami. As for the mudflats and coastal sandy beaches, changes in beach profile as well as the animal communities had been recorded. Benthic epifauna was most affected and there was a strong evidence of community changes.

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Professor. My research interest is on the ecological aspects of marine macrobenthos, in particular the coral reefs. My interest also includes ecological, taxonomy and conservation studies on corals, molluscs and sea cucumbers. I am also focusing on the effect of climate change on the coral reef ecosystem, with special interest on ocean acidification and coral bleaching. I am currently engaged in studies on coral bleaching and ocean acidification in the coral reefs of Coral Triangle, as well as the Straits of Malacca.

Restoration of Coastal Ecosystems and Fisheries in Thailand after Northern Sumatra Earthquake and Tsunami Disasters

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The 2004 Indian Ocean tsunami of 26 December severely affected six provinces (Ranong, Phang-nga, Phuket, Krabi, Trang and Satun) on the Andaman sea coast of Thailand. This paper presents the impact of the tsunami on the fishery and aquaculture sectors including the post rehabilitation. The immediate result of the tsunami was the near destruction of the local economy. The economic disaster was such that it led to a 0.8% reduction in the Thai national gross domestic product (GDP) growth rate for the year 2005. It was estimated that the total impact of the tsunami in the fishery and aquaculture sector of the affected provinces is 6,481 million Baht, 40% of which (2,560 million) are damage to assets and the remaining 60% (3,882 million) are losses in production for the rest of the present year. The livelihoods of many coastal fishery communities in Thailand were completely or partially destroyed by the tsunami. Economies at the community level were severely affected, which led to even deeper poverty. Preliminary assessment (after the tsunami attacked) reveals that the fishery resources decline by half. The price of marine animal also dropped within 3 months after the tsunami. It was found that the assistance by compensation package in the monitory term was far from desirable. The way in which compensation was given caused serious problems, which in turn led to serious conflicts within communities and among communities in tsunami-affected areas. Three main critical issues have to be solved, i.e. illegal fishing, democratization management, and constraint and need in continuing rehabilitation. In addition, lessons learned in the fishery rehabilitation phase for Thailand reveal several future sustainable works, such as creating supplementary income, training programs, marketing system development, financial support, strategic approach need, self-help focus, conflict management, and participatory approach.

Seree Supratid (e-mail : supratid@yahoo.co.th)
Associate Professor. The main research topic of my study covers the risk and vulnerable assessments from natural disasters, such as floods, droughts, and tsunamis. This starts from the policy-maker level in term of an integration between the risk management cycle (prevention and mitigation, preparedness, response, and recovery) and climate change adaptation down to the community level.

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