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Eliciting Local Ecological Knowledge and Community Perception on Fishkill in Taal Lake through Participatory Approaches

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ABSTRACT

Aquaculture of tilapia (Oreochromis spp.) and bangus or milkfish (Chanos chanos) is a predominant activity in Taal Lake since 1975. Participatory Rural Appraisal (PRA) was conducted to collect and synthesize indigenous knowledge and perceptions regarding environmental conditions and fishkills in Taal Lake. Specifically, this study aimed to document anecdotes on land- and lake-use changes through time, commodity shifts and utilization, technological flow, and environmental phenomena. The community's perceptions on probable causes of fishkills were also elicited. Finally, the people's view on the different internal and external factors linked to environmental management as well as their proposed solutions to problems were accounted and analyzed.

The major trends and changes in natural resource utilization, urbanization, terrestrial and aquatic livelihood activities, and occurrence of fishkill in the four municipalities in the past seven decades were illustrated using Timeline activity. Increase in human population is the major driver of changes in the natural resources of these municipalities. The local communities in the four municipalities depend on agricultural farming and fish–based activities in Taal Lake for their livelihood.

The various factors involved in the occurrence of fishkill in Taal Lake could be categorized into environmental (climatic and volcanic) and anthropogenic factors. Oxygen depletion, volcanic activity, lake overturn, sudden changes in water color, seasonal changes, wind, hydrothermal vents, poor water quality, improper aquaculture practices, and various forms of pollution-generating anthropogenic activities were cited to have influenced the occurrence of fishkills.

The devastation brought by fishkill events prompted the community to formulate solutions based on experiences, knowledge of aquaculture industry, and the physical conditions of the lake. The cage operators, for instance, conduct oxygenation of fish cages when low dissolved oxygen (DO) is observed and during transfer of fish cages to other areas. In addition, efforts towards efficient aquaculture practices such as continuous reduction and systematic arrangement of fish cages in the respective zones, reduced stocking density and feeding rates in fish cages, and proper disposal and management of wastes from domestic, industrial and agricultural (poultry and piggery) sources are the suggested solutions to avoid fishkill. The response of the community to reduce the impact of fishkill is anchored on local ecological knowledge, technology, governance and vigilance.

Key words: *Fishkill, Indigenous Knowledge, PRA, Taal Lake, Water Pollution*

INTRODUCTION

Taal Lake, a caldera formed through a series of volcanic eruptions (*Ramos 2002*, *Zlotnicki et al. 2009*), is the third largest lake in the Philippines. Located at 60 km south of Manila (*Zlotnicki et al. 2009*), it has an area of 268 km^2 and a maximum depth of 198 masl (*Papa and Zafaralla 2011*). About 37 seasonal tributaries feed the lake basin that drains into Balayan Bay through the 8.2 km Pansipit River (*Perez et al. 2008*). Taal Lake is separated it into two basins, with the world's smallest active volcano (Taal Volcano Island) located at its center (*Zlotnicki et al. 2009*). A recent review of the lake's biodiversity and limno-ecological features by *Papa and Mamaril Sr.* (*2011*) has synthesized its distinctive characters; however, studies remain scanty and unpublished. Supporting a great floral and faunal diversity, Taal Lake has been listed among one of the conservation and biodiversity priorities in the country (*Ong et al. 2002*). The lake is considered as a highly diverse ecosystem with about 101 described species of fish (*Papa and Zafaralla 2011*) including the world's only freshwater sardine (*Sardinella tawilis*) and the rare

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freshwater sea snake, *Hydrophis semperi*, locally known as duhol (*Hargrove 1991*). Prior to the introduction of aquaculture in 1975 (*Aypa et al. 2008*), local fisher folk used a variety of techniques to obtain several fish species through open water fishing using (*Villadolid 1932*). These populations of fishes offer both fundamental and demand-derived ecosystem services to the surrounding communities (*Holmlund and Hammer 1999*). Taal Lake also serves as the basin for the Taal Watershed proclaimed as the Taal Volcano Protected Landscape (TVPL) through Presidential Proclamation No. 923 s. 1996 covering 12 municipalities and 3 cities in Batangas province.

For the past several years, the practice of aquaculture has made a significant contribution in the country's fish production. Aquaculture of tilapia (*Oreochromis* spp.) and bangus or milkfish (*Chanos chanos*) is a predominant activity in Taal Lake since 1975. A significant number of investors have engaged in fish cage culture that has resulted in increased fish production from 1993 to 1998 (*Macas u.d.*). In 2000, Taal Lake contributed about 52% to the Philippines' total freshwater fish production, making Batangas province the top tilapia and bangus producer in the country (*BAS 2003*). The culture of fish depends primarily on good water quality. This aquaculture productivity, however, equates to environmental tradeoffs (*Naylor et al. 2000*). Along with the progress in the aquaculture sector is also the deterioration of water quality which results to fishkill (*Araullo 2001*).

To achieve greater yield, higher stocking density and intense feeding practice have become rampant (*Hallare et al. 2009*). Both are implicated to contribute, among other reasons, to the lake's pollution, leading to declining fish health and to the occurrence of fishkills (*Yambot 2000*). Particularly in Taal Lake, fishkill is thought to be a result of intensive aquaculture that generates organic loadings (*Vista et al. 2006*) such as feces, uneaten feeds, and metabolites of the fish which settle at the bottom (*Araullo 2001*). These materials are toxic substances that subsequently results to oxygen depletion leading to massive fish die off (*Araullo 2001; Jacinto 2011*).

Moreover, *Araullo* (*2001*) mentioned that the physical impact of aquaculture activities basically revolves around the upwelling and shallowing of lakes. Uncollected materials like bamboos, nets, and poles hamper the circulation and flow of water, hence, leading to the shallowing of lakes. In lakes such as Sampaloc, Calibato, and Mohicap in San Pablo, Laguna and Taal in Batangas, annual fishkill is a natural occurrence due to the anoxic bottom water filled with toxic substances which surface during upwellings.

Fishkill means economic loss as it reduces the stocks of commercial as well as recreational fish species, not to mention the cost of clean-up and tourism forfeiture (*La and Cooke 2011*). Several management schemes for the lake have been proposed by researchers and supported by government agencies such as the Bureau of Fisheries and Aquatic Resources (BFAR) and the Department of Science and Technology (DOST) of the Philipines. However, it appears that the fishing communities have different perspectives and remain accustomed to improper aquaculture practices (*Vista et al. 2006*). The fishing community is composed of open waters local fishermen, fish cage caretakers who may be a local member of the community, or those from outside the community who are mainly hired by fish cage operators to manage the fish cages, and the fish cage operators who are who invest in aquaculture in Taal Lake.

Participatory Rural Appraisal or PRA is a "research/ planning methodology in which a local community (with or without the assistance of outsiders) studies an issue that concerns the population, prioritizes problems, evaluates options for solving the problem(s) and comes up with a Community Action Plan to address the concerns that have been raised" (*FAO n.d*). On the other hand, the Institute for Global Environmental Strategies (*IGES)*, mentioned that PRA is a data collection method that involves both local people and outsiders from different sectors and disciplines. PRA involves outsiders facilitating local people "in analyzing information, practicing critical self-awareness, taking responsibility and sharing their knowledge and conditions to plan and to act" (IGES 2003). The IGES also emphasized the difference between Rapid Rural Appraisal (RRA) which is used almost synonymously to PRA. The organization noted that in RRA, outsiders extract and elicit information from local people. This involves outsiders going to rural places to extract information then take the information to analyze. The difference is that the local people own the information that was elicited in the PRA but it is shared with the outsiders; while in RRA it is otherwise.

According to FAO, PRA is majorly concerned with the different perspectives from the people in the community that are represented in the analysis—in which the community should take the lead in evaluating the situation under study and its possible solutions. FAO added that outsiders may participate as facilitators or in providing technical information but they should not take the lead in the process. *IGES* (*2003*) added that good PRAs should seek to maximize the community's participation as well as the empowerment and ownership that go with this.

Charnley et al. (*2008*) defined local ecological knowledge or LEK as "knowledge, practices, and beliefs regarding ecological relationships that are gained through extensive personal observation of and interaction with local ecosystems, and shared among local resource users". On the other hand, traditional ecological knowledge (TEK) is the "cumulative body of knowledge about the relationships living things (including people) have with each other and

with their environment, that is handed down across generations through cultural transmission" (*Berkes 1999*). According to *Charnley et al.* (*2008*), local ecological knowledge is a relatively new knowledge-- it differs from TEK in that TEK is handed down across generations. The same author added that when LEK is passed on to another culture or generation, it will transform into TEK. Nevertheless, *Anadon et al.* (*2009*) (as cited from *Huntington 2000, Folke 2004*) wrote that local knowledge (be it TEK and LEK) may elicit information regarding various conservation efforts. This statement is supported by *Charnley et al.* (*2008*) saying that "the potential for traditional and local ecological knowledge to contribute to biodiversity conservation has been widely recognized".

With this potential, indigenous knowledge, specifically LEK, is used in studies contributing to conservation efforts. A study evaluated LEK for biodiversity monitoring and management focusing on LEK as a tool for collecting data on local animal abundance and population trends. The study involved shepherds in Spain and ask them to estimate the abundance of *Testudo graeca*. The study revealed that LEK provided high-quality yet low-cost-- 100 times cheaper than linear-transect surveys-- information about the abundance of the species under study. Furthermore, the authors recommended that LEK should be used further as a standard tool for obtaining great varieties of taxa (*Anadon et al. 2009*).

On the other hand, *Pilgrim* (*2006*) conducted a cross-cultural study into LEK by tackling the variations of knowledge in terms of economic development and resource dependence in India, UK and Indonesia. It was revealed that significantly lower ecological knowledge levels were observed in high economically developed but low resource dependent areas. Significant results also revealed that: "As level of resource dependence of a community decreased, the age at which ecological knowledge of individuals became saturated increased and rate of knowledge acquisition slowed. Progressive loss in the younger generations was observed at the industrialized sites. The teaching methods of formal education and the influence of television were found to be contributing to this pattern of loss."Furthermore, the study emphasized that word-of-mouth and direct experience were effective modes of knowledge transfer across all areas. Moreover, the author added that "the revealed patterns of knowledge loss contribute to our understanding of the future of ecological knowledge bases globally and action that may be taken to prevent further decline in the light of economic development" (*Pilgrim 2006*).

A study by *Silvano and Begossi* (*2012*) analyzed fishermen's LEK regarding feeding habits, trophic interactions, habitats, fishing grounds, migration and reproduction of nine coastal fishes in Búzios Island in the southeastern Brazilian coast. The authors mentioned that in some instances, there were no scientific data (i.e reproduction and migration of the most studied fishes) to be compared with the fishermen's LEK and thus will serve as the only source regarding the issues. The authors recommended that to improve fisheries management measures, fishermen should apply their LEK regarding "zoning of marine space, marine protected areas, and closed fishing seasons".

With this premise, this study endeavor to understand the basic views of the local fisherfolks, fish cage operators, fish cage caretakers and other local inhabitants regarding the state of Taal Lake and the adjacent land areas. The general objective of this study was to collect and synthesize local ecological knowledge and perceptions regarding environmental conditions and fishkills in Taal Lake through Participatory Rural Appraisal (PRA). The PRA allows an innovative means of extracting information using a set of approaches that enable people to express and analyze their local knowledge of an event or certain condition (*Chambers 1994*).

Specifically, this study aimed to document narratives and anecdotes on land- and lake-use changes through time, commodity shifts and utilization, technological flow, and environmental phenomena. The aquaculture and local communities' perceptions on probable causes of fishkills were also elicited. Finally, aquaculture and local communities' views on the different internal and external factors linked to environmental management as well as their proposed solutions to problems were documented and analyzed. The results could also be essential in formulating of policies and management schemes for Taal Lake.

METHODOLOGY

Various techniques of Participatory Rural Appraisal (PRA) were employed to document the local ecological knowledge of fishing communities in four municipalities around Taal Lake from May to July 2012. These were municipalities in Batangas Province, namely: Agoncillo, Laurel, San Nicolas and Talisay (**Figure 1**). The basis for selecting the sites was the predominance of fish farming activities. From each municipality, 50 participants composed of fish-cage operators and caretakers, open water fishermen, and other locals were invited to join the PRA activities. The identification and invitation of PRA participants were done with the help of the Municipal Agriculturist who has a record of fish cage operators, open water fishermen and fish cage caretakers from all the fishing villages located along the lake shore. In the sampling of participants, it was ensured that all the lakeshore fishing villages in each municipality were represented equally in the PRA activities. In Talisay, majority of the participants were females, involved in fish cage operations with ages ranging from 30 to 50 years old. On the other hand, in Laurel, San Nicolas and Agoncillo, majority of the participants were

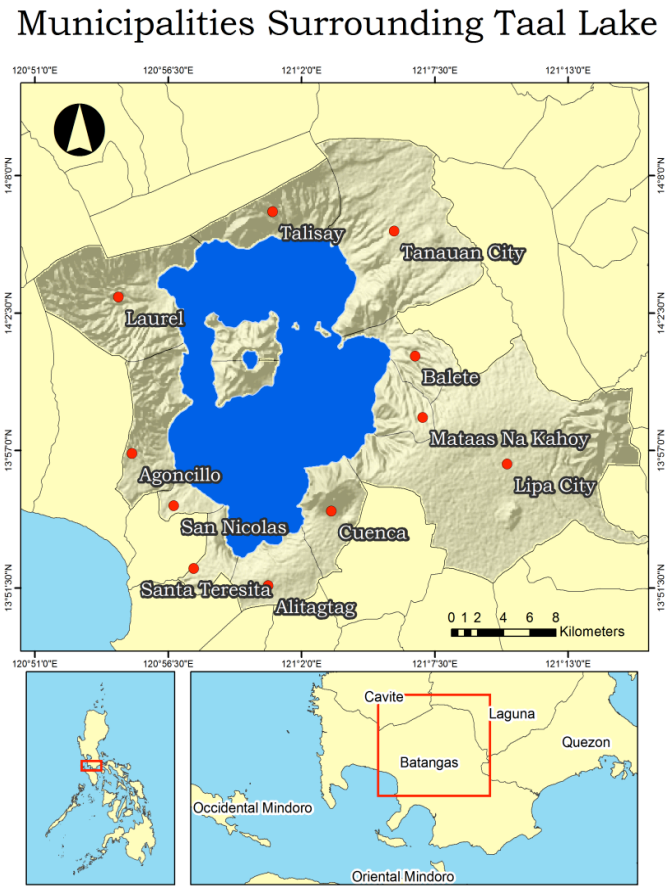

Figure 1. Map showing the surrounding municipalities of Taal Lake in Batangas, Philippines.

male and open water fishermen with ages ranging from 30 to 65 years old.

Timeline and community-based maps were generated to capture local information on significant events that happened in the area through time. For timeline, the participants identified the significant events, changes in the lake and land utilization, infrastructure development and urbanization in the communities surrounding Taal lake from the early years (1940) up to the present (2012). This was done by handing metacards to each participant and they were given ample time (about 10-15 minutes) to write down their answers for each time period covering two decades (i.e., 1940-1960) at a time. After all the participants have posted their filled up metacards, the facilitator read through the answers one by one and lead a focus group discussion for clarifications about the answers. Then the procedure was repeated for the subsequent time periods, i.e. 1960-1980, 1980-2000 and 2000-2012.

To complement the timeline documentation, community-based maps were generated by the participants through free-hand sketching of municipal scenarios in terms of cropping systems, lake utilization, and infrastructure development in 20-year interval periods. Resource flow maps were also drawn to depict the flow of products from the source (i.e. terrestrial and aquatic resources) down to the market and households. The transect line mapping involved driving through the community from the highest area passing through the community down to the lakeshore area to capture salient features of the landscape taking note of the elevation, topography, land uses, cropping systems, etc.

A direct appraisal through causal mapping approach was used to pinpoint the communities' perceptions regarding the causes of fishkill in Taal Lake. Elicited via focus group discussions were the participants' understanding of fishkill and the possible solutions which could be implemented by each individual, the local community, and LGUs to solve this problem. SWOT analysis (strength, weakness, opportunity, or threat) of proposed solutions examined the internal strengths and weaknesses of the communities that might impact the implementation of the solution to the fishkill. It was also designed to familiarize the communities to the external opportunities and threats that might occur during the implementation of the solutions. Opportunities are elements for the communities to take advantage of in addressing the issue. Threats are the elements in the environment that can hinder in addressing the fishkill issue.

RESULTS AND DISCUSSION

The elevation in the municipalities of Talisay and Laurel ranges from 5 m at the lakeshore area to about 600 m in the ridges (**Figure 2a**). Forested areas are found in high elevation areas that form part of the Tagaytay ridge. On the other hand, the elevation in the municipality of Agoncillo reaches up to 300 m while the municipality of San Nicolas has a lower elevation reaching up to 200 m.

The slope map of the Taal Lake watershed (**Figure 2b**) shows that Talisay and Laurel have a wider slope range varying from level or flat to steep. San Nicolas has level to gently sloping/undulating slope, while Agoncillo has level to undulating/rolling slope. These slope categories are also complemented by the transect line map generated from the transect line activity.

Timeline of Changes in Resource Use and Socio-economic Conditions

Timeline illustrates the major trends and changes in natural resource utilization, urbanization, terrestrial and aquatic livelihood activities, and occurrence of fishkill in the four municipalities in the past seven decades. Taal Lake and the adjacent watershed are considered by the locals as important resources for their basic needs. Increase in human population was identified the major driver of changes in the natural resources use of these municipalities. Likewise, infrastructure development was captured in the timeline. The upper and lower portion of the timeline shows the dynamics

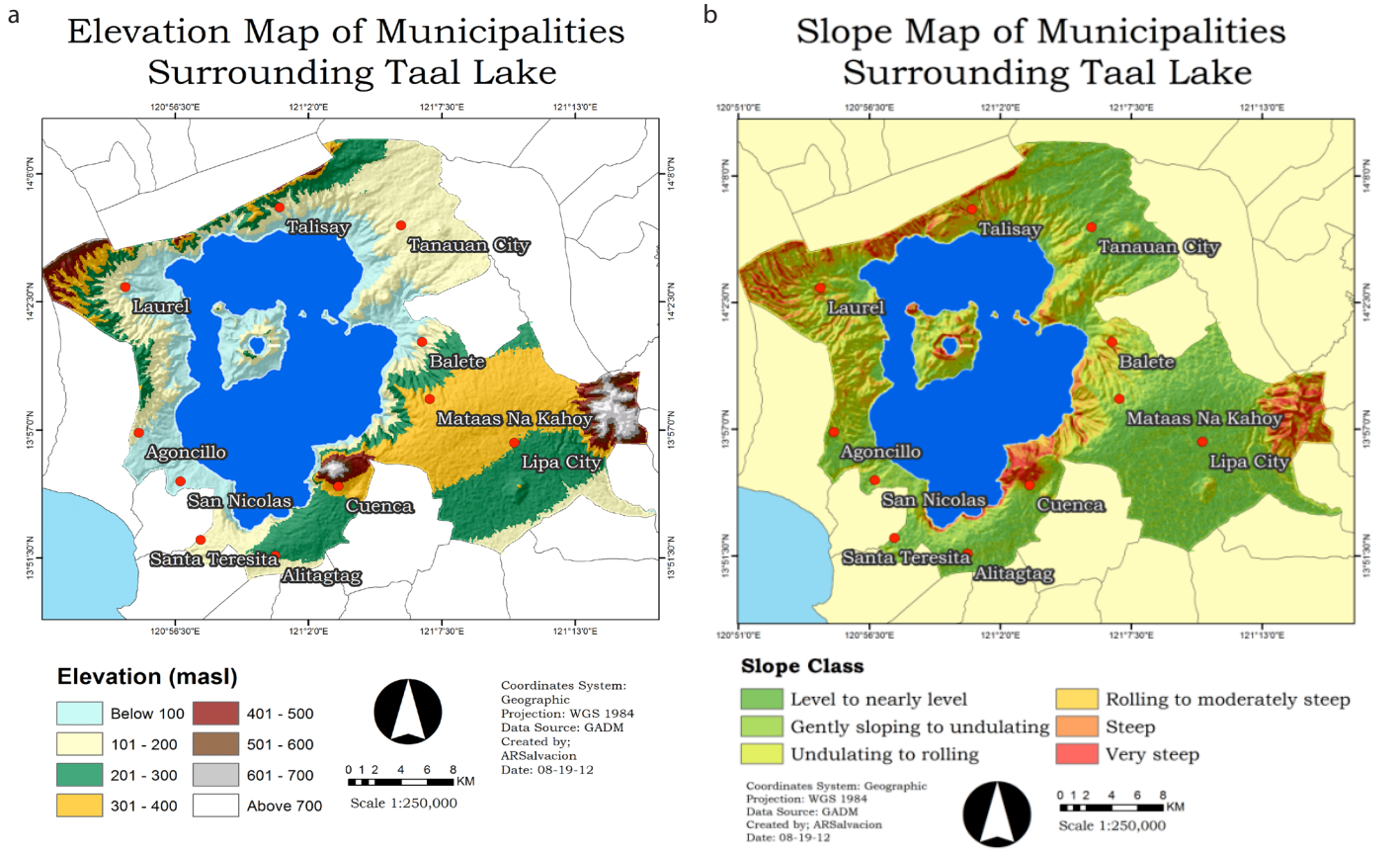

Figure 2. Elevation (a) and slope (b) class maps of the Taal Lake watershed.

of activities and events in the terrestrial and aquatic zones, respectively (**Figure 3**).

Terrestrial Resources

In the early 1900s, the intact forest cover, extensive fertile land and abundant aquatic life in the lake provided resources to the local community members in the four Taal Lake municipalities allowing them to engage in forestry, farming and fishing activities. Prior to the Japanese occupation, the locals of the four municipalities cultivated the fertile volcanic land with a local upland rice variety (*nagpili*), corn, sugarcane, banana, coconut, mango, various vegetables and root crops such as sweet potato and potato. Some farmers engaged in slash and burn system (*kaingin*) in the forested areas for planting local variety of upland rice (*nagpili*).

The forest cover diminished as a result of steady increase in human population in the late 1960s. This increase in population is attributed to growth of local families as well as in-migration from other provinces and regions. These settlers tried to make a living by opening up forest lands into new agricultural farms. In addition, the slash and burn system remained a major forest activity until the late 1970s. Meanwhile, a major eruption of Taal Volcano occurred in the 1970s that caused significant damages in the crops, livelihood and environment.

Agricultural activities for fruit, vegetable, crop production and poultry raising peaked during the decades of 1960-1980. Then these agricultural activities declined in the succeeding years while livestock production for swine and cattle increased from 1980 to early 2000's (**Figure 3**).

In the late 1970s, a few infrastructure such as schools and health centers were established, and power supply started to be made available to the municipalities. Commercialization progressed in the 1980s following rapid built-up of infrastructure (financial institutions, hospitals, schools, markets and community organizations among others) that provided opportunities for employment. Agricultural production and organic farming, however,declined. The depletion of forest resources due to slash and burn practice continued; whereas, some agricultural lands were converted to industrial and residential properties. Agricultural farms were replaced by privately-owned residential properties, commercial and infrastructure development that continued until the 1990s (**Figure 3**).

From the 1970s to the 1990s, power and water supplies were installed in the four municipalities. The younger generation had access to primary and secondary education as basic learning facilities were continuously built in the early

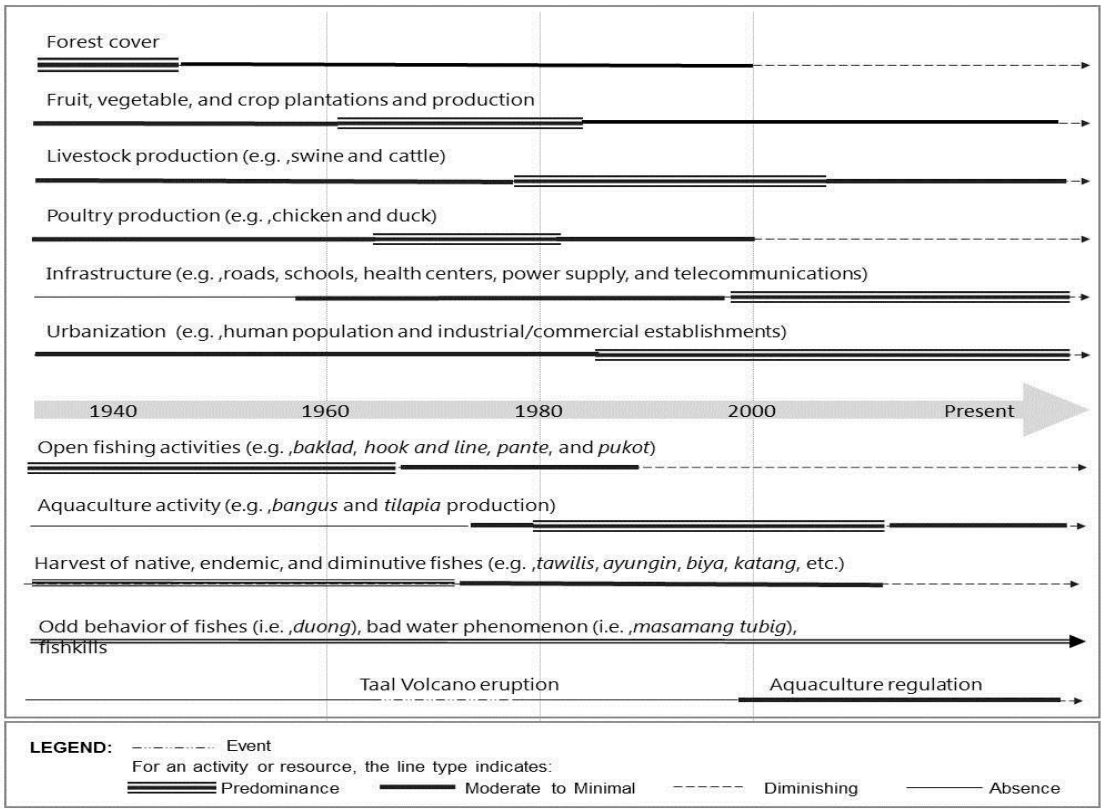

Figure 3. Significant land use and lake use changes, events, and socio-economic activities in the four Taal Lake municipalities.

1990s up to the present (**Figure 4**).

From 2000 until the present, the municipalities of Talisay, Laurel, San Nicolas and Agoncillo remain agriculture-based. While exploitation of the natural resources also happened in the forested areas, agriculture in the irrigated areas was restricted to rice cultivation due to water issues. Farmers were compelled to cultivate rice varieties to sustain at the very least the food production in Batangas. Cultivation of rice now appears to be mainly undertaken to ensure household rice security rather than for profit. However, many households have diversified into other off-farm income generating activities such as livestock, marketing, and fishing. This indicates that agriculture in these municipalities is shifting toward a subsistence rather than profit-making enterprise as farmers increasingly depend on other income sources to meet household expenditures.

Taal Lake Resources

As early as the 1940s, open fishing was the major activity in Taal Lake where various species of fish were harvested using different fishing gears including *baklad* (corral), *pante* (fishing rod), and *pukot* (seine). Endemic fishes such as *tawilis* (*Sardinella tawilis*), ayungin (*Leiopotherapon plumbeus*), katang or crab and the migratory fish *maliputo* (*Caranx ignobilis*) were abundant during those early years. The productive Taal Lake remained a primary natural resource until the successive volcanic eruptions from the late 1960s to 1970s.

Following the devastating Taal Volcano explosion in the mid-1960s, aquaculture of tilapia and bangus was introduced in Taal Lake in the late 1970s. The farmers shifted to aquaculture starting in Talisay and spreading to other municipalities in the succeeding years. Intensive feeding practices in aquaculture took place in the 1980s up to the late 1990s, resulting to remarkable fish production. Open fisheries productivity dropped steadily as fish cage operations continued. The locals attributed this to the introduction of invasive species such as *dugong* (*Parachromis managuensis*), and *karpa* or also commonly called *imelda* (*Aristichthys nobilis*).

Many fisher folks continued the lake–based activities to supplement income from farming. Some foreigners settled in Batangas and invested in the aquaculture industry that monopolized fish cage operations in some municipalities. Employment opportunities for young people led to increased out-migration to urban areas where jobs in factories and industries can be found.

Fishkill was observed in Taal Lake since the 1940's (**Figure 3**). They associated this fishkill phenomenon with bad water which causes odd fish behavior. This odd behavior is characterized by frantic swimming and tendency of fish to jump out of the water gasping for air or swimming towards the lakeshore and die along the coast. This is

locally termed as "*duong*". Following the introduction and flourishing of the fish cage industry, massive fish mortalities occurred frequently in the 1980s up to the late 1990s. Fishkill events were also experienced in the last decade, the most notable of which was in 2011. Adverse impacts of fish kill events in fisheries in all fishing communities were reported.

Land-use Changes around Taal Lake

Changes in the land and water resource use from 1940 to the present are shown in the community–based maps (**Figures 4 to 6**). Through time, the construction of footpaths, highways and roads became instrumental in the inhabitation of forest areas and its conversion to other land uses. The structure, cover, and ecosystem landscape changed though time as the natural land cover was slowly replaced with residential, commercial and industrial areas.

Talisay and Laurel occupy the north and northwestern parts, respectively, of the basin facing the Taal Volcano Island in the south. The communities in these two municipalities continuously utilize the forest, agricultural lands and the lake for sustenance. The remaining fragmented forest lands in the Taal Lake basin are found in these two municipalities. These lush and thickly vegetated forestlands comprise the Tagaytay ridge characterized by very steep topography, thereby making it difficult for conversion to agricultural lands (rice and cornfields) and even to residential developments. The major land cover type in Talisay is cultivated perennial crop in the upland areas, while cultivated annual crop and shrubland cover types are found in the lower elevation areas. On the other hand, cultivated perennial crop and wooded grassland are the major land cover types in Laurel.

The areas accessible to the locals through dirt roads and trails have been converted to coconut and fruit tree farms from the early 1960s up to the present (**Figures 4 and 5**). Lands on shoreline levels are used as ricefields, fish nurseries, livestock farms, residential and recreation areas. The coastal communities of Laurel ventured on duck-raising in the 1960s until the late 1980s as an alternative source of livelihood.

After the volcanic eruption in 1965, the locals returned to their lands. Increasing demand for rice and vegetables became apparent as communities converted the forested areas into agricultural lands to address food demand. Irrigation was introduced in the rice paddy farming system. Some farmers also took interest in raising backyard livestock, resulting in increased supply of animal-derived food products. The emergence of new income-generating activities such as small-scale business (e.g., backyard farms), trade of various food items (e.g., delicacies and specialties, endemic fishes, etc.) and other natural products (e.g., timber and other wood products) flourished as easy access to markets was made available due to cemented foot walks and highways initially built in the early 1970s (**Figure 3**).

In the lake, the fish cage structures and operations thrived since their introduction in the late 1970s. *Tilapia* was cultured more frequently in square cages while *bangus* was reared in round cages. The communities reported that the circular cages facilitated the circular movement of *bangus* and the *bangus* would not hit any corners, as compared with if they were reared inside the squared cages, thus the preference for the circular cages.

On the other hand, the municipalities of San Nicolas and Agoncillo are located on the south and southwestern portions of the lake, respectively (**Figure 6**). The locals from these areas utilize the Pansipit River for additional resources. The topography of both municipalities is more suitable for agriculture and farming cultivation. Sugarcane, banana, rice, coconut and fruit tree farms were planted in the areas. Open broadleaved forest and cultivated perennial crops are the major land cover types in Agoncillo. The coastal communities of Agoncillo ventured on duck-raising as a source of livelihood as early as 1940s until the late 1990s. The lake also provided abundant shellfish for the ducks' feed during this time period.

In both municipalities, residential development and expansion of built up areas as a function of the slow but steady increase in population started at similar periods in the 1960s to 1980s. Infrastructure (roads, bridges, schools, port, etc.), residential (concrete houses), recreation (resorts) and agricultural developments (fingerlings nursery, ricefields, tree seedling nurseries) have continued from the 1980s up to the present. Fish cages for tilapia and bangus farming started to dot the lake in the mid-1970s and prospered in the 1980s up to the 1990s.

Before the introduction of tilapia and bangus cage culture in both municipalities in the 1980s, the coastal communities relied on *baklad* or fish traps set near the coastlines to catch fish as early as the 1960s. *Baklad* is defined in the Fisheries Code of 1998 as "stationary weir or trap devised to intercept and capture fish consisting of rows of bamboo stakes, plastic nets and other materials fenced with split bamboo mattings or wire mattings with one or more enclosures, usually with easy entrance but difficult exit, and with or without leaders to direct the fish to the catching chambers, purse or bags".

Both San Nicolas and Agoncillo are strategically located near the Pansipit River, the path of migratory fishes from Balayan Bay to Taal Lake and vice versa. The *baklad* previously set up along the lakeshore of San Nicolas was famous for catching *maliputo* (*Caranx ignobilis*), an economically important migratory fish. However, this

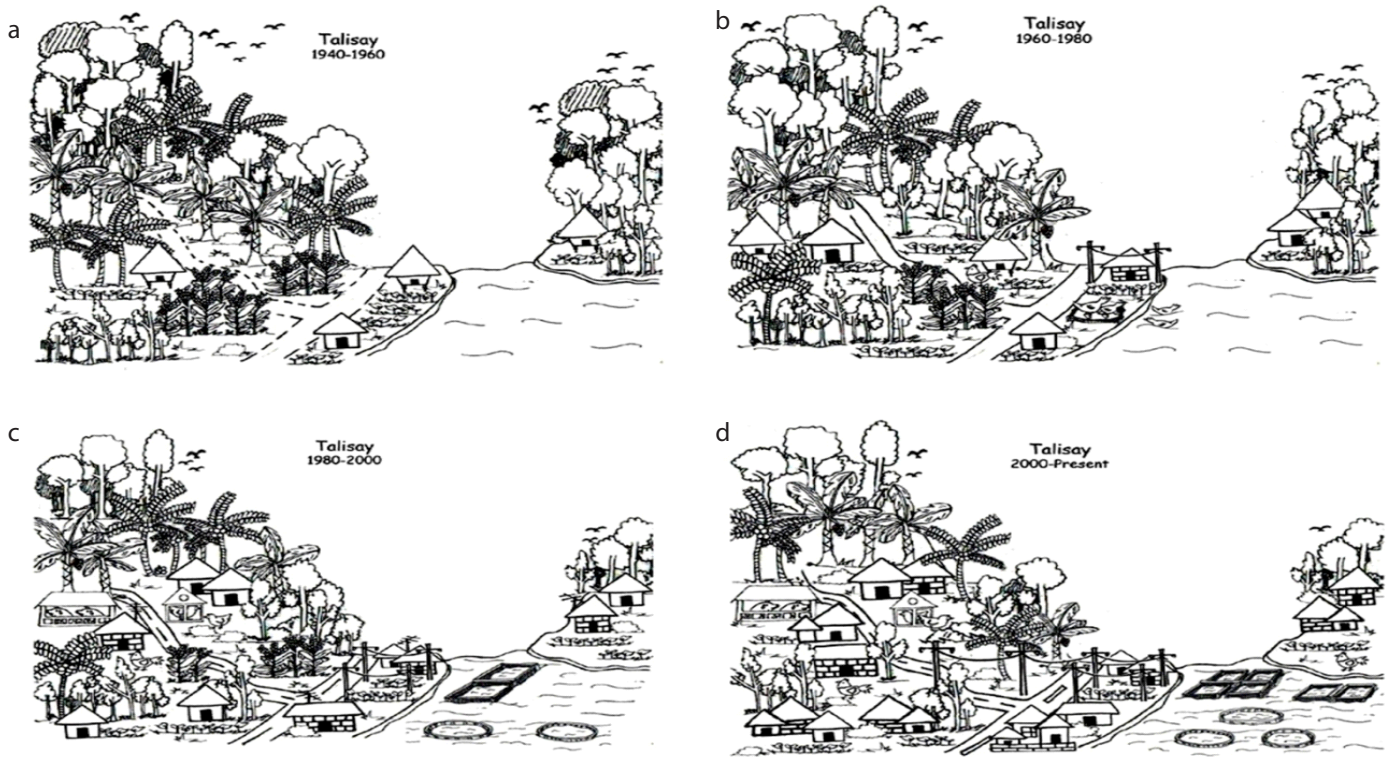

Figure 4. Transitional community-based land- and lake-use maps generated by the locals from a) 1940s–1960s, b) 1960s-1980s, c) 1980s-2000s and d) 2000 to present in the Municipality of Talisay.

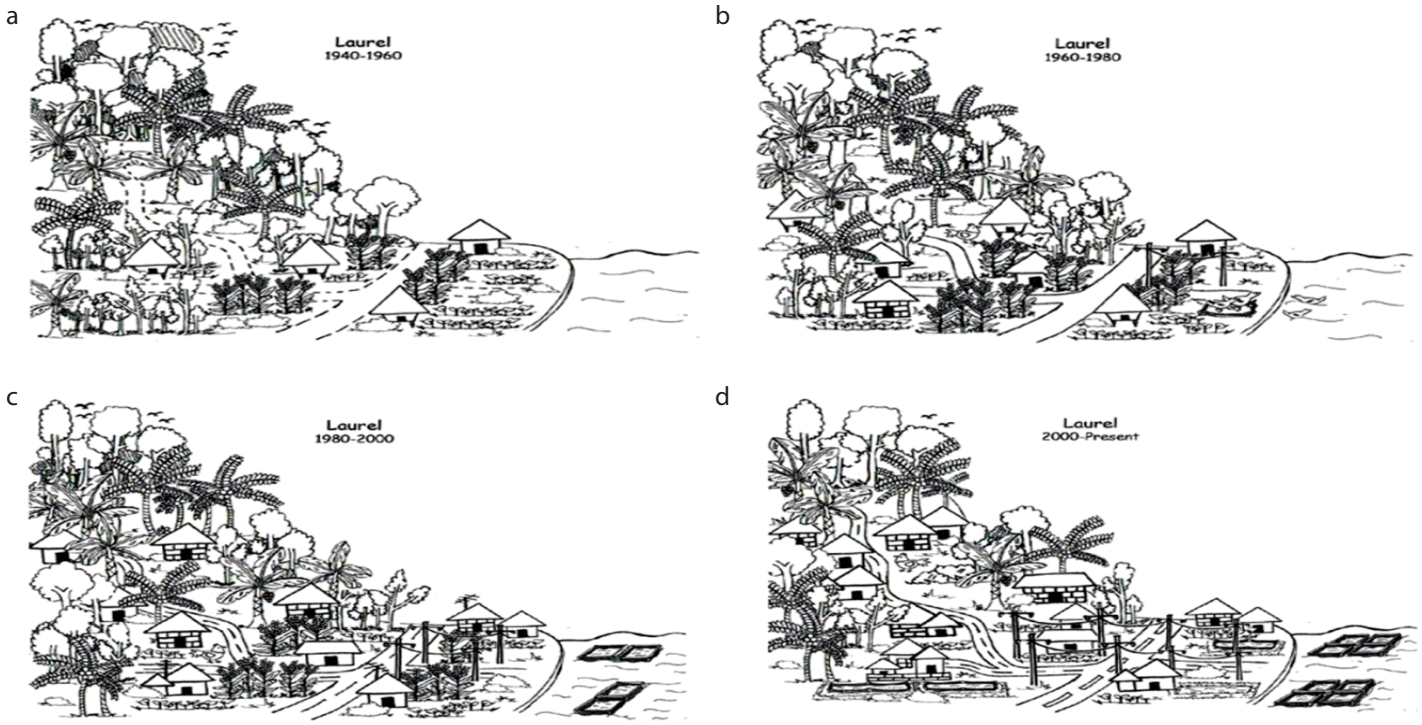

Figure 5. Transitional community-based land- and lake-use maps generated by the locals from a) 1940s–1960s, b) 1960s-1980s, c) 1980s-2000s and d) 2000 to present in the Municipality of Laurel.

fishing method was banned in Lake Taal in 2007 after the stakeholders' adoption of the Unified Rules and Regulations (URR) of Fisheries in Taal Lake. Meanwhile, Agoncillo shifted from *baklad* to intensive cage operation in the 1960s to the present times. Another fishing structure, fish trap, locally known as *patanga*, was introduced in the 1980s and still being used at present in Agoncillo. The *patanga* is a passive gear made up of wooden or metal frame box enclosed with chicken wire positioned in the lake to trap fish (*Palma, et al. 2005*).

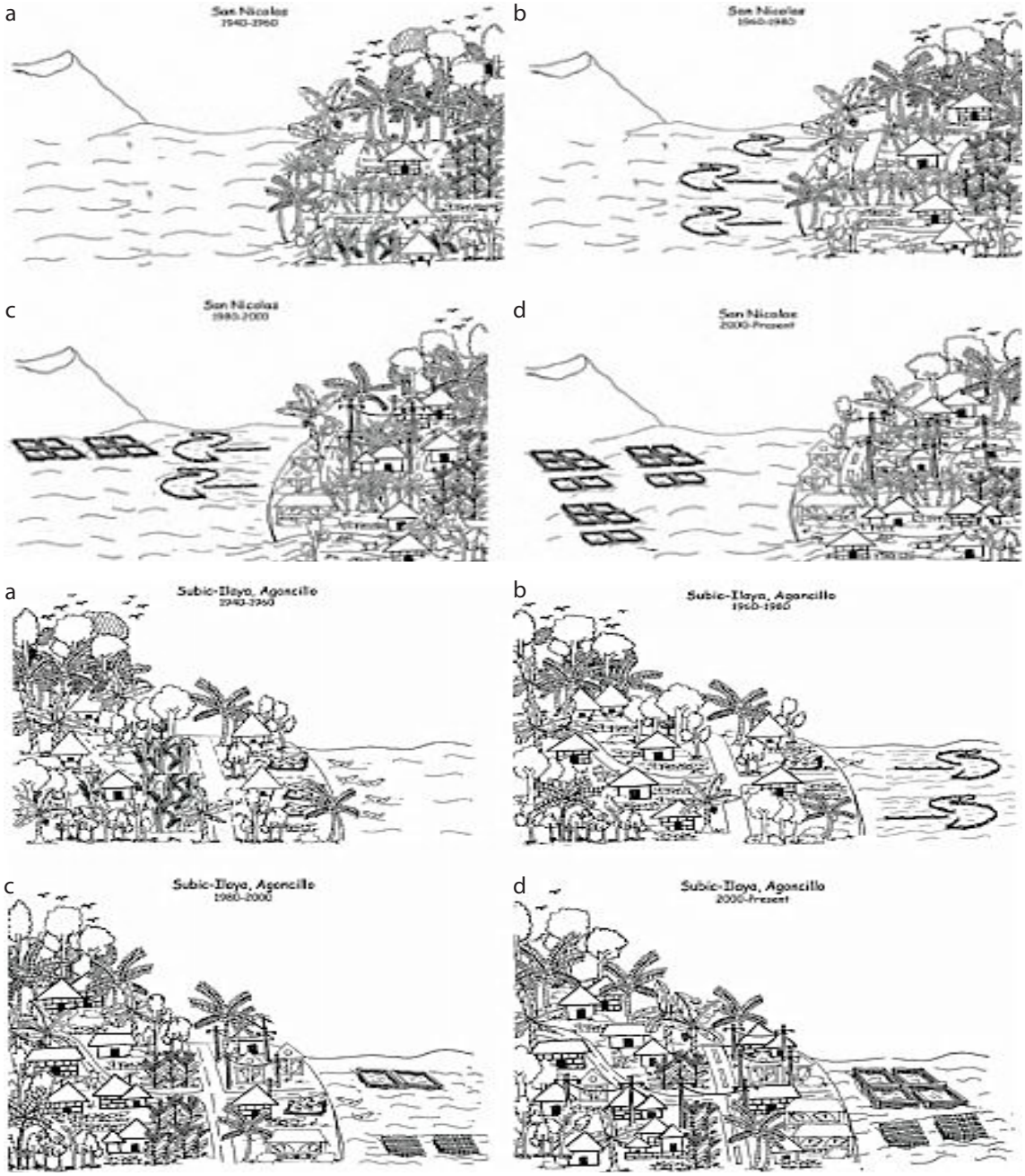

Figure 6. Transitional community-based land- and lake-use maps generated by the locals from a) 1940s–1960s, b) 1960s-1980s, c) 1980s-2000s and d) 2000 to present in the municipalities of San Nicolas and Agoncillo, respectively.

Of the four municipalities, Talisay has the most number of circular cages. These are generally made of steel and is costlier than the square cages made of bamboo poles. Both Talisay and Laurel use the square cages, but the former has circular cages for bangus culture. Despite the difference in the species cultured, both the fish cage operators and the local fisherfolks observed the guidelines set in the Philippine Fisheries Code (R.A. 8550) for aquaculture practice until the Unified Rules and Regulations (URR) for Fisheries of Taal Lake for the management of a protected area was formulated. The guidelines for registration, operation and management were drafted and adopted by the communities in 2007.

Taal Lake Water Resources and Agricultural Commodity Flow

The local communities in the four municipalities depend on agricultural and agroforestry activities in the farms and fishing activities in Taal Lake (**Figure 7**) for their livelihood. The agricultural and agroforestry farms are the sources of fruit and food crops such as banana, coconut, mango, cassava, rice (*nagpili*), corn and onion. In all four municipalities, the various products or materials derived from the forest are either consumed by the household or sold to the market. The farms are used for either animal raising

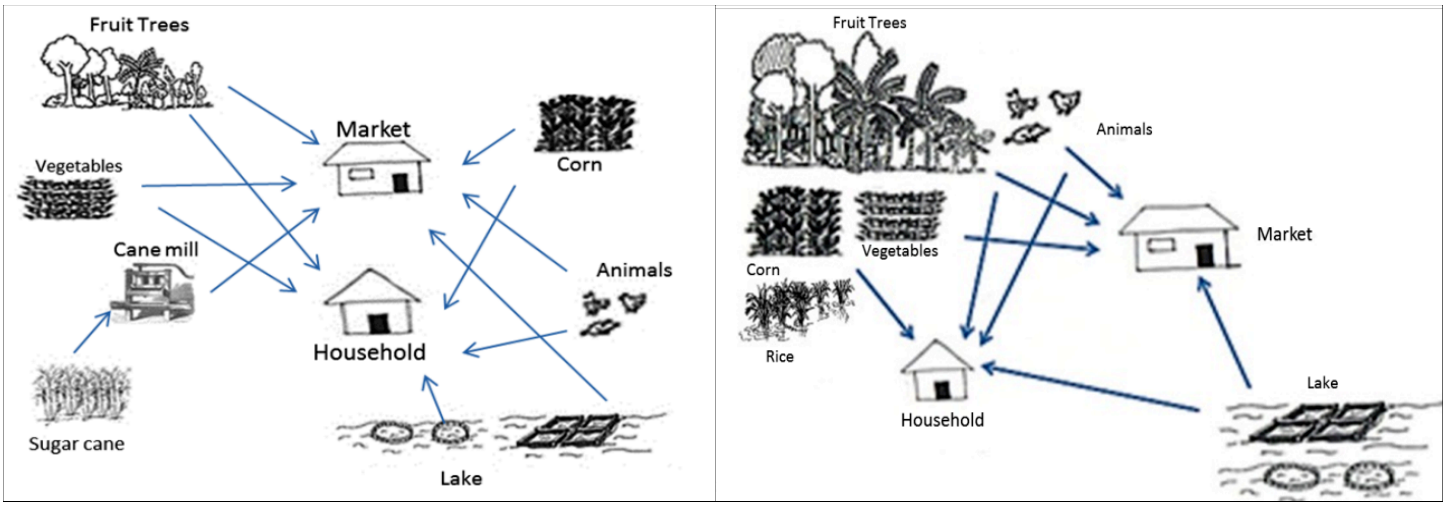

Figure 7. Commodity utilization in the PRA sites surrounding Taal Lake.

or crop production. Rice is grown in the municipalities of Laurel and Talisay while sugarcane is primarily grown in San Nicolas, but vegetables and corn are grown in all municipalities.

All four municipalities use the lake for cage and open catch fisheries. Fishing and cage operation contribute to higher income of the households not only in Talisay but in the rest of the aquaculture areas around the lake. In addition to bangus and tilapia, native species such as *tawilis* (*Sardinella tawilis*), *muang* (*Apogon thermalis*) and *biya* (*Glossogobius guirus*) are caught from the lake either for consumption or for merchandise (*Rosana et al. 2006*).

The majority of the farm harvest and fish catch is consumed by the household and the excess is sold in the market. Additionally, off-farm labor and out-of-town employment are sources of family income even though the locals did not clearly indicate it during the PRA activity.

Local Perceptions on Causes and Solutions to Fishkill

According to *Helfrich and Smith* (*2000*), fish dies due to a variety of reasons. It can be categorized into natural and unnatural causes. As they said, "fish may die of old age, starvation, body injury, stress, suffocation, water pollution, diseases, parasites, predation, toxic algae, severe weather, and other reasons." However, if huge number of fishes were found lifeless floating on water over periods of time, it is just imperative to determine the cause of the occurrence. *Helfrich and Smith* (*2000*) pointed out that fishkills occur because of oxygen depletion which is caused by "(1) the die-off of a large algae bloom, (2) the decay of water weeds after treatment with a herbicide, (3) the turnover of oxygen-poor bottom waters following a thunderstorm, and (4) the runoff of livestock waste and other organics after a heavy rain."

Furthermore, in a study conducted by Rhode Island Department of Environmental Management (*2003*), the lack of oxygen was considered as the direct cause of fish kill along the Greenwich Bay. The absence of oxygen caused aquatic animals to get suffocated. However, the study also emphasized that this condition comes with broad and complex factors. Such factors include natural phenomenon like rain, wind, temperature, geology, and hydrodynamics. Moreover, pollution coming from different sources such as sewages, water run-offs, groundwater flows from polluted areas, and discharges from vessels was also stressed as huge factors in fish kills.

During the conduct of PRA in the four municipalities, several factors were documented to have contributed to the occurrence of fishkill in Taal Lake. These range from oxygen depletion, volcanic activity, lake overturn, sudden changes in water color, seasonal changes, wind, hydrothermal vents, poor water quality, improper aquaculture practices, and pollution (**Figure 8**). The various factors involved in the occurrence of fishkill in Taal Lake could be categorized into environmental (climatic and volcanic) and anthropogenic.

The PRA participants consider fishkill as a natural phenomenon driven primarily by extreme shift in weather conditions, underscoring a possible influence of seasonal change. As discussed in the timeline and causal mapping activity, the natural factors that induced fishkill in the past early years included the changes in weather conditions (**Figure 8**). According to the PRA participants, fishkill were observed during the onset of the rainy season (mid May) after a long hot dry summer. Fishkill can occur within a week after days of intermittent rain during the the start of the rainy season. A possible explanation for this is that when the rain water from the surrounding watershed drains into the lake, the upper layer will be colder than the layer beneath and the cold upper layer of the lake may sink and cause a lake overturn. The 2008 Bureau of Fisheries and Aquatic Resources (BFAR) data showed the highest number of

fishkill incidents occurred in the month of May, the start of the rainy season (*TVPL Management Plan 2009*).

The PRA participants reported that they are expecting fish kill to occur also during the cold months of January to February. During this period, the strong Northeast winds may push the cold upper layer of water in the lake and cause a lake overturn. They also mentioned that they observed fishkill to occur during times when there is a change in wind direction. In Lake Venezuela, *Infante et al.* (*1979*) reported that the abrupt change in wind strength and direction has resulted in fish and Chaoborus mortality.

It was also observed by the PRA participants that the sudden changes in color of the water in the lake may cause immediate fishkill. They reported that they would observe at some instances that in specific locations in the lake, for example in areas near the villages of Aya, Quiling and Tumaway in the municipality of Talisay, the color of the water in the lake will suddenly become emerald green and after a few minutes will become white as vinegar. All fish inside the cages that will be covered by this flowing colored water may die, according to the participants. Thus, to avoid such massive fishkill due to flowing colored water, the fish cage caretakers and operators will immediately tow and move their fish cages in areas away from the green and white colored waters. On the other hand, fish in the open waters try to swim away from the colored water. If become affected, the fish will exhibit the odd behavior, such as jumping from the water and gasping for air or swim frantically towards the coastal areas.

Among the various causes pointed out by the PRA participants, it is noteworthy to emphasize that the observed odd fish behavior may be a compelling sign of impending fishkill that may occur within a few minutes (**Figure 8**).

Taal Lake is a caldera and there are about six craters in the Taal volcano island. Aside from these craters, there are a number of hydrothermal vents on the lake bottom. It was reported by fish cage operators that they have experienced hot water upwelling in areas near their fish cages, for example, in Brgy. Sampaloc, Talisay. There are times when the fish cage caretaker will swim to check the fish cages and they will immedately swim towards the surface water because the water beneath can be very hot, boiling hot.

According to the participants, anthropogenic activities such as population increase, economic development and industrialization contribute to the deterioration of water quality that leads to eutrophication of Lake Taal. There has been an argument that pollution from the fish cages is the most tangible source of organic sediments at the bottom of the lake. The fish cage operators and caretakers would not admit that their aquaculture practices would contribute to the lake pollution. They, instead blame the clogged Pansipit River for the deteriorating water quality in the lake because water from the Taal Lake could not freely drain into Balayan Bay. The other stakeholders, i.e. open water fishermen, on the other hand strongly believe that aquaculture is one of the major sources of water pollution in the lake. Other sources of pollution in the lake are domestic wastes, agricultural wastes from piggeries, and recreational wastes from swimming resorts along the coastal area. The vertical mixing of water bringing the anoxic sediments with naturally low or no oxygen in it from the lake bottom to the surface is detrimental to fish in the surface layers.

Solutions to Problems

The devastation brought by fishkill events prompted the Provincial Government Unit, the Local Government Units (LGUs) and the local community to formulate solutions based on experiences, knowledge of aquaculture industry, and the physical conditions of the lake. The cage operators, for instance, use water pumps to increase the oxygen inside the fish cages when low DO is observed and they transfer the fish cages to other areas. In addition, the Provincial Government Unit enforced efforts towards efficient aquaculture practices such as dismantling and reduction in number of fish cages, systematic arrangement of fish cages in the respective zones to create space for boats to pass through in between fish cages, reduced stocking density and feeding rates in fish cages, and proper disposal and management of wastes from domestic, industrial and agricultural (poultry and piggery) sources are suggested solutions to avoid fishkill. **Table 1** presents the solutions proposed by the local communities from the four municipalities.

The PRA participants from the four municipalities proposed various solutions to address fishkill in Taal Lake (**Table 1**). All the participants from the four municipalities have the same opinion that proper aquaculture practices and proper management of domestic, aquaculture andagricultural wastes are primary solutions to address fishkill in Taal Lake. The use of advanced and available technology such as water pumps to increase the oxygen levels inside fish cages was mentioned in three municipalities of Talisay, Laurel and San Nicolas but not in Agoncillo. The absence of advanced technology in Agoncillo may suggest that the Municipal Agriculturist need to contact the provincial agencies for Agriculture and Environment and Natural Resources for support for these advanced technologies. Further, participants from Agoncillo and Talisay suggested that training and capacitation on technical measures to address fish kill will help them solve the problem of fishkill.

The strict implementation of rules and regulations for aquaculture was also suggested by the respondents from three municipalities of Talisay, Laurel and Agoncillo as a

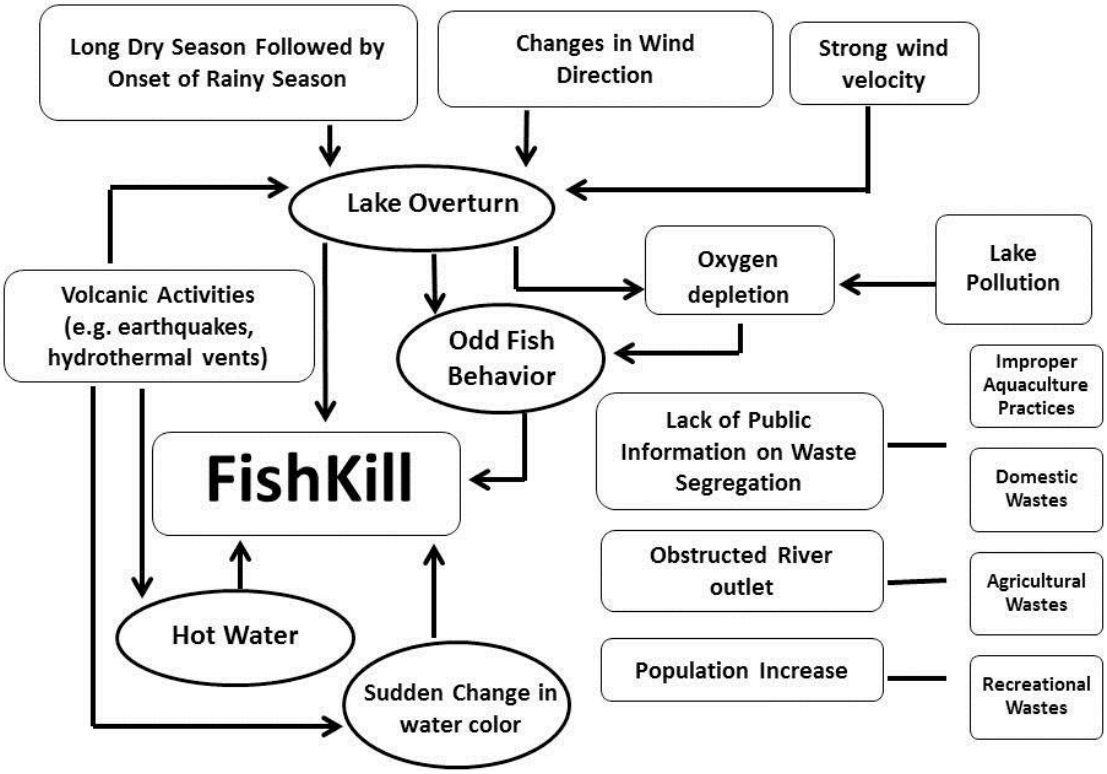

Figure 8. Community-based causal diagram showing the different factors related to fishkill events in Taal Lake.

Table 1. The solutions to fishkill problem in Taal Lake from the municipalities of Talisay, Laurel, San Nicolas and Agoncillo.

Proposed Solutions to Fishkill	Municipalities			
	Talisay	Laurel	San Nicolas	Agoncillo
1. Proper aquaculture practice	*	*	*	*
2. Waste management (domestic and agricultural waste)	*	*	*	*
3. Use of advanced and available technology	*	*	*	
4. Implementation of existing rules and regulation	*	*		*
5. Training and capacitation (technical)	*			*
6. National government agencies (BFAR, PHIVOLCS) support	*		*	
7. Pansipit River conservation and interventions	*	*		
8. Creation of response team	*			
9. Continuous education and public awareness				*
10. Water quality and volcanic activity monitoring and research	*			
11. Alternative livelihood			*	
12. Political will of leaders				*

PRA participants were referring to The Philippine Fisheries Code (RA 8550) and the Unified Rules and Regulations for Fisheries of Taal Lake (2007). The Republic Act 8550, also known as The Philippine Fisheries Code of 1998 is an "act providing for the development, management and conservation of the fisheries and aquatic resources, integrating all laws pertinent thereto, and for other purposes". The Unified Rules and Regulations (URR) for Fisheries of Taal Lake (2007) was drafted through a covenant, in 2006, among all the Local Government Unit leaders (mayors and governor) of Batangas province to protect the Taal Lake. Through this measure to solve fishkill phenomenon in Taal Lake. The covenant, a protected area management plan was drafted which include "activities to maintain and monitor water quality, zoning for forests, fish sanctuary and agro-tourism, a reliance on counterpart contributions by stakeholders, better law enforcement, keeping current population levels, disaster preparedness and solid waste management". Participants from Agoncillo also mentioned that political will of local leaders is very important in the success of implementing the rules and regulations for aquaculture in Taal Lake (**Table 1**).

Likewise, efforts are being done by several agencies and stakeholders towards a responsible management of the aquaculture industry in Taal Lake. The Bureau of Fisheries and Aquatic Resources (BFAR), Philippine Volcanology and Seismology (PHIVOLCS), Department of Environment and Natural Resources (DENR), civil society organizations

(CSOs), church, academe, provincial and local government of Batangas that compose the Protected Area Management Board are actively implementing conservation and protection programs for Taal Lake. The sustainable management programs include general implementation of the Taal Volcano Protected Landscape (TVPL) Management Plan, which involves water monitoring, law enforcement, awareness–raising campaign among others.

Pansipit River is the lone conduit for water and migratory fish species to flow and swim from Taal Lake to the Balayan Bay and back. This phenomenon is crucial in maintaining the ecosystem balance of the Taal Lake. However, with the clogging and narrowing of the river, this natural exchange of fresh water from the lake and salty water from the bay as well as the movement of migratory fish species is critically affected. Thus, participants from Talisay and Laurel opined that conservation and management of the Pansipit River is one of the strategies crucial in addressing fish kill in Taal Lake.

Participants from the municipality of Talisay are very adamant in suggesting that the creation of a response team to relocate fish cages particularly when there are observed changes in the color and when the quality of water approaches critical levels is very important to minimize fishkill. They also mentioned that water quality and volcanic activity monitoring and research are very important activities to prevent fishkill. One fish cage operator from Talisay is also a cooperator in water quality monitoring research being conducted by researchers from the University of the Philippines Los Baños.

Analysis of Strengths, Weakness, Opportunities and Threats (SWOT)

An analysis of strengths, weakness, opportunities and threats (SWOT) enabled the participants to express and share their local knowledge towards understanding the fishkill problem and in assessing the success of their proposed solutions in their communities. The strengths and opportunities are the ones that the community should harness to successfully address the fishkill issue. The weakness and threats are the ones that may hinder the implementation of solutions to fishkill. The availability of technology on water quality monitoring, knowledge on the local environment and proper management practices, committed leadership of the local chief executives, cooperation among the stakeholders, partnerships and alliances, and conservation project in Taal Lake are among the strengths of the communities that will enable them to successfully manage the lake resources and its surrounding environment (**Figure 9**). The Municipal Agricultural Officers (MAO) of the four municipalities are in close coordination with the regional office of the Bureau of Fisheries and Aquatic Resources (BFAR) who is closely monitoring the water quality in the Lake. The BFAR regularly issues water quality updates to the MAOs who in turn will disseminate the information to the village leaders (barangay captains) and fishermen cooperatives and alliances. The BFAR has also installed monitoring boards in the municipalities where they regularly update the information on water quality and provides early warning system advisory. Some of the fisherfolk have knowledge on the proper management of lake resources and other members of the community may learn from them as well. The committed leadership of chief local executives, the very cooperative local stakeholders and the active partnership and alliances between fish cage operators and fish feed industries are important ingredients in the improved and sustainable management of the Taal Lake resources.

On the other hand, the lack of equipment for monitoring, direct communication with government agencies, education on waste management, funds, and discipline of some locals in complying with existing laws for the lake are among the weaknesses that may the hinder the efficient management and sustainable use of the lake resources. One weakness of the local people is the lack of discipline. According to the participants, this is rooted in the lack of information and understanding of the ecological values of the lake as a resource provider to the people. Legislation is not a problem in Taal Lake as the local government units implemented the URR for Fisheries in Taal Lake, which also provided a set of guidelines to sustainable aquaculture practice. According to the participants, the cage operators alliance and the local government should look into ways and means to address the funds for technology and monitoring equipment. Aside, from the interest of the cage operators, government agencies, the local government units and other sectors also benefit from the lake. Cooperation among these entities, according to the participants, must be fostered to maximize efforts and solutions to prevent losses from the fishkill phenomenon.

According to the PRA participants, the need to strengthen the coordination and partnership between and among agencies, fishing communities and other local communities is an important opportunity to harness in order to minimize the impacts of fishkill in the aquaculture industry. Strengthening the awareness on fishkill and capability to address fishkill through the conduct of trainings and establishment of learning centers will enhance local participation in the implementation of identified solutions to address fishkill. The local government should strengthen the feedback mechanism from the communities to evaluate the effectiveness of the existing mechanisms for public information. It should also continue and widen the environmental awareness of the communities to enable them to understand the relationship between the watershed and lake ecosystem as a whole. Cleaning up and dredging of the Pansipit River may improve the quality of water in the lake and allow movement of migratory species between Taal Lake

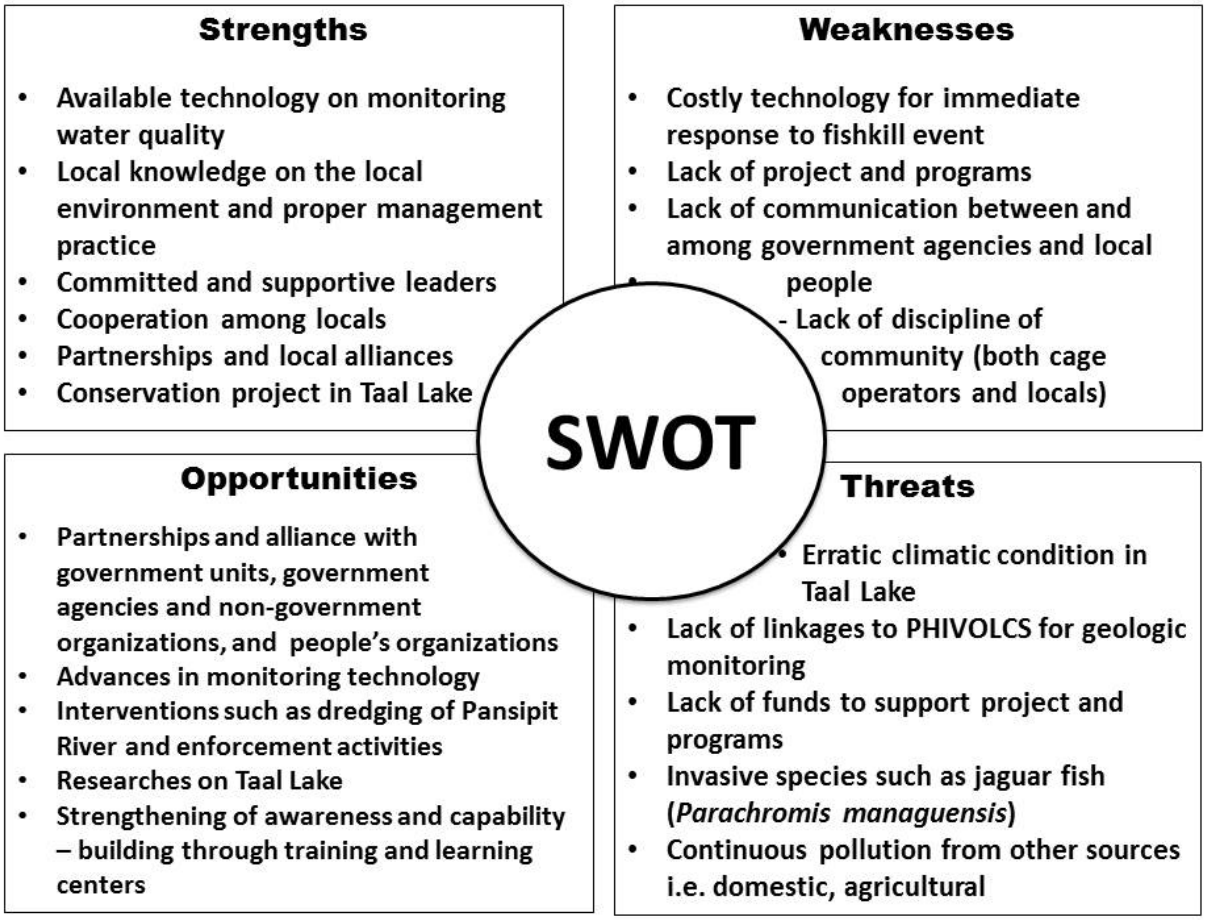

Figure 9. Internal and external factors governing the environmental status of Taal Lake and the adjacent lakeshore municipalities.

and Balayan Bay. Collaboration with academic institutions like UPLB to conduct research and be involved in continued monitoring of water quality are welcome opportunities for the participants.

Erratic climatic conditions in Taal Lake, lack of active linkages with PHIVOLCS for volcanic activities monitoring, lack of funds to support projects and programs, invasive species such as jaguar fish (*Parachromis managuensis*), and continuous pollution coming from agricultural and domestic sources are the threats identified by the participants in the successful management of Taal Lake and its adjacent environment. With the recognition of these threats, the LGUS and local communities may take appropriate actions to address these threats.

CONCLUSION

Taal Lake and its surrounding watershed have undergone land-use and lake use changes from the 1940's until the present. Like the rest of the country, the lush forest cover started to decline in the 1940-50's and slash-and-burn farming system was rampant in the 1960-70's due to increasing food demand by the increasing population brought by in-migration to the uplands. Farming for vegetables, crops, fruits and poultry production was at its peak in the study area in the 1960-1980's. Then, livestock production for swine and cattle were popular in the area in the 1980-2000s. Urbanization and development of various infrastructure started in the mid-1980s until the present. In the lake, open water fishing was the main activity in the lake from 1940-1965 when a variety of fish species were caught in the lake. Aquaculture was introduced initially in Talisay in 1975 and it spread into neighbouring towns of Laurel, Agoncillo and San Nicolas in the 1980s. With the introduction of aquaculture in the lake, the harvest of endemic fish species gradually declined through the years.

Fishkill associated with bad water is a phenomenon that has been occurring, almost annually, in the volcanic Taal Lake since the early years. The magnitude of fish casualty, however, is minor from the 1940s to the 1970s compared with the last three decades. The result of the PRA have revealed the extensive local ecological knowledge of the participants on the environmental and anthropogenic factors contributing to the occurrence of fishkill in Taal Lake. These range from oxygen depletion, volcanic activity, lake overturn, sudden changes in water color, seasonal changes, wind,

hydrothermal vents, poor water quality, improper aquaculture practices, and pollution.

The devastation brought by fishkill events prompted the Provincial Government Unit, the Local Government Units (LGUs) and the local community to formulate solutions based on experiences, knowledge of aquaculture industry, and the physical conditions of the lake. All the PRA participants were united in the opinion that proper aquaculture practices and proper management of domestic, aquaculture and agricultural wastes are primary solutions to address fish kill in Taal Lake. Immediate solutions to impending fishkill include the use of advanced and available technology such as water pumps to increase the oxygen levels inside fish cages and the creation of a response team to relocate fish cages particularly when there are observed changes in the color and when the quality of water approaches critical levels is very important to minimize fish kill. Medium and short-term solutions are the strict implementation of the Unified Rules and Regulations for Fisheries of Taal Lake (2007) and the conservation and management of the Pansipit River.

The participants are aware of their strengths and opportunities that will enable them to successfully implement their proposed solutions. The response of the community to reduce the impact of fishkill is anchored on local knowledge, technology, governance and vigilance.

REFERENCES

Acedera, M.M. 1993. "Assessment of the Environmental Impacts of the Proposed Water Resource Development Project on the Lake Water and Aquaculture Industry of Taal Lake, Batangas Province (Philippines)". University of the Philippines Los Baños.

Anadon, J. D., Gimenez, A., Ballestar, R. and Perez, I. (2009), Evaluation of Local Ecological Knowledge as a Method for Collecting Extensive Data on Animal Abundance. *Conservation Biology*, 23: 617–625. doi: 10.1111/j.1523-1739.2008.01145.x

Araullo, D.B. (2001). Aquaculture practices and their impact on Philippine lakes. In CB Santiago, ML Cuvin-Aralar and ZU Basiao (Eds.). Conservation and Ecological Management of Philippine Lakes in Relation to Fisheries and Aquaculture (pp. 25-28).Southeast Asian Fisheries Development Center, Aquaculture Department, Iloilo, Philippines; Philippine Council for Aquatic and Marine Research and Development, Los Baños, Laguna, Philippines; and Bureau of Fisheries and Aquatic Resources,Quezon City, Philippines.

Aypa, S.M., Ingthamjitr, S., Amarasinghe, U.S., Simon, D. and De Jesus C.. 2008. "Fish Cage Culture in Asian Lakes and Reservoirs: Potentials and Constraints" In: Aquatic Ecosystems and Development: Comparative Asian Perspective. Biology of Inland Water Series. (eds. F. Schiemer, D. Simon, U.S. Amarasinghe, and J. Moreau). Backhuys Publishers: Leiden, The Netherlands: 305-338.

Bandhari, B. (2003). Participatory Rural Appraisal . Institute for Environmental Strategies. Retrieved October 14, 2014, from http://pub.iges.or.jp/contents/eLearning/wat

Berkes, F. (1999). Context of Traditional Ecological Knowledge. In Sacred Ecology: Traditional Ecological Knowledge and Resource Management (p. 8). Taylor & Francis.

Bureau of Agricultural Statistics (BAS). 2003. "Fisheries Statistics of the Philippines, 1997-2002". Bureau of Agricultural Statistics, Dept. of Agricultural. Retrieved 04 May 2013 at http://www.bas.gov.ph.

Chambers, R. 1994. "Participatory Rural Appraisal: Analysis of Experience". *World Development* 22: 1253-1268.

Charnley, S., Fischer, P., & Jones, E. (2008). Traditional and Local Ecological Knowledge About Forest Biodiversity in the Pacific Northwest. Alaska Resources and LibraryInformation Services. Retrieved October 14, 2014, from http://www.arlis.org/docs/vol1/A/233598591.pdf

FAO Corporate Document Repository. (n.d.). Appendixes. Retrieved October 14, 2014, from http://www.fao.org/docrep/w7483e/w7483e

Folke, C. (2004). Traditional Knowledge in social-ecological systems. *Ecology and Society* 9:7

Hallare, A.V., Factor, P.A., Santos, E.K. and H. Hollert. 2009. "Assessing the Impact of Fish Cage Culture on Taal Lake (Philippines) Water and Sediment Quality Using the Zebrafish Embryo Assay". *Philippine Journal of Science* 138: 91-104.

Hargrove, T.B. 1991. The Mysteries of Taal: A Philippine Volcano and Lake, Her Sea Life, and Lost Towns. Bookmark, Manila: 244 pp.

Helfrich L.A, & Smith, S.A., (2000). Fish Kills:Their Causes and Prevention. Forestry and wildlife, 420 (252). Virginia Cooperative Extension

Holmlund, C.M. and M. Hammer. 1999. "Ecosystem Services Generated by Fish Populations". *Ecological Economics* 29: 253-268.

Henry P. Huntington 2000. Using Traditional Ecological Knowledge in Science: Methods and Applications. *Ecological Applications* 10:1270–1274. http://dx.doi.org/10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2

Infante, A.D., O. Infante, M.Marquez, W.M. Lewis Jr. and F.H. Weibezahn. 1979. "Conditions Leading to Mass Mortality of Fish and Zooplankton in Lake Valencia Venezuela". *Acta Cient. Venezolana* 30:67-31.

Jacinto, G.S. 2011. "Fish Kill in the Philippines-Déjà Vu". *Science Diliman* 23: 1-3.

La, V.T. and S.J. Cooke. 2011. Advancing the Science and Practice of Fish Kill Investigations. *Reviews in Fisheries Science* 19: 21-33.

Macas, R.F. undated. "An Ecosystem Approach on the Management of Taal Lake for Sustainable Fisheries". Bureau of Fisheries and Aquatic Resources 4A Regional Office, NIA Compound, Diliman, Quezon City.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and M. Troell. 2000. "Effects of Aquaculture on World Fish Supplies". *Nature* 405: 1017-1024.

Ong, P.S., Afuang, L.E. and R.G. Rosell-Ambal. 2002. Philippine Biodiversity Conservation Priorities: A Second Iteration of the National Biodiversity Strategy and Action Plan. University of the Philippines Center for Integrative and Development Studies, Quezon City.

Palma A.L., E. C. Mercene, M. R. Goss (2005) In Lasco, R.D., M.V.O. Espaldon and M.A. Tapia. Ecosystems and People. The Philippine Millenium Ecosystem Assessment. Sub-Global Assessment. College of Forestry and Natural Resources. University of the Philippines Los Banos, College, Laguna, Philippines. 233 pp. P. 118-119.

Papa, R.D.S. and M. Mamaril, Jr. 2011. "History of the Biodiversity and Limno-ecological Studies on Lake Taal with Notes on the Current State of Philippine Limnology". *Philippine Science Letters* 4: 1-9.

Papa, R.D.S. and M.T. Zafaralla. 2011. "The Composition, Diversity, and Community Dynamics of Limnetic Zooplankton in a Tropical Caldera Lake (Lake Taal, Philippines)". *The Raffles Bulletin of Zoology* 59: 1-7.

Perez, T., Enriquez, E.E., Guerrero III, R.D., Simon, D. and F. Schiemer. 2008. "Catchment Characteristics, Hydrology, Limnology, and Socio-Economic Features of Lake Taal, Philippines" In: Aquatic Ecosystems and Development: Comparative Asian Perspective. Biology of Inland Water Series. (eds. F. Schiemer, D. Simon, U.S. Amarasinghe, and J. Moreau. Backhuys Publishers: Leiden, The Netherlands: 63-80.

Pilgrim, S. (2006). A Cross Cultural Study into Local Ecological Knowledge.Operation Wallacea. Retrieved October 14, 2014, from http://opwall.com/wp-content/uploads/FINAL-thesis_Pilgrim.pdf

Ramos, E.G. 2002. "Origin and Geologic Features of Taal Lake, Philippines". *Aquatic Ecosystem Health and Management* 5: 155-162.

Rhode Island Department of Environmental Management (2003), The Greenwich Bay Fish Kill- August 2003 Causes, Impacts and Responses. Rhode Island Department of Environmental Management.

Rosana M. R., E. V. Agasen, L. S. Villanueva, J. P. Clemente Jr., N. S. Kawit and J. T. de la Vega. (2006). Status and Economic Impact of Parachromis Maraguensis in Taal Lake, Philippines. *Journal of Environmental Science and Management* 9(2):1-19.

Silvano, R., & Begossi, A. (2012). Fishermen's local ecological knowledge on Southeastern Brazilian coastal fishes: contributions to research, conservation, and management. Scientific Library Online. Retrieved October 14, 2014, from http://www.scielo.br/pdf/ni/v10n1/13.pdf

US Legal (2014). Genetic Pollution Law and Legal Definition. Retrieved from http://definitions.uslegal.com/g/genetic-pollution/ last October 15, 2014. USLegal,Inc.

Villadolid, D.V. 1932. "Methods and Gears Used in Lake Taal and the Pansipit River. Philippine" Agriculturist 20: 571-579.

Vista, A., Norris, P., Lupi, F. and Bernsten R.. 2006. "Nutrient Loading and Efficiency of Tilapia Cage Culture in Taal Lake, Philippines". *The Philippine Agricultural Scientist* 89: 48-57.

Yambot, A.V. 2000. "Problems and Issues of Nile Tilapia Cage Farming in Taal Lake, Philippines" In: Proceedings on Cage Aquaculture in Asia. (eds. I.C. Liao and C.K. Lin). Manila, Philippines.

Zlotnicki, J., Sasai, Y., Toutain, J.P., Villacorte, E.U., Bernard, A., Sabit, J.P., Gordon, J.M., Corpuz, E.G., Harada, M., Punongbayan, J.T., Hase, H. and T. Nagao. 2006. "Combined Electromagnetic, Geochemical, and Thermal Surveys of Taal Volcano (Philippines) during the Period 2005-2006". *Bulletin of Volcanology* 71: 29-47.

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