A Strategy for Fisheries Resources Management in Southeast Asia: A Case Study of an Inland Fishery around Tonle Sap Lake in Cambodia

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Abstract
Various researches are usually required for fisheries resources management including stock structure identification of some fisheries target species using genetic methods, stock assessment based on existing statistical data, and impact assessments of the transition of fisheries management on fishers' livelihoods through social studies. However, to conduct all this research is quite difficult due to several constraints in developing countries. Therefore, establishment of a reseach strategy for fisheries management in developing countries based on the minimum requirements is quite important. One series of research focused on clarification of minimum requirement was conducted on inland fisheries in Cambodia. Genetic studies can be used for stock identification, and existing statistical analysis based on stationary fishing gear data, demonstrated the ability to understand stock trends using indicators. Social studies emphasized the importance of the participation of fisheries communities and traders in stock management. Our results demonstrated a model for the research of fisheries management in developing countries as follows: a fisheries community can be initiated and sustained through community-based stationary fishing gear operations with licenses from the government, and scientists can reveal the distribution of fish stock as management targets; consequently, governments can better understand fish stock status based on fisheries data from community fishery groups in a particular area and set applicable regulation for fisheries activities. In conclusion, the collaboration of communities of fishery groups, governments, and scientists is necessary for natural resource management for sustainable use in countries in which the livelihoods of people are deeply embedded in ecosystem services.

Received on May 3, 2014
Accepted on January 5, 2015
Online published on March 31, 2017

Keywords
- Cambodia
- Tonle Sap Lake
- fishery management
- community based activity
- stock assessment
- genetic population structure
- future Earth

1. Introduction

Insufficient data collection systems for conducting statistical analyses on fisheries and low credibility of statistical data due to financial deficits and human resources shortage are recognized as substantial issues that need to be addressed in order to improve fisheries resources management in developing countries, including Cambodia (Lieng *et al*. 1995). Because there is high biodiversity and diversity in fishing methods and fishing gear in tropical and sub-tropical zones, collection of enough statistical data for stock assessment of several target species is difficult compared with temperate zones. Additionally, various stakeholders in fishery resources make it difficult to evaluate the impacts of fisheries on natural resources and peoples' livelihoods. Therefore, it has been suggested that the resource management based on a single benchmark; for example, the maximum sustainable yield (MSY) approach is not applicable or suitable for fisheries man-

doi:10.5047/absm.2017.01002.0023

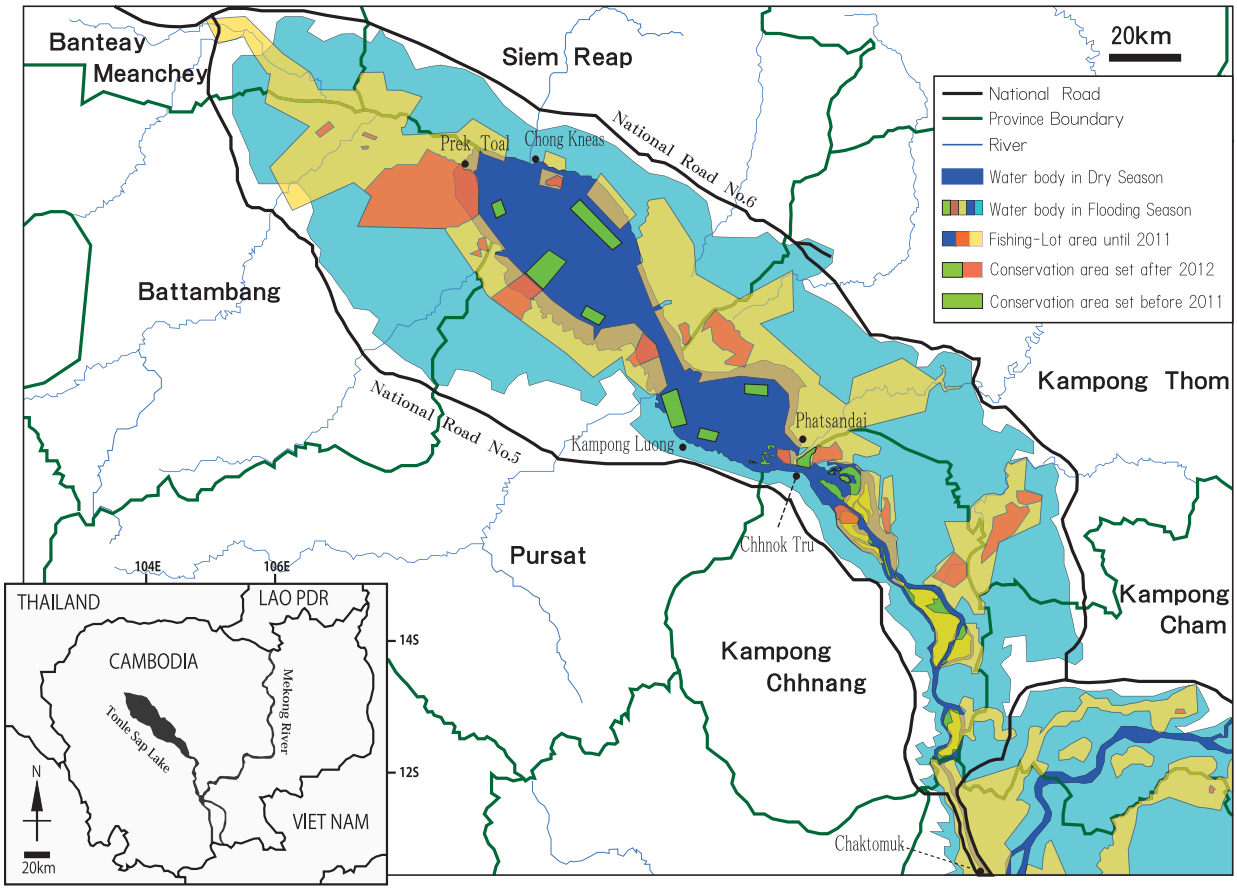

Fig. 1. Map of Tonle Sap Lake with "fishing-lots" until 2011 and conservation zones based on a map made by the FiA in 2013.

agement in developing countries in tropical and subtropical zones (Lieng *et al.* 1995; Welcomme 1999, 2001; van Zalinge 2002; Ishikawa and Arimoto 2008).

Indigenous and/or traditional methods, including utilization of local ecological knowledge, have been treated as important tools for management of natural resources pooled in commons in developing countries (e.g., Ostrom 1990, 1992; Murai 1998). However, these approaches, including the indigenous methods, usually lack robust scientific evidence of effective resource sustainability, and they may not solve conflicts and/or avoid abuse by many kinds of stakeholders using the same natural resources, especially in cases where the commercial activities do not coincide with economic profitability. In addition, global economic linkages have changed the decision making priorities for natural resource management in developing countries from economic efficiency to sustainability, and each government is expected to show scientific evidence of sustainable utilization of natural resources, e.g., the Millennium Ecosystem Assessment Program under the United Nations. This change encourages governments to collaborate with local people in developing countries, because the government cannot collect in-depth data regarding natural resources without collaboration.

Fig. 2. Photo of an ancient fishery carving on a wall in Angkol Tom.

However, the local people cannot collect enough scientific evidence of natural resources sustainability by themselves if they live in acute poverty.

Perception of the importance of natural resources by local people is a basic necessity for resource management in developing countries. It is important to elabo-

doi:10.5047/absm.2017.01002.0023

Table 1. Chronological table of fisheries management in Cambodia after 1863. Authors compiled based on Mouhot (1939), Thay (2002a, b), Sverdrup-Jensen (2002), Amakawa (2004), Takahashi *et al*. (2005), Hori *et al*. (2006), Zhou (2007), Ishikawa *et al*. (2008) and Hun Sen (2012).

Year	Domestic affairs
Until 15th century	The king of Angkor could issue fishing concession to investors and traders, the fishing concession could be subleased to fishers.
1863	*Cambodia became France's protectorate*
1872	Begin commercial fisheries in Cambodia
1908	Fishing law and regulations were published by France
1920	Fishing period was settled
1929	Fishing-Lot systems was devised by a French expert
1940	Fishing-Lot system was adopted
1953	*Independence from France*
1956	First fishing law was adopted
1970–1975	Many fishing lots were occupied by rebel armies of Vietnam War
1975–1979	The Pol Pot Regime. Commercial fishing was abandoned, and fishing activities by local authorities were carried out.
1979–1982	Occupied by Vietnamese troops. No commercial fishing and no fishing regulation. Vietnamese fishermen immigrated into Cambodia.
1982–1989	Commercial fisheries were conducted by the solidarity groups named Krom Samaki.
1989	Fishing law was modified. Fishing areas were privatized and commercial fisheries were conducted by license owners (so called Lot owner).
1993	*National election was taking place and new Cambodian government was established*
1998	Second fishing law was adopted (Three fishing gear categories figured out)
1999	Many conflicts between Fishing-Lot owners and local fishermen were reported
2000	Reform of the fishing management system. 56% of Fishing-Lot areas were released from lot owners to local fishing communities
2001	Community Fisheries Development Office (CFDO) was established (365 Fishery communities were formed)
2011 May	Prime Minister ordered removal of Stationary fishing gears in Tonle Sap Lake
2011 July	Directors of five provincial fisheries offices around Tonle Sap Lake were resigned by Prime Minister
2011 August	Prime Minister decided to tentative close 35 Fishing-Lots in Tonle Sap Lake for two years. 647,406 ha of conservation area was established in flooding forest around Tonle Sap Lake
2011 December	Prime Minister decided extension of Fishing-Lot closure until 2014.
2012 February	Prime Minister decided permanent closure of Fishing-Lot.
2012 March	Fishing gear category was reformed, and large and middle scale fishing gears were outlawed (many small scale fishing gears became middle scale fishing gears in the new category)

rate not only on the economic aspects, but also on the security of the local peoples' livelihoods. At the same time, compilation of available data and additional scientific research to collect essential information for resource assessment are required. Considering the link between human affairs and natural resources, rational and reasonable management measures should be developed in rural areas where peoples' lives are deeply embedded in natural resources utilization (Jentoft 2006).

In this paper, we discuss an implementation strategy for fisheries mangement in developing countries based on historical and current situations of Cambodian inland fisheries.

2. Transition of inland fisheries management in Cambodia

Cambodia has abundant fish and rich water resources, including the Mekong River and Tonle Sap Lake from the Angkor era (e.g., Zhou Daguan 1297; Mouhot 1864) (**Figs. 1, 2**). These fisheries resources, especially inland fisheries resources, have an important role in the livelihood of rural people as protein sources. Many carvings of fish and fishermen on the walls of the ancient Angkor temples show a deep relationship between the people and the fish (Ishikawa *et al*. 2005a, 2008) (**Fig. 2**). Because of the abundant fish resources, the Cambodian government and policy makers have historically had little concern for fisheries resources management, except for governing fishing opportunities for tax revenue by selling fishing rights (Degen and Nao 1998; van Zalinge *et al*. 2000; Tana and Todd 2002).

In 1863, Cambodia became a protectorate of France (**Table 1**). During the French colonial period, commercial fishing in Tonle Spa Lake was conducted by Vietnamese laborers who were employed by the Chinese who bought fishing concessions (Delvert 1983). As a consequence, fish paste and smoked fish were sold in local markets, and salt-dried fish was exported to Singapore and Hong Kong (Mouhot 1864). Taxes from commercial fisheries comprised a major part of the

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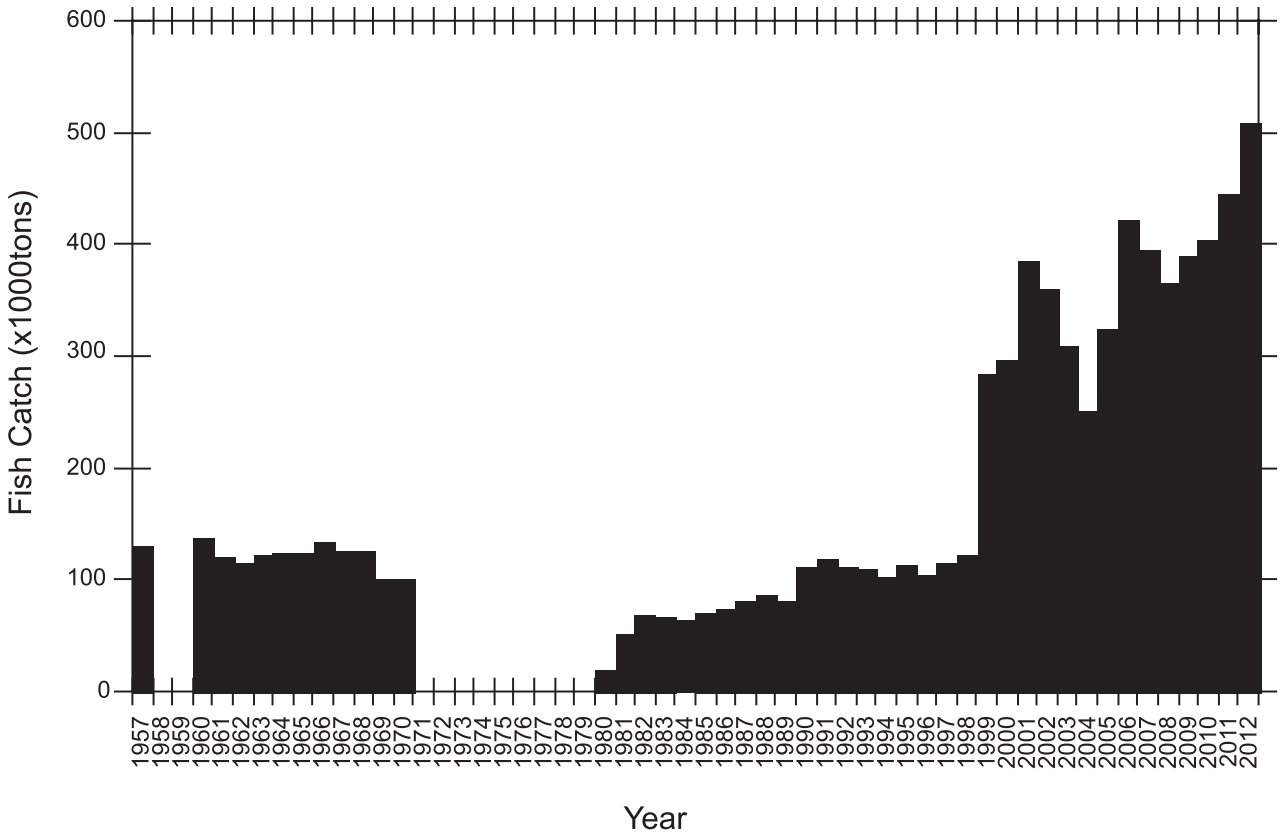

Fig. 3. Fish catch fluctuation in Cambodia from 1940 to 2012. Data from the DoF and FiA. From 1940 to 1998, fish catch by large- and middle-scale fisheries are calculated; from 1999 to 2012, fish catch by small-scale fisheries were included in the calculations.

revenue of Cambodia at that time. In 1908, the oldest fishery law in Cambodia was published following those of the French colonial systems (**Table 1**) (Ishikawa *et al*. 2008). Under the fishery law, large fishing gear systems exclusively operated in licensed areas, so called "fishing-lots," which were invented to facilitate tax collection by French experts in 1929 and implemented in 1940 (Ahmed and Tana 1996; Ahmed *et al*. 1998; Thay 2002a, b; Deap *et al*. 2003; Takahashi *et al*. 2005). After independence from France, the second fishery law was promulgated in 1956 by the Department of Fisheries (DoF). A basic framework of the fishery law and regulations was adopted in Cambodia until 2011, although there were several modifications and/or interruptions in implementation based on changes of the Cambodian government. From 1940 to 1999, commercial fish yields in Tonle Sap Lake were stable except during the period of civil war (Sam *et al*. 2003) (**Fig. 3**). From 1975 to 1979, the Pol Pot regime focused on rice production, and commercial fisheries activities were abandoned (Ishikawa *et al*. 2005a). In 1979, another communist government was established by the support of Vietnam, and numerous Vietnamese fishermen immigrated to Cambodian fishing grounds (Amakawa 2004). From 1982 to 1989, commercial fisheries were controlled by solidarity groups called "Krom Samaki," which were formed by the communist regime to increase yields by collectivization of labor forces (Amakawa 1997). However, almost all fishery businesses failed because of a lack of management and fishing skills (Ly 2003; Rab *et al*. 2005; Sokhem and Sunada 2006). In 1989, Vietnamese troops left Cambodia, and four Cambodian parties and the secretary general of the United Nations agreed to a comprehensive settlement of the Cambodian civil war in 1990. Then, the previous fishery law that was based on "fishing-lot" system was promulgated in 1989 (Tana and Todd 2002), and it remained valid until 2011 (Hori and Ishikawa 2012; Sato 2013).

Based on the previous fishery law in Cambodia, inland fishing activities were divided into three categories: large-, middle-, and small-scale fisheries (DoF 1990; Takahashi *et al*. 2005). Large-scale fisheries are industrial/commercial fisheries that operate in "fishing-lots" in and around Tonle Sap Lake and by bag net in the Mekong and Tonle Sap Rivers (DoF 1990) and licenses are sold at auction every two years. Middle-scale fisheries included commercial fisheries and also required a license to fish in "non-lot" areas (DoF 1990; Takahashi *et al*. 2005). Finally, small-scale fisheries

doi:10.5047/absm.2017.01002.0023

are sometimes called family fishing or rice field fishing and involve subsistence activity without licenses, but the sizes and kinds of fishing gears were regulated by DoF (DoF 1990). The small-scale fishing is conducted in lakes, rivers, and rice fields as well as "fishing-lot" areas during the non-fishing season (DoF 1990; Takahashi *et al*. 2005). Everyone is able to conduct small-scale fishing at any fishing ground. The putative spawning period of many fish species occurs from June to September in the north area of Chaktomuk and from July to October in the south area of Chaktomuk; this spawning period was treated as closing season for the large- and middle-scale fisheries. Fishermen of large- and middle-scale fisheries are supposed to report their fish catch to the government, small-scale fishermen have no obligation to report their catch (DoF 1990; Sensereivorth *et al*. 1999; Takahashi *et al*. 2005; Ishikawa *et al*. 2005a).

In 1998, Ahmed *et al*. reported a large contribution of small-scale fisheries to total fish production and protein intake of Cambodian rural people based on data from the Mekong River Commission (MRC) and DoF of Cambodia (Ahmed *et al*. 1998). In this report, the fish catch from small-scale fisheries was estimated to be approximately the same as the sum of those from large- and middle-scale fisheries. After this estimation, small-scale fisheries have been the focus of fisheries resources management (Dixon *et al*. 2003; Hori *et al*. 2006). Additionally, the inconsistency of the fishing rights among different categories of fisheries caused conflicts between "fishing-lot" owners and local people and also increased the number of small-scale fisheries (Mak 2000). Moreover, illegal fishing activities that include utilization of fishing gear prohibited by fishery law and fishing in "fishing-lots" by non-licenced persons also increased after independence, and these are serious resource management issues for the Cambodian government (e.g., van Zalinge and Nao 1999; Loeng 1999; Dixon *et al*. 2003; Ishikawa *et al*. 2008). However, no licenses and no regulations are required for small-scale fisheries. The Cambodian government has no power to control and collect exact data regarding the small-scale fisheries, so establishment of fishing communities and forming fishermen networks are necessary for future data collection of small-scale fisheries.

In 2000, the Cambodian government introduced a community-based fisheries management (CBFM) (Thay 2002a, b; Levinson 2002). The Community Fisheries Development Office (CFDO, currently called the Community Fishery Development Division) was established in the DoF in 2001 (Thay 2002a, b; Levinson 2002). CFDO promoted building of "community fisheries" (CFis) in cooperation with local villagers (McKenney and Tola 2002). CFis are based on the principle that all Cambodian citizens have the right to form CFis in their own local area on a voluntary basis to take part in the sustainable management, conservation, development, and use of fisheries resources (Hori *et al*. 2011). Villagers who are members of community fisheries can conduct small-scale fishing in the community area with voluntary surveillance of illegal fishing (Thay 2002a, b). We obtained information regarding the reform of management structure of the Tonle Sap fishery from several staff members of the DoF, and the DoF reformed into the Fisheries Administration (FiA) by sub-decree Number 188 on 14 November 2008, signed by Samdec HUN Sen; moreover, we also obtained information on the policy of fisheries management that addresses how CFi development would be maintained. CFis are comprised of villagers who live near fishing areas and have Khmer citizenship. Members of CFis voluntary establish and take initiative to improve their own standard of living by sustainably using and processing fisheries resources to contribute to economic and social development and poverty alleviation (FiA 2008). Around the same time of CBFM introduction, the Cambodian government changed 73 "fishing-lot" areas (56% of total "fishing-lot" area in surface) to open-access fishing grounds in order to decrease fisheries conflicts among the large- and small-scale fishermen who catch fish inside and/or around "fishing-lots" as well as among small-scale fishermen in 1999. This prompted a countermeasure that succeeded in decreasing the conflicts among fishermen, the number of conflicts in 1999 was 1990, but in 2001 it was 493 (Ishikawa *et al*. 2008). On the other hand, governments could not receive fish catch data from fisheries in "fishing-lots," even though the data are very important for stock assessment.

In July 2011, Prime Minister Hun Sen made a surprise announcement regarding the reform of fisheries management, and he ordered closure of 35 "fishing-lots" in Tonle Sap Lake to make a wide open-access fishing area for the people for two years (**Table 1**) (Ratner 2011; Hori and Ishikawa 2012; Sato 2013). On 29 February 2012, the Cambodian Daily, which is a newspaper in Cambodia, revealed that Hun Sen ordered creation of a protected area in/around Tonle Sap Lake of up to 647,460 ha and permanently closed the "fishing-lots." In March 2012, all "fishing-lots," including in the Mekong River area, were closed (**Tables 1, 2**).

Social changes affected the "fishing-lot" closure in Cambodia (Sato 2013). Democratization has been promoted in Cambodia, and elections in local communities were conducted in 2002, 2007, and 2012. The results of these elections influence many aspects of politics in Cambodia. Instead, there are fewer than 100 "fishing-lot" owners, but more than four million people, 26.7% of the total population in Cambodia, engage in diverse fishing activities in and around Tonle Sap Lake (Sato 2013). Considering the proportion of stakeholders of Tonle Sap Lake, the government cannot allow an oligopolistic situation of commercial fish-

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eries through the "fishing-lot" system. Additionally, recent rapid economic development has diminished the fanatical importance of revenue from the "fishing-lot" system (Sato 2013). Hun Sen estimated that the values of fish catch and taxes from fisheries license systems were no more than 2 million US dollars, which represented 0.2% of the national budget, and he discussed the small importance of inland fisheries in the Cambodian economy, because the Cambodian economy has increased 6% in recent years (Sato 2013). Policy change can sometimes have a greater impact on natural resource sustainability than resources utilization, especially in developing countries. Therefore, the link between policy change, which is affected by global changes, and fisheries management from a historical point of view are important for understanding the current state of management and planning future management strategies.

After the United Nations Conference on Environment and Development was held at Rio de Janeiro in 1992, "sustainability" was globally the central position for both conservation and development. In the fisheries sector, sustainability of fisheries and fisheries resources have been treated as the most important issues compared with the increase of fish catch amounts in management and research. In 1995, the Food and Agriculture Organization (FAO) of the United Nations published the "Code of Conduct for Responsible Fisheries" to promote sustainable fisheries through monitoring and regulations of fishing activities (FAO 1995). Moreover, several approaches to regulation of fisheries activities have been proposed from conservation sectors (e.g., Conventions on International Trade in Endangered Species of Wild Fauna and Flora). These international actions also affect policy making in developing countries, and many international activities lead by developed countries require scientific evidence for sustainability; even weakness of fisheries statistics data collection systems and limited biological knowledge of fisheries species are common problems for fisheries resources management in developing countries that have high biodiversity. Additionally, many people in developing countries subsist on fisheries, so fisheries resources management focusing on sustainable use is very important for many peoples' livelihoods. Fisheries science research should address these difficulties to come up with applicable measures for sustainable fishing.

3. Inland fisheries resources and community fisheries in Cambodia

Clarifying the minimum requirements of statistical data for stock assessment and understanding the roles of fisheries in the lives of people with regard to both food security and job opportunities are tasks for fisheries science, because these data are indispensable for creating acceptable management measures for sustainable fisheries. In this regard, we tried to understand stock structure in order to identify appropriate monitoring sites for evaluating stock status. Then, we evaluated stock situations using existing statistical data for each stock. These studies provide a model for studying fisheries in developing countries.

3-1. Fisheries stock structure and data collection sites in Tonle Sap Lake

Each species usually has several reproducing stock units (populations), and each stock size fluctuates accordingly. Therefore, stock assessment and/or stock trend estimation should be conducted on each reproducing population. Additionally, stock structure infrequently changes without extensive environmental changes; e.g., dam constructions that disturb fish migration and spawning behaviors. Thus, if stock structure clarification is conducted, it could be utilized for a long duration of time and could help determine appropriate sites for stock status and trend monitoring.

Population structure examination and stock identification are usually conducted thorough statistical analysis and/or detailed ichthyological study using morphological analyses. This kind of research sometimes requires a large amount of fisheries statistics and numerous ichthyological studies, especially in areas with high biodiversity. In almost all developing countries, taxonomic studies and statistics data are limited because of limited financial support and a large number of target species. Therefore, empirical methods based on statistical data and taxonomic studies are not appropriate for developing countries, even though they are widely used in many developed countries.

One alternative approach is using genetic methods for stock identification. Genetic analysis often has higher diagnostic power for population identification compared with morphological analysis. Genetic populations are not always the same as the unit of fisheries management. A management unit may be part of a genetic population or include several genetic populations. If management units would be decided according to genetic population structures, stock monitoring could be conducted more efficiently.

The genetic population structures of *Thynnichtys thynnoides*, bronze featherback *Notopterus notopterus* and climbing perch, *Anabas testudineus* had been examined in the lower Mekong River Basin including several sites around Tonle Sap Lake (Ishikawa *et al.* 2005b; Takagi *et al.* 2010, 2011). Although no genetic differences among sites were detected in *T. thynnoides* and the bronze featherback, genetic homogeneity among Stung Treng, Lao PDR, Siem Reap and Kampong Chhnang were discovered in the climbing perch (**Fig. 4**). This genetic separation of fish populations between Tonle Sap Lake and Mekong River

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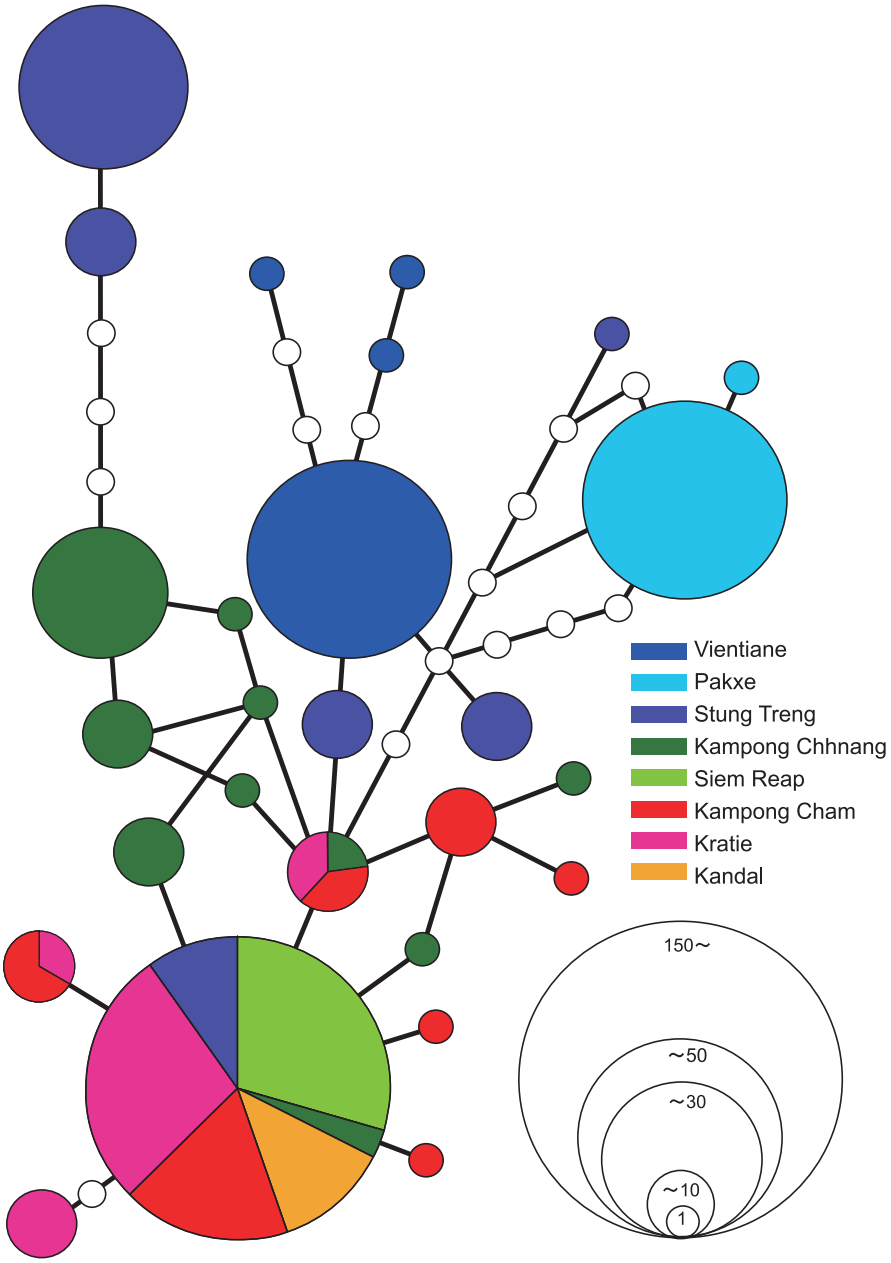

Fig. 4. MtDNA haplotype network of the climbing perch *Anabas testudineus* based on 1047-bp sequences of the ND2 region (after Takagi PA, Ishikawa S, Nao T, Lim Song S, Hort S, Thammavong K, Saphakdy B, Phomsouvanhm A, Nishida M, Kurokura H. Population structure of the climbing perch, *Anabas testudineus*, in the lower Mekong River basin. *Fisheries Management and Ecology*. **18**, 145–153, figure 3, © 2011, with permission of John Wiley & Sons, Inc.). Different haplotypes are represented by different colored circles, with the size of the circle representing the number of samples of each haplotype. Single-base mutations are indicated by the solid line between circles. Hypothesized haplotypes absent in the sample are indicated by white circles.

coincide with the body size differenciations reported by Taki (1975).

Cambodian traditional knowledge divides all fish into "white fish," which compose 60% of total inland fish catches, and "black fish," which compose 40% of total inland fishery yields; the former seem to migrate widely and the latter seem to migrate short distances (Rainboth 1996; Roberts 1997; Sverdrup-Jensen 2002). *Thynnichtys thynnoides* and the bronze featherback are classified as white fish, and the climbing perch is treated as a black fish. Considering the results of genetic studies, single populations of white fish and population separation between northern and southern parts of the lake for black fish was inferred.

According to statistical data analysis using fish catch data from large-scale fishery inside of "fishing-lots"

doi:10.5047/absm.2017.01002.0023

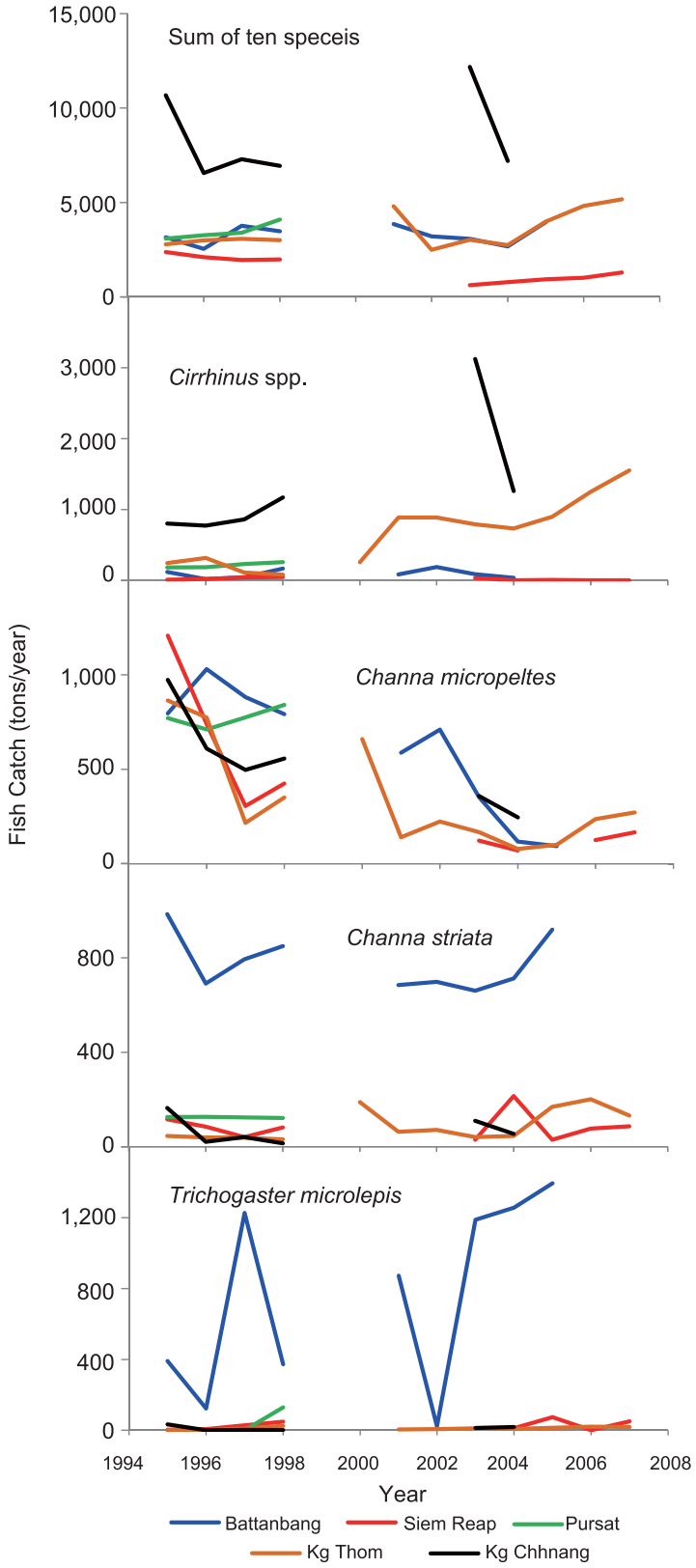

Fig. 5. Interannual fluctuation of catch amount in Battanbang, Kampong Chhmang, Pursat, Siem Reap, and Kampong Thom Provinces. The fluctuation is expressed as the sum of the catch amount of 10 species and the catch amount of *Cirrhinus* spp., *Channa micropeltes*, *Channa striata*, and *Trichogaster microlepis* (after Enomoto K, Ishikawa S, Hori M, Hort S, Lim Song S, Nao T, Kurokura H. Data mining and stock assessment of fisheries resources in Tonle Sap Lake, Cambodia. *Fisheries Science*. **77**, 713–722, 2011, figure 2).

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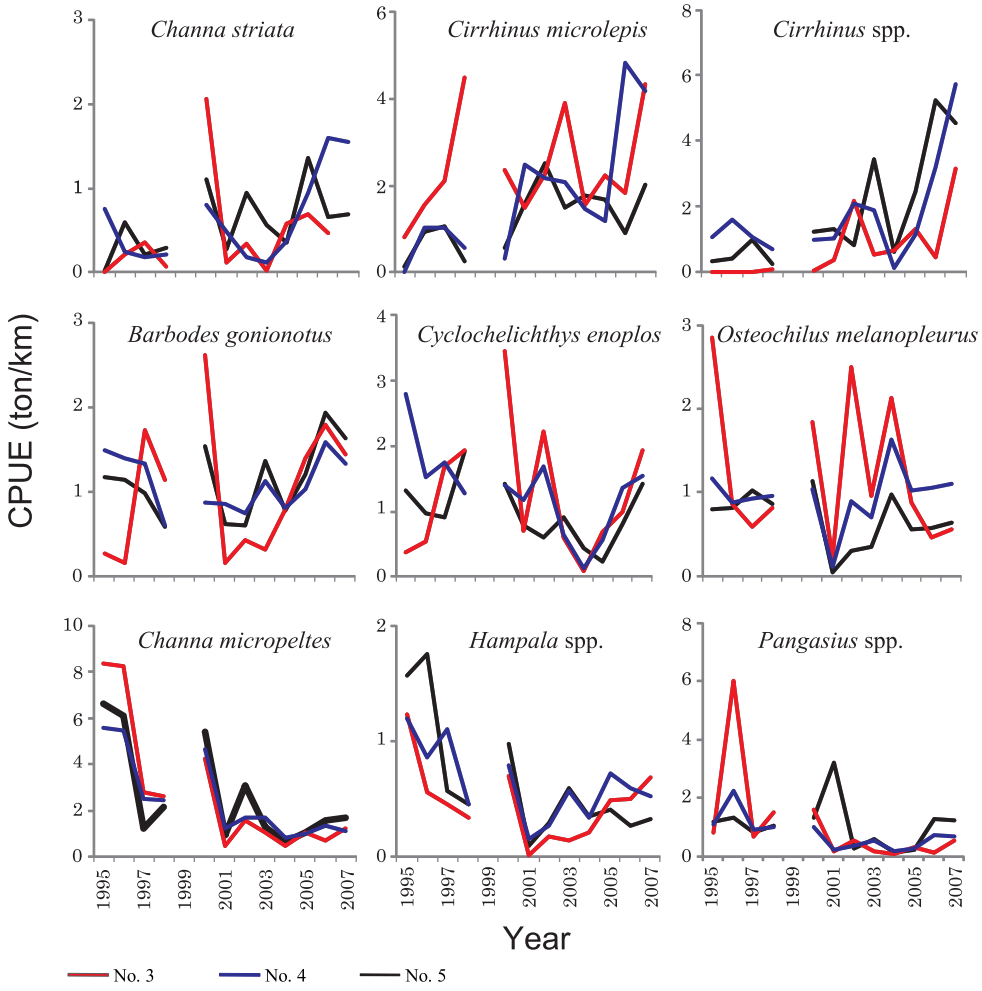

Fig. 6. Results of CPUE calculation of fish species in lake lots, in particular lot number 3, lot number 4, and lot number 5, in Kampong Thom Province (after Enomoto K, Ishikawa S, Hori M, Hort S, Lim Song S, Nao T, Kurokura H. Data mining and stock assessment of fisheries resources in Tonle Sap Lake, Cambodia. *Fisheries Science*. **77**, 713–722, 2011, figure 5).

of five provinces in Tonle Sap Lake (Siem Reap, Kampong Thom, Battanbang, Pursat, and Kampong Chhnang; Enomoto *et al.* 2011), there were no substantial differences of fish catch trends of the 10 major species, including both "white fish" (*Barbodes gonionotus*, *Cirrhinus* spp., *Cyclochelichthys enoplos*, *Hampala* spp., and *Osteochilus melanopleurus*) and "black fish" (*Channa* spp., *Pangasius* spp., and *Trichogaster microlepis*) for 10 years. However, consistently, fish catch amounts of *Channa micropeltes* and *Trichogaster microlepis* in Battanbang were larger than in other provinces, and that of *Cirrhinus* spp. in Kampong Chhnang was larger than in other provinces (**Fig. 5**). Battanbang and Kampong Chhnang have unique geographical and hydrologic features, respectively; Battanbang is located in the northernmost region of Tonle Sap Lake and has a wide flooding forest area; on the other hand, Kampong Chhnang is located in the southernmost part of this lake and connects with Tonle Sap River. Although the geographical differences and features could affect fishing operations and fish catch, the assumption of fish stock separation between the northern and southern parts of Tonle Sap Lake could be considered reasonable.

Considering both the results of genetic and statistical analyses, at least two monitoring sites for stock evaluation might be recommended for reliable data collection in northern and southern parts of the lake. Because major sites with fish are located at Kampong Luong in Pursat, Prek Toal in Battambang, Chong Khneas in Siem Reap and Chhnok Tru in Kampong Chhnang (Chea and McKenney 2003a, b) Chong Khneas and Chhnok Tru could be candidates for high priority monitoring sites for fish resource evaluation.

3-2. Stock assessment in Tonle Sap Lake

After understanding stock structure and establish-

doi:10.5047/absm.2017.01002.0023

ment of appropriate monitoring sites for stock assessment, methodology stock evaluation is the next issue for sustainable fishery management, especially in developing countries with high biodiversity. Low reliability and limited scientific knowledge and statistical data to calculate actual stock sizes in developing countries are sometimes argued to be limitations (Lieng *et al.* 1995; Welcome 1999; Ishikawa and Arimoto 2008). These conditions for stock evaluation make the MSY approach difficult for adoption in developing countries, even though it is widely used in developed countries. Additionally, the high biodiversity and mixed catch of fish species also make the MSY calculation difficult. Recently, reference points including MSY were criticized by Hilborn (2002) and Matsuda and Abrams (2008).

More than 500 species inhabit the Tonle Sap Lake area (Rainboth 1996; Baran 2005), and no less than 149 fish species are caught by more than 200 types of fishing gears that have different fishing capacities (Ian *et al.* 2006). One fishing gear catches various species at the same time using different fishing pressures. If regulation of the fishing gear operation successfully adjusts MSY on a particular species stock, it would not ensure the MSYs of other species. Moreover, if fisheries regulations based on the most serious stock situation are to be performed, it would be too extreme for the fishermen because they cannot live on fishing alone and many local fishermen are not full-time fishermen but part-time fishermen depending on their basic survival needs for small-scale fishing (Hori *et al.* 2006, 2011). Therefore, they are forced to choose between two miserable options; one is to abandon their fishery and change their primary job, and the other is to ignore and violate the regulations to maintain their lives.

Although many reports demonstrated the deterioration of fish stock in Tonle Sap Lake (e.g., van Zalinge and Nao 1999; Loeung 1999; Lamberts 2001; Baran and Myschowoda 2008), a few reports showed decreased fish catch amounts of certain large fishes, e.g., *Catlocarpio siamensis* (Mattson *et al.* 2002), *Pangasianodon gigas* (Pholprasith and Tavarutmaneegul 1997), and *Channa micropeltes* (Enomoto *et al.* 2011) (**Fig. 6**). However, fish catch of these large fish occupied less than 10% of total catch, and the total fish catch amount is still high (van Zalinge and Nao 1999; van Zalinge *et al.* 2000). Enomoto *et al.* (2011) reported fish catch increase of several species, including *Cirrhinus* spp. and *Thunicthys* spp. (**Fig. 6**) in recent years. The deterioration of fishery stock in Tonle Sap Lake has been asserted based on the hypothetical state of exploitation of stock without exact scientific data (van Zalinge and Nao 1999) (**Fig. 7**). According to this hypothesis, because these large fish have low fecundity, catch decrease of large fish seems to be a symptom of total stock deterioration. Therefore, fish stock assessment in Tonle Sap Lake should be reexamined based on reliable data collected from appropriate monitoring sites in order to avoid redundant negative impacts on rural people through extreme regulation of fisheries.

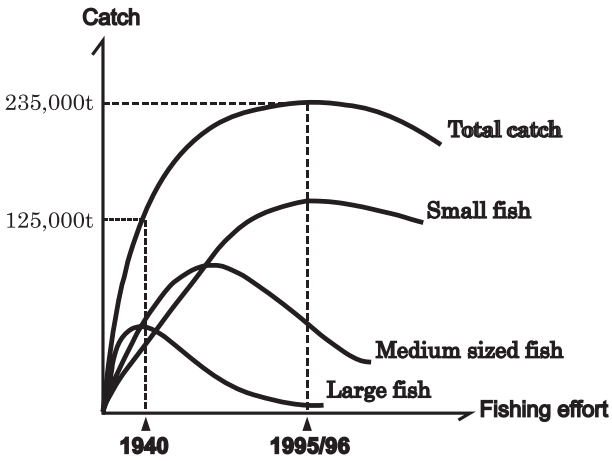

Fig. 7. Fish resource degradation hypothetical model for explaining that the fishing impacts on large fish is higher than those of medium and small fish. This model is often used in many governmental reports for showing deterioration of fish stock without total catch decreasing (modified from van Zalinge and Nao (1999)).

Fishery stock assessment using an indicator could be proposed for developing countries (FAO 2003). Considering the species composition of several fishing locations and the trophic levels of target species, some species could be indicators of fisheries stock. Adaptive management using catch per unit effort (CPUE) of indicator species is preferable in developing countries, including Cambodia. To calculate the CPUE, catch data are sorted by species, and fishing effort data of particular fisheries are required. In Cambodia, CPUE has been calculated for Dai fishery and gill net fishery (MRC 2005). However, in the case of gill net CPUE calculations, numbers of nets were used as a proxy of fishing effort, but net size differences were not considered because of a lack of data. Therefore, for CPUE calculated from data on different types of nets such as "Dai" and/or "Bamboo Fence" is appropriate, because fishing efforts can relatively easy be estimated.

Enomoto *et al.* (2011) showed the possibility of using CPUEs for stock trend estimation in Kampong Thom. They calculated the CPUEs of 10 important species, including both white and black fish (e.g., *Channa* spp., *Pangasius* spp., *Cyclochelichthys* spp., *Cirrhinus* spp.) for 10 years from 1995 to 2006 (excluding 1999), based on the fish catch reports of the large-scale fishery in Kampong Thom (**Fig. 6**). As a result, the CPUEs of *Channa micropeltes* and *Pangasius* spp. which are all "black fish," showed ap-

doi:10.5047/absm.2017.01002.0023

parent stock deterioration. However, the CPUE of *Channa striata*, which is a large fish, was stable, and those of several white fish, including *Cirrhinus* spp. and *Cyclochelichthys* spp., gradually increased for 10 years. Therefore, the results of the CPUE analyses did not indicate stock deterioration for all species.

From the 1940s until 2011, fishery statistics data, including fish catch amount, species composition, and price, were collected through the "fishing-lot" system in Cambodia. After the fishery reform, the "fishing-lot" system was terminated and continual fisheries statistics data could no longer be collected. This means that there are no reliable data for stock assessment, except data from scientific surveys and fishery communities. Therefore, fish catch and conservation data as well as information from the CBFM system will become more important. However, the management and registration of fisheries activities are decided by each CFi under new fishery law (FiA 2008), and the utilization and dependency of each CFi on fishing differ from one another, as each community has different geographic features and livelihood situations. Thus, to keep consistency and comparability of data became difficult. Therefore, minimum requirements for data should be established for CFis for useful data collection.

3-3. CBFM in Tonle Sap Lake

Based on the reform of fisheries policy in 2011, commercial fisheries, including large- and middle-scale fisheries, were abolished. CFis are the only functioning system regarding fishery management in Tonle Sap Lake (**Table 1**). Under the new CFi management policy and through dialogues between CFi members and FiA of the Cambodian government, freshwater bodies were sectionalized into conservation and community fisheries zones based on the consideration of spawning habitat distributions of aquatic organisms and hydrological features of each area. However, in some areas, FiA decided the conservation areas without CFis before the reform. In August 2012, compartmentalization of conservation and community fishing zones was almost completed.

Under the CFi system, establishment of CFis and autonomous regulations of fisheries by CFis are thought to be fundamental (Syrabo *et al.* 2002; Levinson 2002; MRC 2003). Discussion between CFi members and the FiA could contribute to high compliance of local regulations. Sato (2013) reported that almost all small-scale fishermen initially welcomed this "fishing-lot" closure, as they believed to be able to use a wider fishing area. However, villagers who live mainly on fishing, even the CFi members, have a very negative opinion of the reform, and they have large fishing grounds compared to before the reform (Hori and Ishikawa 2012). Because the FiA has started drafting a new fishing law and fishing gear lists in order to identify legal and illegal activities under new management policy, several small-scale fishing gears were tentatively categorized into middle-scale gears, which were listed in the fishery law of Cambodia promulgated in 1998 that cannot be used in Tonle Sap Lake under the new system that started in 2011. The shapes of many middle-scale fishing gears are similar to those of small-scale fishing gears, but the sizes of the middle-scale gears are bigger than those of the small-scale gears. Under the fishery law promulgated in 1998, middle-scale fisheries were categorized as commercial fisheries, and people conducting middle-scale fishing pay a license fee to the government. To date, nobody has explained why several small-scale fishing gears were categorized as middle-scale gears or why middle-scale fishing was terminated under the new system. In some villages, many people conducted middle-scale fishing and the fish catch was their main income source before "fishing-lot" closure. Consequently, they cannot operate their main fisheries activities after the fishing gear regulation reform. This reform had a substantial influence on fishermens' lives as well as their incentives for participating in the CFi system with regard to fishing ground and conservation areas compartmentalization (Hori and Ishikawa 2012). Large community fishing zones cannot make up for the losses of fish catch caused by exclusion of middle-scale fishing gear. Regarding the reform of fisheries policy, "fishing-lot" closure was addressed in newspapers and TV programs, but the change of fishing gear categories was not widely broadcast.

The "fishing-lot" closure did not take open fishing grounds for all CFis. During our field survey in 2013, we learned that the entire "fishing-lot" area of the No. 2 Lot in Battambang transformed into a conservation zone by the government without any explanation to the local community. Additionally, Prek Toal, which is located near the No. 2 Lot in Battambang, did not get additional CFi zones. We also learned of another situation during our field survey in 2013 at Phatsandai in the Kampong Thom province: the CFi of Phatsandai got CFi zones, but these CFi zones are far from their villages, and the conditions of the fishing areas are not appropriate for fisheries. Inside the conservation zone, nobody can fish or hunt any animals. Additionally, members of the CFi were allocated a CFi zone and asked to voluntarily patrol against illegal activities within and around the conservation zones near their CFi zones. In the case of Phatsandai, a few core members of the CFi patrol every two or three days, and they shoulder the petrol fees of boats during their patrol. A core member of the CFi of Phatsandai told us in our interview in 2013 that the cost-sharing system and mechanism among CFi members had not yet been discussed in the CFi, and the cost of patrolling was a big issue for the new fisheries management system.

doi:10.5047/absm.2017.01002.0023

4. Future fisheries management in Cambodia

There are three important points that need to be addressed for future fisheries management in Cambodia: (1) how to collect reliable data for stock assessments after "fishing-lot" closure, (2) how to enhance functions of CFi for sustainable fisheries, and (3) how to tackle non-fisheries impacts on fisheries resources (e.g., climate change and dam construction, which cause habitat loss for aquatic organisms). We propose the following ways to address these issues: (1) utilization of stationary fishing gear by the community, (2) trader involvement, and (3) collaboration with environmental studies.

4-1. Utilization of stationary fishing gear by the community

Detailed fisheries statistics data collection using community-based stationary fishing gear has been conducted in Rayong, Thailand. The Japanese type of set-net, "Otoshi-ami," was introduced in the coastal waters off of Mae Rumpheung beach, Rayong Province, Thailand, in 2003. The Set-net was established by the fishermen community with support from the Southeast Asian Fisheries Development Center (SEAFDEC) and the Eastern Marine Fisheries Research and Development Center (EMDEC) of the Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand, and it has been operated by the fisherman community from the beginning (SEAFDEC 2005, 2008). Additionally, Japanese fishermen of Himi City in Toyama prefecture who are conducting set-net fishing, and several researchers of Tokyo University of Marine Science and Technology gave some technical support to the fishermen community for their fishing operations and post-harvest treatments, including managing fish sales under the grass-root program of the Japan International Cooperation Agency (JICA). Himi City is very famous in Japan because of its long history of set-net fishery. The International Set-Net Fishing Summit was held in Himi City by the Himi City government in 2002. One of the SEAFDEC staff members who participated in this summit conducted a campaign to introduce set-net in front of Mae Rumpheung beach in 2003. The main members of the set-net fishermen community were the participants of this campaign. They live in seven villages along the Mae Rumpheung beach, and they have different jobs, including professional fishermen, farmers, and factory laborers. All fish caught by the set-net are sold by cooperative selling; half of the profits are shared by community members as their salary, and the remaining profits are stored by the community for the management costs of the set-net (Manajit *et al*. 2011; Munprasit *et al*. 2012). After the completion of the JICA project in 2005, set-net operation and maintenance was conducted by the fishermen community.

Fig. 8. Photo of the middle-scale stationary fishing gear called "Lob loc."

The case of the set-net in Rayong, Thailand suggests the possibility that community-based fishery activity can help to create a fishermen community with sustainable management (SEAFDEC 2005, 2008). Additionally, collaborative selling and sharing of profits make it possible to collect detailed fisheries catch data that can be used for stock trends and trophic level analyses (Seak *et al*. 2011, 2012; Manajit *et al*. 2011). The collaborative management of the set-net fishery can improve management capacity of fishermen (SEAFDEC 2005, 2008). A similar approach to the set-net introduction in Thailand could be applicable for other developing countries, including Cambodia.

As determined by interviews with Cambodian fishermen in 2012, many fishermen longed for the middle-scale stationary type fish gear called "Lob loc" (**Fig. 8**). This stationary type fishing gear is prohibited to use under new fishing regulations in Cambodia, because of its size and high fishing capacity. The government might be afraid of increasing the amount of this gear and high pressure on fisheries resources. However, the set-net is also prohibited by law in Thailand. The Thai government approved set-net introduction and operation as a case study for CBFM (SEAFDEC 2005, 2008). This treatment can be applicable to the middle-scale fishing gears in Cambodia, and it would help promote collaboration between the government and local people involved in community-based fisheries management.

Based on statistical data from stationary fishing gear in Cambodia for stock fluctuation, which was used by Enomoto *et al*. (2011), a feedback approach using indicators including CPUE could be an alternative to the MSY approach for fisheries management in developing countries (FAO 1999; Seak 2012). Because the trend analysis and monitoring of fish stock is quite dif-

doi:10.5047/absm.2017.01002.0023

ferent from those conducted in developed countries and because there is substantial uncertainty, there might be negative opinions from conservation sectors. However, trend monitoring of stock status is an alternative method that is applicable in developing countries and can promote collaboration between the government and fishermen with the capacity for building fishermenss' skills in stock assessment and fisheries management, which are quite important for collecting reliable fisheries statistics data. Waiting for the completion of a fisheries statistics data system that is similar to those used in developed countries for collecting enough data for empirical stock assessment is a waste of time in developing countries. An indicator (e.g., CPUE, egg numbers, and body size of spawner) can provide stock status in a timely manner if the indicators were evaluated for a long duration of time. Additionally, an indicator should be easily understood by members of the fishermen community in order to derive high incentive of the community to participate in stock management. In this regard, CPUE and fish size seem to be good candidates for indicators.

For future fisheries management of inland fisheries in Cambodia, there should be clarification of the population structures of major fisheries species using genetic analysis, establishment of data collection site for each population, and collection of fisheries catch data through collaboration between the government and fishing community by the stationary fishing gears, stock trend analysis using indicators, and returning the results to the fishing community for appropriate fish pricing which can be done by the participation of traders into the community. In addition, some of the profits from the stationary fishing gear can be used for the patrolling costs of conservation areas. Mutual trust between the government and fishing community as well as a cost-sharing mechanism for the community is a fundamental need for sustainable CBFM.

4-2. Trading system and community-based fisheries management

Traders can buy the fish at a low price from fishermen who were lent money; this system is common in many Southeast Asian countries (Iwakiri 1979). Because the trader is usually the one who determines the price of the fish, involvement of the traders in fisheries management is quite important. Fishermen in Cambodia do not directly sell their fish catch to consumers and/or processors but to traders who come near the fishing grounds, and the traders lend money to the fishermen (Hori *et al*. 2009). However, in the case of Cambodia, traders usually live in the same village as the fishermen, and they are sometimes members of CFis; as a result, the "patron-client relationship" between traders and fishermen is not very strong (Tana and Todd 2002; Hori *et al*. 2009). A trader cannot buy fish at a lower price than other people, even he has lent money to the fishermen. Since the fish markets are far from fishing villages, transportation costs of each fish will exceed the expected profit from a market price when they collect a small amount of fish. Therefore, traders collect a particular amount of fish in a few days for their business (Hori *et al*. 2009). The traders and fishermen have a mutually dependent relationship; therefore, the traders' participation in the CFi is required for sustainable community-based fisheries resource management in Cambodia (Hori *et al*. 2009; Hori and Ishikawa, 2012). Participation of traders in CFi management facilitates appropriate pricing of fish and the data collection of fish catch.

However, in the case of oligopoly situations in the fish trade by particular traders who live outside of fishermen villages, appropriate pricing mechanisms would not work. These traders, who have strong influence over the price of fish, might need to account for their own income increase. In order to prevent oligopoly or monopoly situations, assessment of traders by the local community and license system of trader will be necessary.

4-3. A strategy for sustainable fisheries in developing countries

It has been said that natural sciences alone cannot provide an adequate basis for the management of natural resources with complex linkage between nature and human activity (Jentoft 2006; Haapasaari *et al*. 2012), and the importance of multi-desciplinary practices for reality-based natural resource management has been discussed (e.g., Belgrano and Fowler, 2008, 2011). Although holistic research for fisheries management is unnecessary and impossible because of currently segmented research fields, identification of appropriate institutions that can conduct stock monitoring and govern resources based on historical, social and scientific studies are required. Additionally, understanding the key factors for active participation of members of the institution for stock monitoring and governance would be indispensable. In the case of Cambodia, CFi is a targeted institution for monitoring and governing fisheries resources in Tonle Sap Lake, because all fishing activities are conducted inside of the CFi zone, and CFis have the right to decide on regulations for fishery activity inside their CFi zone after "fishing-lot" closure. However, CFis do not have a system in place to collect data for stock monitoring. If CFis can operate with middle-scale stationary fishing gear such as "Lob loc" as a collaborative activity of members, they can easily collect reliable data similar to that of the set-net fishery in Thailand. Moreover, the utilization of middle-scale stationary fishing gear could derive high incentives for self governance of fish stock from CFi members, because it could be a main income source

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Table 2. Community fisheries and conservation areas of six provinces around Tonle Sap lake in 2013. Sources were obtained through filed survey by authors from CFDO.

Province	Total area (ha)	Community fisheries area (ha)		Conservation area (ha)	
Siem Reap	22,725	20,690	(91.05%)	2,035	(8.95%)
Banteay Meanchey	6,398	6,149	(96.11%)	249	(3.89%)
Battambang	102,718	50,169	(48.84%)	52,550	(51.16%)
Pursat	24,848	13,898	(55.93%)	10,950	(44.07%)
Kampong Chhnang	45,084	35,125	(77.91%)	9,959	(22.09%)
Kampong Thom	69,353	51,850	(74.76%)	17,503	(25.24%)
Total	271,126	177,881	(65.61%)	93,246	(34.39%)

Table 3. Proposed implementation strategy of fisheries resources in developing country.

Academic fields	Practices
Social science	1. Social survey to identify workable institutions for fishery managements 2. Livelihoods survey to identify keys for active participation of people for fisheries managements 3. Local ecological knowledge survey to identify the target species of stock assessments
Biology	1. Taxonomic study to clarify the target species at scientific level 2. Population genetic study to decide efficient monitoring sites
Statistics	1. Mining of existing data of fishery statistics to identify applicable data collection system 2. CPUE and/or stock trend analyses for valid stock monitoring

for them.

In Cambodia, fisheries statistical data were collected from the large-scale fishing conducted in "fishing-lots," and the statistical data were used for stock assessment until the lot closure in 2011 (van Zalinge and Nao 1999). Then, community-based fisheries resource management by CFi has been sought by FiA; however, the members of CFis do not have high incentive to co-manage with the FiA, because they cannot conduct the middle-scale fishing, which has been a major income source after the lot closure by fishery management reform. To cope with these difficulties, we would like to propose collaborative fishing using middle-scale stationary fishing gear by CFis, following the set-net fishery strategy in Thailand (SEAFDEC 2005, 2008). Pooling and sharing systems of collaborative fishing would facilitate long-term data collection of fish catches with high incentive of CFi members to co-manage the areas.

After collection of reliable data for stock assessment, several target species should be selected for stock assessment with consideration of local ecological knowledge for acceptance of results of assessment by local fishermen. In the case of Cambodia, the target species should be selected from both white and black fish. Results of population studies can be used to help compile CFi statistical data for stock assessments. Additionally, at least one monitoring site should be included for each population, and stock assessment should be conducted based on the trend analysis instead of empirical reference points including MSY. We tried to show the feasibility of this implementation strategy in Cambodia based on several previous studies that were discussed in this paper (**Table 3**), and we hope that the strategy will be adopted in many developing countries.

4-4. Environmental studies and fisheries management

Global climate change affects inland fisheries in Cambodia; in particular, precipitation changes the width of the flooding forest in which many fish spawn and aquatic habitats distributions. Additionally, hydrologic changes by infrastructure construction, including dam building, also affect habitat deterioration of aquatic organisms. Climate and hydrologic changes influence fisheries stocks more than fishing activities (Takagi *et al*. 2005). Consequently, fisheries resource management based on CFis and conservation area creation cannot assure the sustainability of fisheries resources and aquatic biodiversity. Currently, several dams are under construction and planned in Cambodia for energy generation and expansion of irrigation paddy fields. The impacts of these changes on fisheries resources and aquatic biodiversity have not been precisely examined to date.

Because fisheries resources highly fluctuate in nature, adaptive management with timely stock assessments are required for sustainable utilization. Then, stock assessment using indicators based on statistical

doi:10.5047/absm.2017.01002.0023

data collected by the fishermen community can achieve timely evaluation. The importance of participation of several stakeholders in resource management was addressed in the "Future Earth" initiative, which was proposed by the International Council for Science (ICSU). The ICSU emphasized the importance of interdisciplinary collaboration and participation of various kinds of stakeholders to plan and conduct solution-oriented environment research and activities. Our studies on inland fisheries in Cambodia using genetic and statistical analyses as well as social studies for establishment of applicable fisheries resource management measures coincide with the Future Earth approach, although in the Future Earth initiative local fishermen have not been classified as stakeholders. These solution-oriented research approaches and activities in fisheries science should be conducted by many fields.

Acknowledgments

We are grateful to the staff of the Fisheries Administration (FiA) of Cambodia who participated in the field surveys and data collection. We are also especially thankful to Dr. Akira Takagi and Dr. Kazuhiro Enomoto for their help with gathering information. This study was partly supported by JST-CREST, JSPS KAKENHI grant numbers 24510357, 24780189, and 22241058, and the collaborative research project entitled "Coastal area capability enhancement of Southeast Asia" under the Research Institute for Humanity and Nature.

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