International Journal of Biodiversity Science, Ecosystem Services & Management

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tbsm21

A comparison between biodiversity monitoring systems to improve natural resource management in Tonle Sap Biosphere Reserve, Cambodia

Sophat Seak [a] , Dietrich Schmidt-Vogt [b] & Gopal B. Thapa [a]

[a] School of Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand

[b] Centre for Mountain Ecosystem Studies, Kunming Institute of Botany, Chinese Academy of Sciences, Heilongtan, Kunming, 650204, PR China

Available online: 10 Jan 2012

To cite this article: Sophat Seak, Dietrich Schmidt-Vogt & Gopal B. Thapa (2012): A comparison between biodiversity monitoring systems to improve natural resource management in Tonle Sap Biosphere Reserve, Cambodia, International Journal of Biodiversity Science, Ecosystem Services & Management, DOI:10.1080/21513732.2011.649301

To link to this article: http://dx.doi.org/10.1080/21513732.2011.649301

International Journal of Biodiversity Science, Ecosystem Services & Management
i*First*, 2012, 1–15

Taylor & Francis
Taylor & Francis Group

A comparison between biodiversity monitoring systems to improve natural resource management in Tonle Sap Biosphere Reserve, Cambodia

Sophat Seak[a]*, Dietrich Schmidt-Vogt[b] and Gopal B. Thapa[a]

[a]*School of Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand;* [b]*Centre for Mountain Ecosystem Studies, Kunming Institute of Botany, Chinese Academy of Sciences, Heilongtan, Kunming 650204, PR China*

The choice between professional and community-based methods for monitoring biodiversity and biological resources is largely dependent on the availability of resources. Professional methods are more expensive than community-based methods and are often not feasible in developing countries where technical and financial resources are limited. There is, therefore, a need to assess already existing or develop new simple, cost-effective approaches to monitor biodiversity and biological resources in developing countries. This paper examines and compares three systems for monitoring biodiversity and biological resources in Tonle Sap Great Lake of Cambodia: (1) state-managed monitoring, (2) NGO-managed monitoring and (3) community-based monitoring. Data were generated using key informant interviews, focus group discussions and direct observation. The three types of monitoring are assessed with respect to perceived cost, methodological rigour, ease of use, compatibility with existing day-to-day activities of the local stakeholders and efficiency of intervention. Recommendations are made on how to improve each individual type of monitoring as well as the overall quality of monitoring on Tonle Sap Lake.

Keywords: biological resource monitoring; community-based monitoring; biodiversity monitoring; NGO-managed monitoring; state-managed monitoring; Tonle Sap

Introduction

Biodiversity and biological resource monitoring as components of sustainable management of natural resources can be utilized for attaining conservation goals (Margoluis and Salafsky 1998; Nordic Agency for Development and Ecology and Department of Environment and Natural Resources 2001). The main function of monitoring is to generate a regular (time series) supply of data and information on patterns and trends of biodiversity and biological resources as a basis for management responses to ensure that species and habitats remain in a healthy state (Teder et al. 2007). Monitoring is also a means to inform policy-/decision-makers and the society as a whole on the condition of the natural environment (Stork et al. 1996; Vreugdenhil et al. 2003).

Monitoring can be practised in three different forms and by three different agencies: (1) professional monitoring (usually undertaken by experts and scientists) (Alzinga et al. 2001; Kéry and Schmid 2004; Bani et al. 2006; McGeoch et al. 2006; Katzner et al. 2007); (2) monitoring by government rangers or other officials (Gray and Kalpers 2005); and (3) monitoring by local communities on the basis of their local ecological knowledge systems (Danielsen et al. 2000, 2008; Obura et al. 2002; Danielsen F, Burgess ND, et al. 2005; Danielsen F, Jensen AE, et al. 2005; Noss et al. 2005). Danielsen et al. (2008) have further typified these forms into five categories of monitoring on the basis of involvement of local people and professional researchers: (1) externally driven and professionally executed monitoring, (2) externally driven monitoring with local data collectors, (3) collaborative monitoring with external data interpretation, (4) collaborative monitoring with local data interpretation and (5) autonomous local monitoring.

Professional monitoring by scientists is often carried out for only a number of selected species, habitats or environmental variables using sophisticated methods (Alzinga et al. 2001; Bani et al. 2006; Joseph et al. 2006). The techniques and tools employed by professionals to monitor biodiversity and biological resources are, for instance, population and species diversity indices (Shannon Weaver, Simpson and Berger–Parker) (Feinsinger 2001), utilizing complex statistical data analysis which requires a substantial amount of resources and time (Sutherland 1996; Danielsen F, Burgess ND, et al. 2005). Monitoring by scientists is generally perceived to gain more attention from policy- and decision-makers who focus on larger spatial scales (e.g. national and international) and longer time spans, while community-based monitoring tends to inform decisions on local spatial scales and over shorter time spans (Danielsen et al. 2010).

Ranger-based monitoring is usually carried out with technical and financial support from external agencies, particularly NGOs, or academic institutions. The quality of data depends largely on the quality of training, and on the commitment of the rangers. The interventions are likely to be limited to areas where rangers are stationed, while the implementation of interventions must be commissioned

*Corresponding author. Email: sophat.seak@ait.ac.th

ISSN 2151-3732 print/ISSN 2151-3740 online

http://dx.doi.org/10.1080/21513732.2011.649301
http://www.tandfonline.com

by the rangers themselves and/or by their line authorities (Danielsen F, Jensen AE, et al. 2005; Gray and Kalpers 2005).

Community-based monitoring as defined by Danielsen F, Burgess ND, et al. (2005) has been practised in the developing countries around the world. In order to be successful, monitoring methods should be simple and well integrated within the local ecological knowledge base as well as with daily livelihood activities. Community-based monitoring was found to be sustainable over the long term, meaningful in the local context, less costly than professional method and manageable with locally available resources (Steinmetz 2000; Sheil 2001; Uychiaoco et al. 2005; Danielsen et al. 2010). Community-based monitoring methods are discussed by Danielsen F, Burgess ND, et al. (2005), Gaidet et al. (2003), Gaidet-Drapier et al. (2006) and Rijsoort and Jinfeng (2005). The approach is considered to be especially suitable for the developing countries where resources and technical capacity are often inadequate (Yoccoz et al. 2003).

At Tonle Sap Great Lake of Cambodia, owing to the lake's importance for fisheries as well as for conservation (Lamberts 2006), all three types of monitoring are being carried out by different agents: government, NGOs and local communities. These types fall into the categories 1, 2 and 3 according to Danielsen et al. (2008), as outlined above. The focus of monitoring differs among the three types. Monitoring by government officials and community members is focused on biological and fisheries resources, while monitoring by NGOs is focused on biodiversity. The immediate objective of monitoring is to protect the lake's biodiversity and to conserve its biological resources, which are under severe threat from overfishing, destruction of flooded forest for agricultural and settlement purposes, fuelwood collection (Campbell et al. 2006) and invasive alien species (Neou and Lane 2002; Lim et al. 2004). So far there has been no study to document and comparatively assess these three systems with respect to constraints and opportunities, and with a focus on how they can be enhanced.

This paper reviews and investigates biodiversity and biological resource monitoring at Tonle Sap Great Lake (biosphere reserve), Cambodia, by looking at (1) state-managed monitoring, (2) NGO-managed monitoring and (3) community-based monitoring. The primary objective of this paper is to assess the three existing monitoring systems from the perspective of methodology rigour, perceived cost, user-friendliness, compatibility with existing day-to-day activities of the local stakeholders, efficiency of intervention and constraints and opportunities for execution. The paper, moreover, provides the basic framework for an in-depth discussion of locally based monitoring methods (see Seak et al. 2011).

Methods

Study location

This study was carried out on Tonle Sap Great Lake of Cambodia, designated as a UNESCO World Biosphere Reserve in 2000. We selected Boeng Tonle Chhmar (BTC), one of the three core areas of the biosphere reserve (Figure 1), as the study area for the following reasons: (1) the area is rich in biodiversity and home to many endangered and threatened species; (2) livelihoods of local communities are based on biological resources and have an impact on biodiversity; and (3) all three types of monitoring (state-, NGO- and community-based monitoring) are practised in this area.

Administratively, the BTC core area is located in Peam Bang Commune, Stuong District of Kampong Thom Province, covering an area of 14,560 ha (MOE et al. 2002). The lake is characterized by open water and temporarily flooded areas with their associated creek systems that provide an excellent habitat for aquatic fauna. BTC is covered by three different and overlapping management regimes: it is the core area of the Biosphere Reserve; it is a Ramsar site; and it comprises three commercial fishing lots (lots 5, 6 and 7) (Figure 2). With the support of the UNDP-funded Tonle Sap Conservation Project, a ranger post was built in 2006 as a basis for patrolling and for awareness raising on biodiversity conservation and sustainable resource use among the local fishermen.

The core area consists of four registered villages (Peam Bang, Pov Veuy, Daun Sdeung and Balot) with a total permanent population of approximately 2500 persons (494 households). The resident population is heavily dependent on fisheries and other aquatic biological resources in the area. The population may rise up to several thousands during the fishing season (November–May) because of seasonal fishermen who migrate from the neighbouring uplands of Kampong Thom, Pursat and Siem Reap Provinces to this area, which is reportedly one of the most productive fishing sites within the Tonle Sap Lake.

Each village has established its own community fisheries. Community fisheries in Peam Bang, Daun Sdeung and Pov Veuy villages were established and are managed with the assistance of the Fisheries Administration (FiA) since 2001. Community fisheries are currently supported by the Asian Development Bank (ADB)-funded Tonle Sap Sustainable Livelihood Project. The community fishery in Balot village is in fact a community-Protected Area supported by the MOE with the assistance of the Tonle Sap Conservation Project (Figure 2).

Data collection and analysis

Data collection

The information and data required for analysis of the NGO-managed monitoring were collected from both secondary and primary sources, while data on state-managed and community-based monitoring were gathered from the study site. The research was qualitative, and the following tools were employed in a step-by-step process: (1) key informant interviews, (2) focus group discussions and (3) direct observation.

Key informant interviews were carried out during August and September 2008 with 69 interviewees selected

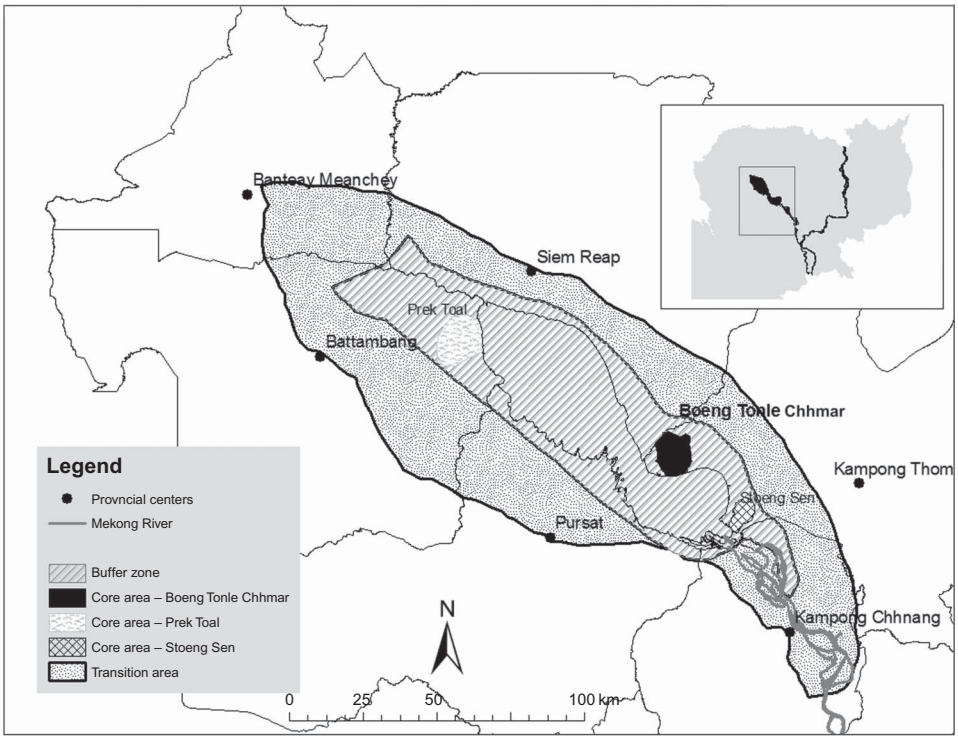

Figure 1. Map of Tonle Sap Biosphere Reserve, Cambodia, including core areas. The reserve was technically and legally divided into three zones: transitional zone, buffer zone and core areas. BTC core area is marked in black. The GIS data were made available for public use by MOE.
Notes: BTC, Boeng Tonle Chhmar; MOE, Ministry of Environment.

through purposive sampling, as being representative of the dominant stakeholders in the study area, in order to explore as many monitoring methods and interventions as possible. The selection of key informants was based on whether they are involved in monitoring and conservation activities of biodiversity. The interviewees, spanning both sexes and a range of age groups, were selected from six stakeholder groups:

(1) Head and vice head of each of the four villages, with knowledge of biodiversity status, legal framework and administrative arrangement;
(2) Active members of community fisheries/protected area, including heads of community fisheries/protected area (five members each from Peam Bang, Daun Sdeung and Balot villages, and seven from Pov Veuy village as the largest village in the area);
(3) Elderly fishermen (five each from Peam Bang, Daun Sdeung and Balot villages, and seven from Pov Veuy village) are not active members of either community fisheries or protected area, but have a tremendous pool of knowledge on traditional monitoring methods and interventions. Members are different from those in group 2;
(4) Ten rangers including two ranger managers of MOE who are working in the BTC core area;
(5) Four fisheries officers who are working in the core area and three fisheries managers of FiA; and
(6) Three NGO staff from the Wildlife Conservation Society (WCS, an American-based international NGO). WCS is the only NGO that has worked closely with MOE rangers on monitoring biodiversity and conservation activities in the Tonle Sap Biosphere Reserve.

Key informant interviews were used to gather data on existing monitoring methods and to identify suitable criteria for a comparative assessment of types of intervention, perceived cost of each system, sustainability of method implementation, socio-economic status of each village and constraints on implementing monitoring. We consulted with ranger managers of MOE (who are government counterparts of the WCS), with WCS project officers, with fisheries managers of FiA and with heads of communities (fisheries and protected area) to understand the costs associated with each monitoring system. Due to internal financial regulation and a dearth of distinctive records of expenditure for each method, we were unable to estimate the exact cost. Cost for the NGO-managed system was estimated as total average cost per year since monitoring activities started in 2006, which, however, cannot be more than a tentative assessment.

Focus group discussions for a comparative assessment of the three monitoring systems (see 'Criteria considered for comparative analysis of the monitoring systems' for more detail) were carried out in November 2008 after data from key informants had been analysed to categorize

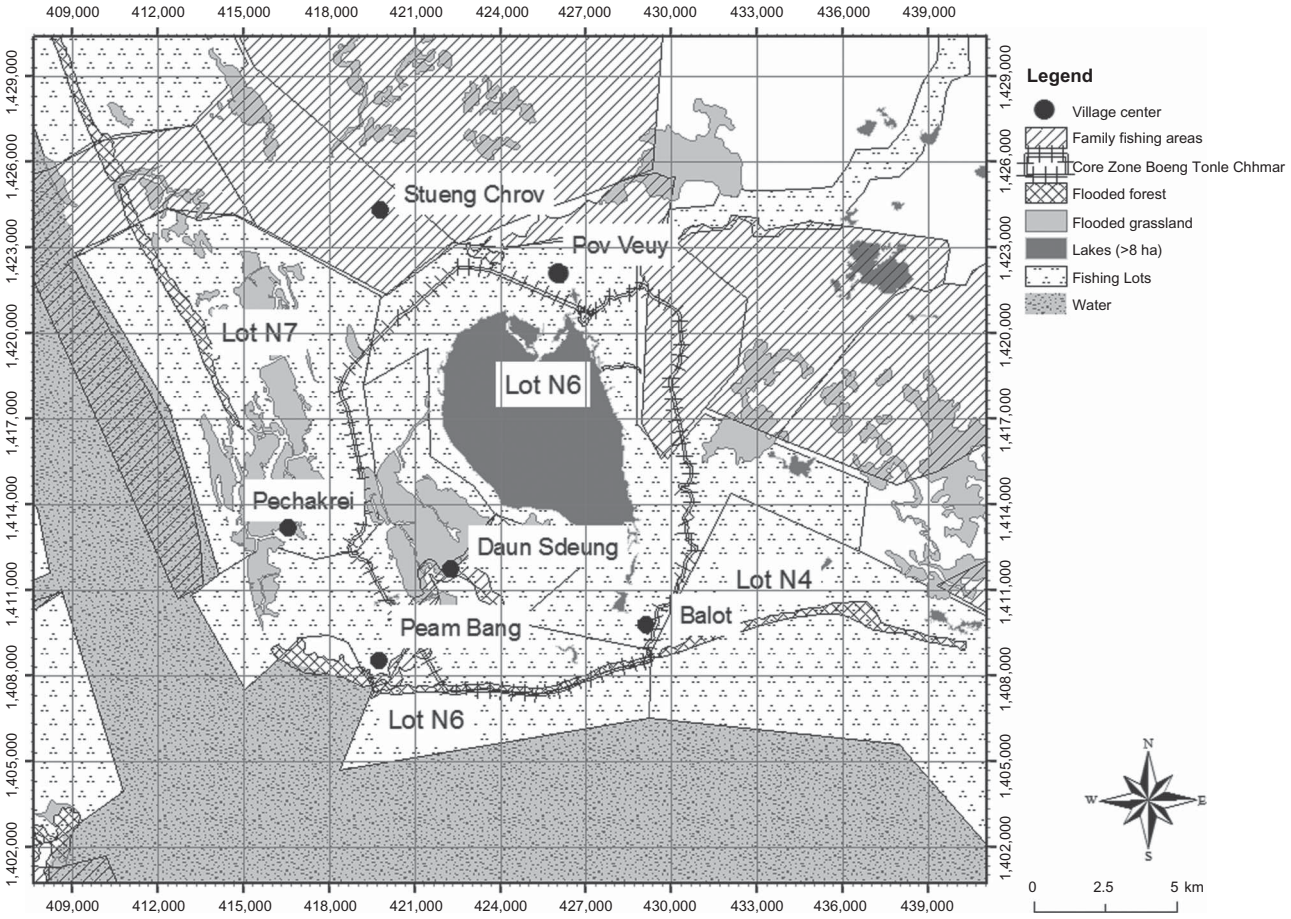

Figure 2. BTC core area in Tonle Sap Biosphere Reserve, Cambodia: Land-use and management zones and villages. BTC covers three commercial fishing lots, a core area, community fisheries and community protected area which is located in Balot village. We acknowledge the GIS data from MOE and FiA.
Notes: BTC, Boeng Tonle Chhmar; MOE, Ministry of Environment; FiA, Fisheries Administration.

the monitoring methods and interventions and to estimate the perceived costs. We organized separate focus group discussions with four groups of stakeholders: (1) community fisheries/protected area were combined with village heads and elderly fishermen as these groups represent the local community level (four focus group discussions were undertaken in three community fisheries, and one in a community protected area); (2) fisheries officers; (3) rangers; and (4) NGO staff. The members of the community fisheries/protected area stakeholder group were asked to assess community-based monitoring methods; fisheries officers, rangers and NGO staff were asked to assess state- and NGO-managed methods as well as community-based methods (Table 1). The purpose was to avoid bias and to capture the perceptions of all stakeholders with regard to each type of monitoring method. Focus groups consisted of 10–15 persons from each community (fisheries and protected area), 10 rangers, and 4 fisheries officers. With respect to NGO-managed monitoring, we emailed questions and approached a project officer and two supporting staffs of WCS directly in their office in the capital, as well as three senior WCS rangers in the field for a comparative analysis of the methods practised by their field staff. At each focus group discussion meeting, the participants were informed clearly of the objective and criteria of assessment (Table 2) of each method to ensure that they fully understood how to grade each method.

Direct observation was employed to verify data gathered; detect hidden data on biodiversity, habitat, use and fishing gear; and obtain information relevant for the comparative assessment of methodology rigour, perceived cost, ease of use, compatibility and suppression (intervention) that respondents might not have wanted to reveal during interviews and focus group discussions. For this purpose, we made three separate visits in September and November 2008 to spend time with villagers from each community, as well as with rangers and fisheries officers, and to participate in fishing, hunting and patrolling activities.

Criteria considered for comparative analysis of the monitoring systems

The main purpose of the analysis was to assess each of the three monitoring systems by evaluating them on the basis of the following criteria: (1) methodology rigour,

Table 1. Matrix for selecting stakeholder groups for assessment of three monitoring systems in Tonle Sap Great Lake, Cambodia.

Stakeholders	Monitoring systems			Explanation
	State	NGO	Community	
Community			x	Community members were asked to assess only community-based methods, because they had no knowledge of state- and NGO-managed monitoring methods. Trained by rangers and fisheries officers.
Fisheries officers	x	x	x	Fisheries officers were more experienced in monitoring and working in BTC than rangers. Officers also received additional training on NGO methods with rangers, but did not actually follow those methods, because their monitoring tasks are for law enforcement purposes.
Rangers	x	x	x	Rangers were trained by NGO staff and were then allowed to conduct monitoring by themselves. Rangers helped train community protected area members to undertake monitoring as well. Rangers are basically aware of state- and NGO-managed and community-based monitoring systems.
NGO staff	x	x	x	NGO staff are professional experts who have comprehensive skills and knowledge on all three monitoring methods.

Table 2. Explanation of criteria used for the analysis of the three monitoring systems investigated in Tonle Sap Great Lake, Cambodia.

Criteria	Explanation
Methodology rigour	The degree to which a monitoring method is perceived as generating relatively accurate and precise data.
Perceived cost	The perceived cost of implementing a monitoring method.
Ease of use	The degree to which a monitoring method is perceived as being easy to understand and use, given the capacity and skills of the persons carrying out the method.
Compatibility with existing day-to-day activities	The degree to which a monitoring method is perceived as being consistent with existing local practices and day-to-day activities of the local stakeholders being monitored.
Efficiency of intervention	The degree to which a monitoring method is perceived as being able to provide a basis for efficient intervention.

(2) perceived cost, (3) ease of use, (4) compatibility with existing day-to-day activities of the local stakeholders and (5) efficiency of interventions (Table 2). The five criteria were chosen on the basis of preliminary field survey results, key informant interviews and a review of the relevant literature (Danielsen et al. 2000; Hartanto et al. 2002). Stakeholders from the three systems were then consulted on these criteria in order to attain consensus on context and content of each criterion. A weighted score, ranging from 0 meaning no influence to 1 for low, 2 meaning medium and 3 meaning high influence, was assigned to each method through participatory assessment in the course of focus group discussions (Table 1). The groups were asked to score each method against each criterion and to provide reasons for the scores given. The average score for each method was calculated from the scores of each focus group discussion meeting of the different stakeholder groups (community, fisheries officers, rangers and NGO staff). The summary and average scores of each method were then verified through separate consultation with managers from each monitoring system in order to validate as to whether the scores reflect the reality of these practices. Finally, researchers verified the scores on the basis of observations on practices, protocols, results of monitoring reports and documented interventions.

Results

State-managed monitoring of fisheries resources

The primary purpose of state-managed monitoring is to generate data to take appropriate interventions against illegal activities. At present, officials from the FiA of the Ministry of Agriculture, Forestry and Fisheries (MAFF) (formally named ‘fisheries officer’, a government servant who is assigned by FiA to manage and monitor fisheries resources), and of the Nature Protection and Conservation Administration (NPCA) of the MOE (officially named ‘ranger or “park ranger”, a government servant who is assigned by MOE to manage and monitor natural resources’) are responsible for monitoring the biological resources in their designated areas. The FiA is arranged into a vertical hierarchy comprising central level, inspectorate, cantonment, division and Sangkat fisheries (the smallest unit of FiA). The day-to-day monitoring is carried out at the Sangkat fisheries level. The NPCA is structured according to the MOE arrangement and organized into central department, provincial department and district office (MOE 2008). Daily monitoring activities are undertaken by rangers at the provincial level. Monitoring on Tonle Sap Lake follows the standard laws of Fisheries and Protected Area Management.

According to Article 7, Paragraph 4 of the Cambodian Fisheries Law (adopted in 2007), FiA is fully responsible for law enforcement, including inspection, monitoring, surveillance and controlling of all fisheries activities (FiA 2007). According to Article 6 of the Protected Area Management Law (adopted in 2008), NPCA has been given the right to carry out monitoring, surveillance and suppression of illegal activities through its rangers in the protected area domain (MOE 2008). Officials from the above two administrations are designated as judicial police through a joint declaration between MAFF and Ministry of Justice (MOJ) for fisheries officers; and MOE and MOJ for rangers. Monitoring by officials of the two administrations is sometimes conducted in close cooperation with local authorities such as police, military police and the commune heads.

In the BTC core area, five fisheries officers are assigned to perform monitoring. They generally hold a bachelor degree in fisheries management or similar subjects. There is little support in the form of either financial or physical resources, such as boats or other technical equipment, from the central government. Officers raise their funds through fines. Rangers from the Kampong Thom Provincial Environment Department, on the other hand, comprise of 10 persons with educational backgrounds ranging from junior secondary school to university undergraduate degrees in various fields. These rangers are supported by the UNDP- and ADB-funded Tonle Sap Conservation Project and by the Tonle Sap Environmental Management Project since 2007 and are thus better endowed with both equipment and financial support. In the course of the project, rangers have received extensive training in biodiversity conservation, protected area management, monitoring and conflict management in natural resources. Despite the legal requirement for close collaboration, these two institutions rarely cooperate with each other for monitoring and intervention.

The two administrations do not practice standardized monitoring methods (the uniformly designed methods in one package which is used across government agencies for the same purposes). They usually practice conventional monitoring methods (that are adopted from professional approaches according to individual agencies' preference and interest) like patrol, logbook and diary. The most preferred method is patrolling. According to the information by ranger managers of the MOE, and by fisheries officials of the FiA, the cost required for state-managed monitoring in the core area is roughly around $1.07/ha/year.

Monitoring methods

Patrol. This method is employed to detect illegal activities rather than surveying trends and condition of biological resources in the lake. Patrolling is usually carried out in locations where illegal resource exploitation can be expected to occur. Monitoring is carried out by boat in the wet season and by both boat and walking in the dry season (Figure 2). Monitoring is harder in the dry season than in the wet season because of the difficulty of traversing dense thorny shrubland. Each patrol involves two to five guards (fisheries officers or rangers) who record resource uses, disturbances and especially illegal activities. The patrolling equipment consists of motor boat, GPS, notebook and sometimes guns. Rangers receive *a priori* training (1–2 weeks) on patrol from WCS and financial assistance from the Tonle Sap Conservation Project. Training includes designing record sheets, using GPS and MIST (Management Information System), and planning for effective patrols and interventions. Fisheries officers have a strong background in patrolling as they were trained by their central administration since when first deployed to the lake. Rangers patrol twice a month. Fisheries officers, who are more focused on illegal activities, patrol at irregular intervals. After each patrol, the team leader has to summarize the observations and report them to the head of division.

Logbook. The logbook method is used only by fisheries officers and is designed to record trends of annual catch in commercial fishing lots and by medium-scale fishermen. During the open season (fishing season) (October–May), two or three fisheries officers are placed by the FiA into each fishing lot in order to fill in the logbook. The logbook was designed by FiA and has been approved by MAFF. The conventional logbook contains names of fishing lots and operators, location, area, date of record, fish species and volume by day, fishing practice like gear used, labour and time spent to capture a certain amount of fish. The logbook is forwarded to FiA for further analysis. In principle, actions for protection and conservation can be taken if fish stock is declining.

Diary. This method is simple using a notebook to record information and data on biodiversity and its disturbance. It is used by some fisheries officers and rangers to record their daily activities and observed events such as illegal fishing, hunting and forest fires. These records can support data obtained by other methods so that interventions can appropriately be proposed. The diary method is rarely used, because it is not legally required and because fisheries officers and rangers think that this method cannot provide solid evidence of resource use in their locality. Further, the method relies heavily on what is being seen and what is verbally informed.

Efficiency of interventions. Data or information derived from monitoring are used for various purposes. Data gathered during patrols on illegal activities are used for immediate suppression. Data from logbooks are used for stock assessment, management planning and determination of future fees for fishing concessions (Table 3).

NGO-managed monitoring of biodiversity

There are many NGOs involved in conservation of Tonle Sap Lake's biodiversity. However, only WCS has experience in monitoring. Its work started in the Prek Toal

Table 3. Types of monitoring results and management interventions from each monitoring method in Tonle Sap Great Lake, Cambodia.

Monitoring methods	Example of monitoring results	Management interventions
State-managed monitoring		
Patrol	Monitors report illegal exploitation of natural resources, including illegal fishing gear, habitat destruction and offenders	Suppressed illegal activities on the spot, confiscated illegal gear, issued warning letter, educated offenders. If serious illegality, offenders were arrested and complaints were filed to the court. Core area management plans were established (2008–2012) (MOE and MAFF 2007). Conducted awareness raising on importance of biodiversity and existing law and regulation among local community fishers
Logbook	Fisheries officers recorded trend and abundance of fish species	FiA estimated stock of following year, determined future fee and terms of fishing concessions. Government issued new regulations to protect endangered species (Royal decree 0305/149 in 2005 and Sub-decree 123 in 2009), determined catch size and what gear can be used
Diary	Monitors record illegal fishing, hunting and forest fire verbally reported by villagers	Monitors used these data to support monthly reports submitted to central headquarters, and to support future investigation of violators
NGO-managed monitoring		
Count: tree marking and mapping	Trends in size and evolution of bird colony population	NGOs and concerned agencies urged government to designate core area (bird sanctuary), colony demarcation from disturbance, increasing patrol activity to protect bird colony by rangers, awareness raising for fishers and tourists to protect colony
Count: aerial survey	Extent of bird colony (number of occupied trees)	Same as above, and reported to donors for continued funding support of conservation efforts
Catch record for water snake	Trade volume, species composition and change in population size	Increased conservation measures among concerned government agencies. Government issued regulation on ban of exploitation of endangered wild animals (Royal decree 0305/149 in 2005 and Sub-decree 123 in 2009)
Key informant interview for water snake	Demand and supply, and market shifts around the lake	Increased law enforcement effort to protect endangered species
VHF receiver for crocodile	Reported success of reintroduction of crocodile (critically endangered Siamese) into the lake, information on ecology, ranging behaviour and habitat preference	Increased protection measures of released crocodiles among rangers and local fishermen. NGOs established programme support for additional release of crocodile into wild
Square technique for Bengal Florican	Reports on Bengal Florican population, habitat quality and disturbance	Government issued a decree to designate 310 km^2 of grassland surrounding Tonle Sap Great Lake for Bengal Florican conservation (known as the Integrated Farming and Biodiversity Area). NGO staff and rangers carried out awareness raising and education among local communities on conservation and protection
MODIS for forest fire	Area of flooded forest destroyed by fire	Relevant agencies (ranger and fisheries officers) increased activity of protection of habitats of core area, banned farming at the lake (including clearing flooded forest to farmland) and banned use of fire for hunting and fishing by local fishermen.
All above	NGOs used the data to establish programme to support diversifying livelihoods of local communities	Diversified livelihood activities (aquaculture, livestock husbandry, floated home garden projects) funded by NGOs
Community-based monitoring		
Patrol	Community monitors reported natural resource use, including illegal activities	Community suppressed illegal activities on the spot, reported severe cases to fisheries officers for further action, proposed conservation area, planned for next patrol cycle, conducted awareness raising for violators of communities' and government existing regulations on fisheries

(*Continued*)

Table 3. (Continued).

Monitoring methods	Example of monitoring results	Management interventions
Surveillance	Community members reported conservation area encroachment, status of refuge for breeding, spawning and feeding of fish and birds	Encouraged members to protect conservation area from encroachment (by outside fishers)
Village meeting	Community members reported decrease in their daily catch and decline in fish, bird and other biodiversity features in the area; intimidation by commercial fishing concessionaires, outsider encroachment and too small fishing ground	Community leaders raised awareness among fishermen about existing fisheries law, regulations and rule for gear use, fishing season and area closure. Created benefit-sharing rules. Established community fisheries and protected conservation area. Requested to enlarge fishing area for community as current community fishing grounds are not able to support growing number of fishermen

Notes: VHF, very high frequency; MODIS, Moderate Resolution Imaging Spectrometer.

core area (one of three core areas of Tonle Sap Biosphere Reserve after BTC and Stung Sen; Figure 1) in 1994 and is focused on the conservation of large water birds and reptile species of international significance (Clements et al. 2007). Many rangers, recruited from local communities, have previously been fishers and hunters. Activities started with reconnaissance and documentation. Research on biodiversity importance and threats was conducted from 1996 to 2000. Conservation activities including monitoring of globally significant reptile species (Goes 2005) and large water birds (Van Zalinge et al. 2008), finally, started in 2001. The monitoring package was financially supported by the Tonle Sap Conservation Project and included the development of monitoring protocols for selected species (WCS 2007). Through the Tonle Sap Conservation Project, WCS provided technical support for monitoring in the BTC and Stung Sen core areas from the late 2007 onwards. The methods and procedural settings developed in Prek Toal were adapted to the new sites through repeated experiments, test and revision. Rangers were trained to implement the monitoring programme. The cost for conservation and monitoring activities by WCS was estimated to be approximately $3.36/ha/year, including cost for international experts.

Monitoring methods

The monitoring methods were designed by WCS monitoring specialists with separate protocols for specific species. The methods can be applied only after repeated hands-on training and with continued financial support. Below are examples of monitoring methods (Goes 2005; Clements et al. 2007; Gray et al. 2007; WCS 2007).

Large water bird monitoring protocols

Three distinct methods are being used: count, tree marking and mapping and aerial survey. Birds and nests are counted from fixed platforms, usually built in tree tops. Trained rangers use binoculars for counting and recording the number of individuals of species. Tree marking and mapping is employed to calculate the number of visible nesting trees, to obtain independent counts by different observers of these trees and to identify trees that are counted from more than one platform. This method is also used to supplement the count method. At the same time, an aerial survey is conducted by WCS experts with the aim of estimating the overall extent of the colonies based on a count of occupied nests on trees. Literate as well as illiterate rangers received monthly technical training and one or two lessons on general knowledge of biodiversity conservation from 2002 to 2003. Training of rangers included lessons on data collection (use of map, compass, GPS, colony count, weekly summary report, bird survey techniques and tree mapping), as well as lessons on Tonle Sap biodiversity (large water bird colonies and environmental issues), and on legal framework (Cambodia Wildlife Law and Associate Regulations) (WCS 2007).

Monitoring and evaluating trade in water snakes

Catch record and key informant interviews were employed for this purpose. The catch record was obtained from daily catch record sheets of traders at landing sites. It lists the number of individuals of species being sold, their weight (kg) and their price. The catch record was supplemented by key informant interviews to gather additional information on trade in snakes, hunting locations, changes in supply, demand and possible threats. Key informants were traders, fishers, rangers and consumers. These methods are relatively straightforward and require little training of rangers. Training includes filling in datasheets and simple data analysis (enter, process and analyse). However, in order to be able to carry out monitoring of population changes by CPUE (Catch per Unit Effort), rangers were trained in the field for 2–3 days and their progress discussed at monthly sessions.

Monitoring movements of released Siamese crocodiles (Crocodylus siamensis)

Highly sophisticated very high frequency (VHF) receiver devices were used to track the movement of Siamese crocodiles after they had been released into the wild. This device collects information on ecology, habitat and ranging behaviour. Two rangers in Prek Toal have received extensive training over 2 weeks in September 2006 by WCS experts from the University of Florida, FL, USA, in using radio telemetry techniques for the handling of this device. They have in turn trained others in the use of this method.

Monitoring Bengal Florican (Houbaropsis bengalensis) *population and grassland habitat*

This is done using the square survey technique, with squares of normally 1 km^2. Squares are plotted randomly in the monitoring site and rangers are trained to record the call and display of males as an indicator of Florican abundance. The survey is usually conducted in the peak period of Florican display (March–April). Before applying this method, rangers receive extensive training on data collection (use of maps, use of GPS to locate surveyed squares, sampling of survey squares, detecting male calls and filling in datasheet) and bird ecology (habitat and home range). Data analysis is done by WCS experts.

Forest fire monitoring using MODIS

This method requires professional experts and uses satellite images and PC application to detect change of land-use and fire incidence in flooded forests in the Tonle Sap Great Lake region, particularly in core areas. For this purpose, images can be downloaded from the WCS website. This is carried out every year in order to report forest fire incidents and prepare emergency plan to tackle with fire.

Efficiency of intervention

The management interventions that follow up on monitoring are classified as immediate and long-term measures. The immediate measures include crackdown on illegal activities (including confiscating evidence and products, warning and issuance of notices to stop committing illegal activity), awareness raising and informing local community residents about laws. Suppression of illegal activities is carried out only by those rangers who are designated judicial police, not by NGO personnel.

Long-term measures include revision of monitoring methods and replication in other core areas of Tonle Sap Great Lake, development of management plans for the three core areas (MOE and MAFF 2007), strengthening conservation capacity of concerned stakeholders (especially rangers and fisheries officers), demarcation of conservation areas, setting up of local rules and regulations and influencing policymaking on natural resource management at central level. For concrete examples, see Table 3.

Community-based monitoring of fisheries resources

Before 2000, local fishermen in Tonle Sap Great Lake were in conflict with commercial fishermen because of inadequate fishing grounds for local community fishermen. In response to protests by local fishermen, the Royal Government of Cambodia conducted a large-scale fisheries reform in early 2000, releasing 50% of commercial fishing ground for community management. As a result of this, community fisheries were established in BTC in 2001. The function and organization of community fisheries is governed by the Fisheries Law (adopted in 2007) and the Sub-decree of Community Fisheries Management (issued in 2005) (FiA 2008). Each community fishery must produce a statute and regulations outlining specific roles and responsibilities for its members. Monitoring is also spelled out in the statute, and regulations were submitted by the head of community to the line agencies (FiA) for formal approval. Community protected areas were also established in the area. The community protected area's function and organization is identical with community fisheries, except that it is under MOE.

Prior to the establishment in 2001 of community fisheries or community protected areas, local residents were not involved in systematic biodiversity monitoring. Once they were permitted by law to organize community fisheries, monitoring was conducted as part of the requirement of community-based natural resource management as stated in their contract with FiA or NPCA. Similar to state-managed monitoring, local community-based monitoring is performed mainly to control resource utilization, rather than to detect trends of biological diversity. The idea of monitoring originated from fisheries officers or rangers who have assisted villagers in the establishment of community fisheries.

Monitoring procedures in the BTC core area have not yet been formalized. Communities use commonly practised methods such as patrol, surveillance and focus group discussion in community meetings, for which they were trained by fisheries officers and rangers. Training for patrol includes planning of the patrol, identification of patrol route and recording, reporting and suppression of illegal activities. It also includes the observation of bird species and organizing community meetings. The monitors are community members who have a basic knowledge of reading and writing Khmer language for note taking during patrols and meetings. It is not necessary that all monitors should read and write, but at least one or two literate members are required to lead the monitoring team during a patrol. Monitoring is limited to community fishing grounds or conservation areas. Areas outside these domains receive less attention due to overlapping authority of different agencies (for instance, with fisheries officers and rangers).

Monitoring by the four registered communities was initiated with the technical and financial support of the Tonle

Sap Conservation and Tonle Sap Sustainable Livelihood Projects through MOE (for community protected area) and FiA (for community fisheries). Each community has been equipped with motor boats, digital cameras, binoculars and icons (radio receiver/transmitter) for patrol and surveillance purposes. The cost for community-based monitoring was estimated to be $0.12/ha/year.

Monitoring methods

Community-based patrol. Patrols are undertaken on a weekly basis. The major purpose is to check on illegal activities in the designated fishing and conservation grounds. The community members involved in patrolling are volunteers and are rotated at intervals of 3–4 days depending on the number of members available. The patrol is conducted in locations selected because of their significance for important species and for resource use. Patrols are carried out by boat during the wet season, and by walking during the dry season. A patrol consists of three to four persons with experience in biological resources and familiarity with the area. Patrol equipment includes pocket-sized notebook, pen or pencil, binocular and knife. During the patrol, members note down all activities that they think are contrary to the law. They rarely record biological diversity. There is, moreover, no standardized form for recording.

Community-based surveillance. Of the four communities studied, only Balot village was found to carry out surveillance with the support of the Tonle Sap Conservation Project. Surveillance is focused on a 27 ha conservation area, within the community protected area, established as a refuge for breeding, spawning and feeding of a variety of fish, bird, reptile and mammal species. Community members report on outsider encroachment and state of wildlife in the area. Seven members, working voluntarily, rotate on a 3-day interval basis. Community members are not allowed access to this clearly demarcated area for resource exploitation. A platform was built in the conservation area for continual observation and as a shelter for community members on duty. One local police man and three rangers assist the community in surveillance, in case community members encounter armed men.

Community meeting. The community meeting is also known as a focus group discussion and has the main objective to solicit data or information about the general trend or condition of biological resources as well as irregularities occurring in the area, for example, fish poaching, outsider encroachment and other illegal activities. Meetings are held at the community centre on a monthly basis with voluntary participation of 8–12 villagers, especially those who are actively involved in biodiversity conservation efforts. The community leader usually presides over this meeting and one community member takes notes. This method was initiated by rangers and fisheries officers and later transferred to the community heads.

Efficiency of intervention. The data and information generated by patrolling and surveillance are used for suppression of illegal activities, preparation of better monitoring plans, awareness raising and education, planning and demarcation of conservation areas. Information from community meetings is used for conflict resolution, setting up benefit sharing guidelines among community members, better information of what is happening in the community and encouragement of community participation in conservation as well as monitoring (Table 3).

Discussion and comparative analysis of the three monitoring systems

The analysis of the three monitoring systems is carried out according to the criteria shown in Table 4.

Table 4. Comparison of three monitoring systems in Tonle Sap Great Lake, Cambodia.

Monitoring methods	Methodology rigour	Perceived cost	Ease of use	Compatibility	Efficiency of intervention
State-managed monitoring					
Patrol	Medium	High	Medium	High	High
Logbook	Medium	Low	High	High	Medium
Diary	Low	Low	High	High	Low
NGO-managed monitoring					
Count: tree marking and mapping	High	Medium	Medium	High	High
Count: aerial survey	High	High	Low	Low	High
Catch record for water snake	Medium	Medium	Medium	High	Medium
Key informant interview for water snake	Medium	Medium	Medium	High	Medium
VHF receiver for crocodile	High	High	Low	Low	High
Square technique for Bengal Florican	High	Medium	Medium	High	High
MODIS for forest fire	High	High	Low	Low	High
Community-based monitoring					
Patrol	Medium	Medium	Medium	Medium	High
Surveillance	Medium	Low	High	Medium	High
Village meeting	Medium	Low	High	High	Medium

Notes: VHF, very high frequency; MODIS, Moderate Resolution Imaging Spectrometer.

Methodology rigour

The 'patrol' method used for state-managed and community-based monitoring is at a medium level of methodology rigour: there is no standardized record sheet specifically designed for the patrol activity and patrols are sporadic in terms of timing and places visited. Government officials (rangers and fisheries officers) and community people record what they observe, but do not know what to do with the recorded data except for reporting to the central level. Records are often poor because recording parameters (biodiversity feature, type of illegal activities and temporal scale for record) are unclear and there are no guidelines for government officials for systematic maintaining diaries. The logbook record under state-managed monitoring is also at a medium level of methodology rigour because it is based on irregular checking of catch at the request of fishing lot concessionaires, who also may pursue under-reporting in order to pay less tax to the government.

The NGO-managed monitoring methods counting (tree marking–mapping and aerial survey), VHF receiver for crocodile, square technique for Bengal Florican and Moderate Resolution Imaging Spectrometer (MODIS) for forest fires all have a high level of methodology rigour as they are done by hired professional staff assisted by trained local rangers. Catch record and key informant interview for water snakes, however, were graded at medium level as they rely heavily on the willingness of traders and fishers to provide data – traders are often afraid of being taxed or forced by fisheries officers to make other payments if they disclose information about their business.

Surveillance and village-meeting methods, practised under community-based monitoring, were assessed to be of medium level of methodology rigour mainly due to the lack of standardized record forms. Surveillance is primarily designed for strict protection of the conservation area designated for brood stocks and as spawning ground. Village meetings are held on a monthly basis or whenever there is a need for disseminating information from government agencies or NGOs. The information provided during meetings is often not well structured as members recall past events at random and not in a systematic way. However, the quality of information is largely influenced by temporal scale as well, meaning that the shorter time the information is collected after events, the better its quality.

Perceived cost

Patrol in the state-managed system was ranked as costly. The high cost is due to the investment for basic equipment like motor boats as well as operational costs (petrol, food and wages for fisheries officers and rangers), which are employed for monitoring purpose only. The cost for patrols undertaken by local communities was perceived to be at a medium level, because communities provide in-kind contribution to this task, including boats and equipment which have been used for their livelihood activities as well. Costs occur mainly in the form of operational costs for fuel and food that can be shared within the community. On the other hand, time spent by community members on patrol may be graded as high cost as it prevents them from engaging in their daily livelihood activities, especially fishing. The logbook method of the state-managed monitoring system commands a relatively low cost since expenditures for equipment and operation are shared with fishing lot operators. Similarly, cost of the diary method is low as rangers or fisheries officers record their observations during regular work at the guarding post – they only need a notebook and a pen.

Count by aerial survey, VHF receiver for crocodile and MODIS for forest fire under the NGO-managed system are rated to be incurring high cost because of expensive equipment and operations when compared with count by tree marking–mapping for birds, catch record and key informant interview for water snake and square techniques for Bengal Florican which require only medium investment and operational cost.

The perceived cost of surveillance in community-based monitoring is low as only a minimal budget is required to build a shelter for the guard in the conservation area. The community members provide labour on a voluntary basis. Village meetings come at low cost as this is a social event, where people are willing to share the cost for snacks and drinks.

Though information was limited, consultation with managers of each system indicated that cost is \$3.36/ha/year for the NGO-managed system, \$1.07/ha/year for the state-managed system and \$0.12/ha/year for the community-based system. These figures are tentative as detailed cost information was unavailable due to inadequate (state- and NGO-managed systems) or lacking (community-based system) financial records. Cost estimates are largely based on rough estimations of the current market price via consultation with heads of communities.

Ease of use

The patrol method for both state-managed and community-based monitoring systems was ranked to be of medium ease to use, because the method requires proper planning, design of record sheets, measurements, skill in observation and willingness of investigators to walk through dense and thorny scrubland. It was observed that monitors of these two systems currently have an insufficient capacity to execute these methods. Logbooks, on the other hand, are easy to use, since fisheries officers have had years of experience with this method, which is required by law and applied only in commercial fishing lots. Catches are recorded in the logbook during the open fishing season from November to May. The diary method receives a high score (i.e. are easy to use), because anyone is able to keep daily records of visual observations and information provided by others.

Bird count via tree marking–mapping, water snake catch record, key informant interview and Bengal Florican square technique of the NGO-managed system are ranked at medium level because rangers and enumerators need to

be trained by WCS experts. Count by aerial survey, VHF receiver and MODIS for forest fire methods have a low score because in addition to training needs there is a continuous need for backup and coaching support by professional experts.

The surveillance and village meeting methods under the community-based system were assigned a high score for ease of use because surveillance is carried out according to a schedule agreed upon by community members.

Compatibility with existing day-to-day activities

Patrol, logbook and diary methods utilized under the state-managed scheme were graded as highly compatible with existing day-to-day activities, because these methods have been integrated into rangers' and fisheries officers' daily work. This is particularly true for fisheries officers who have been using these methods since the establishment of commercial fishing lots in the 1950s. On the other hand, patrol under community-based initiative was assessed to be of medium compatibility as the method was introduced to communities by rangers and fisheries officers in 2006, which has provided communities with little time to gain experience in their application.

Under the NGO-managed monitoring system, compatibility of bird count by tree marking–mapping and Bengal Florican square technique as well as water snake catch record and key informant interview was ranked high. The first two methods have been specifically designed for use by local staff and rangers since 2002. The high compatibility of water snake catch record and key informant interview is due to the methods being adapted to and based on fishermen's or trader's daily livelihood activities. Square technique for Bengal Florican is considered the best option to measure the relative abundance of this species as any person is able to conduct the method with just some basic training. Count by aerial survey, VHF receiver and MODIS for forest fire have been assigned low rank because they require continuous support both financially and technically from WCS or other related agencies. They are also not compatible with existing activities of rangers and concerned government officials, because these techniques are newly introduced and require substantial training.

Village meeting and surveillance of the community-based system have been assigned high and medium levels of compatibility with existing day-to-day activities of local fishers, respectively. Community people have utilized village meetings before as a time-tested means to organize social events and disseminate information. However, even though surveillance is carried out according to a schedule agreed upon by community members, some find it difficult to align tasks assigned to them with their livelihood activities. It has thus been assigned a medium level of compatibility.

Efficiency of intervention

The efficiency of intervention is the capacity of each method to provide sufficient data and information for sustainable management of biodiversity. There is likely to be a close link between efficiency of intervention and degree of methodology rigour, because it provides a clear compass for intervention action. The degree of intervention efficiency depends also on the specific character of each method and on the determination of government officials as well as of communities.

The efficiency of intervention was rated high for patrolling under both state-managed and community-based monitoring systems as the method is used for law enforcement purposes only, especially for the suppression of illegal fishing and hunting. Other components of biodiversity conservation are not necessarily considered for systematic record under this method. The logbook method is rated at medium scale, as it is considered not good enough for stock assessment, determining tariff for subsequent public biddings (fishing lots are renewed at every 2 years through public auction processes) and identification of species which are endangered, threatened or vulnerable. As the data managed by fisheries officers are not open for public scrutiny or verification, it is a matter of the political will of top FiA officials as to whether the management performance is enforced with information supplied through monitoring. The diary method was rated low because there are no systematic record sheets and because some information has been passed-on second hand from fishermen and colleagues.

The monitoring methods, under the NGO-managed monitoring scheme, count via tree marking–mapping and aerial survey, VHF receiver for crocodile, square technique for Bengal Florican and MODIS for forest fire have all been assigned a high score. Data produced by these methods are conveyed directly to key decision-makers and donors, who are capable of appropriate intervention at the national level for policy change and planning of protected area management, for example, establishment of core areas and bird sanctuary and shift of core area directors (change of directors). Catch record and key informant interview for water snakes were scored at medium level as the efficiency to translate them into action depends on the willingness of traders and fishermen to provide data. Such data are insufficient evidence for immediate crackdown and therefore need to be complemented by other methods, particularly better planning of patrol work.

Surveillance, as mentioned earlier, is used for the sole purpose of guarding the conservation area from outsiders and therefore gains a high score for intervention, because any encroachment can be stopped immediately. Efficiency of intervention by village meetings is assigned medium weight because illegal activities cannot be intercepted right away. However, meetings are still useful for planning patrol cycles and for community awareness raising.

Comparative analysis

Monitoring methods are adapted to the specific goal and mission of each monitoring system. State-managed and community-based monitoring schemes are presently

carried out with the primary purpose of law enforcement, including curbing illegal activities. They are also useful for awareness raising in local communities and for serving the long-term aims of biodiversity conservation, provided that there is strong legal recognition and support of the government and financial support of external agencies. NGO-managed monitoring also serves biodiversity conservation albeit in a selective manner, focusing on the protection of endangered species of global and national conservation significance (Royal Government of Cambodia 2005, 2009). Within these limits, the data generated under the NGO system are capable of providing input for long-term management and strategic planning requirement as long as there is a continuous commitment by NGOs for both technical and financial support.

Each monitoring method is facing its particular challenges and constraints which may hamper implementation. The success of the state-managed monitoring methods of patrol, logbook and diary depends on the capacity and willingness of operators (rangers and fisheries officers) to implement these methods in the face of limited resources and little support by the government. Hence, monitoring is likely to be carried out mainly with the aim of gaining commissions from confiscated fish catch and from fines imposed on illegal activities rather than with the aim of producing quality data. Community-based monitoring is facing problems due to limited local experience in monitoring, lack of integration of local ecological knowledge into the design of monitoring methods, lack of a sense of ownership over resource use and management and lack of financial and institutional support. NGO-managed monitoring is wholly dependent on the availability of funding support and on the continued guidance of local rangers by professional staff. These rangers will find it hard to continue these methods once the project is completed. Many of them have little education and are often hardly capable of implementing advanced methods designed by NGOs.

None of the three systems is monitoring biodiversity on a broad scale: state-managed and community-based systems focus on commercial species, while NGO-managed monitoring focuses on endangered species. This leaves a lot of biodiversity uncovered. Another problem is that the three systems, though implemented in the same area, are not integrated with each other. There is no coordination of activities and no exchange of information between them. This must be considered as an inefficient use of already limited resources.

The results of the comparative assessment of the three methods are likely to be influenced by the bias of the stakeholders involved. The bias may be because the respective groups of stakeholders differ from each other with respect to levels of position, education, skill and experience with monitoring tasks. For instance, NGO staff, fisheries officers and rangers have a better understanding of the evaluated methods than community members, since they have a longer experience with monitoring as well as with conservation efforts. Hence, they might intentionally rate the monitoring methods in favour of the ones they have been practicing. In order to minimize the influence of bias on the results of the assessment, we have designed the data collection techniques as shown in Table 1 and included researcher validation. However, there is no way to entirely avoid bias attaching to the perceptions of the different stakeholder groups selected for this study.

The capability of each method to generate reliable data is largely but not entirely dependent on the quality of protocol and level of training and supervision offered to local communities, rangers and fisheries officers. Level of training can influence the quality of methods in some, but not all cases, because despite good protocols available or excellent training and supervision provided, the successful implementation of methods depends also on the willingness and commitment of monitors, the legal requirements of the government and the financial and technical support from NGOs and donors. The community-based approach may require temporary technical support from rangers, fisheries officers and external researchers before it can fully function on its own (as in category 3 of Danielsen et al. (2008)). The NGO-managed system, on the other hand, can be sustained through its own funding and resources.

Conclusions and recommendations

The analysis and comparison of the three monitoring systems has shown that each one of them has been designed for a specific purpose ranging from monitoring the state of natural resources for their sustainable management to monitoring biodiversity for conservation purposes. Even the systems focusing on biodiversity do so in a selective manner only. Other weaknesses, apart from fragmented coverage of biodiversity, are lack of coordination among the three systems, lack of standardized recording procedures and dependence on external agents for funding and capacity building.

Improvement and continuation of the three monitoring systems could be accomplished through: (1) requiring that each monitoring scheme produces regular reports on trend of biodiversity; (2) sharing data among and between agencies and interested individuals; and (3) provision of appropriate backup support including sufficient training and capacity building on comprehensive monitoring methods for rangers and fisheries officers and integration of local ecological knowledge for community-based system. It is also suggested that monitoring and reporting, carried out by the different agencies, be better coordinated.

State-managed monitoring could be improved by modifying the conventional patrol method so as to gather data not only on illegal activities and human disturbance, but also on the trends of biological diversity of various targeted species at regular time intervals. While the design of the logbook can be considered to be generally good, the data entered should be scrutinized by independent bodies (academics, NGOs, officers) during unannounced spot checks. An administrative panel, as outlined in respective laws, should ensure that monitoring personnel produce monthly,

quarterly, biannual or annual reports based on the monitoring data. The report and data derived from the logbook, particularly those on fish catch, must be made available to the public, including local communities, researchers and NGOs.

The sustainability of the NGO-managed monitoring programme should be enhanced through closer cooperation with concerned government agencies. Rangers should work in places close to where they are from. Monitoring methods should be as simple as possible with an emphasis on local knowledge systems so that local rangers do not need to learn new and complicated technical skills. Finally, whenever needed, data on monitoring should be made available to the public for awareness raising, enabling greater participation in fighting illegal activities and possibly making financial contributions to the monitoring programme.

The design of community-based monitoring should be based on existing norms and practices, integration of local ecological knowledge, and should take into consideration the need to coordinate with livelihood activities. There is also a need for coaching by outsiders in monitoring methods, analysis and interpretation of monitoring data so that regular reports can be produced. In order to ensure greater community participation in management and conservation, the co-management approach should be adopted and strengthened. In this manner, the quality of monitoring as well as the coordination and cooperation of the three systems in Tonle Sap Great Lake could be enhanced.

Acknowledgements

This paper was upgraded from a series of comments made during the M-POWER (Mekong Programme on Water, Environment and Resilience) annual meeting held in Kunming, China in February 2009. We acknowledge the funding support from USEPAM/Danida. We are also grateful to the Challenge Program on Water and Food, Echel Eau and IFAD (International Fund for Agricultural Development) for support of project PN50 (M-POWER) and for the additional grant to support the field work. Heartfelt thanks are conveyed to Dr. Rajendra Shrestha and Prof. Henning Schroll for giving continuous advice while writing this paper. Sincerest thanks are given to Dr. Ram Baskakoti, Dr. Richard Friend, Dr. Robert Arthur (World Fish Centre) and Dr. Robert Steinmetz (biologist of WWF Thailand) for providing valuable comments on research methodology. Sincere thanks are conveyed to the editors of this journal and two anonymous peer-reviewers who gave very constructive comments to finalize this manuscript for publication.

References

Alzinga CL, Salzer DW, Willoughby JW, Gibbs JP. 2001. Monitoring plant and animal populations. Malden (MA): Blackwell Science.

Bani L, Massimino D, Bottoni L, Massa R. 2006. Multiscale method for selecting indicator species and priority conservation areas: a case study for broadleaved forests in Lombardy, Italy. Conserv Biol. 20(2):512–526.

Campbell IC, Poole C, Giesen W, Jorgensen JV. 2006. Species diversity and ecology of Tonle Sap Great Lake, Cambodia. Aquat Sci. 68(3):355–373.

Clements T, O'Kelly H, Sun V. 2007. Monitoring of large waterbirds at Prek Toal, Tonle Sap Great Lake 2001–2007. Contribution to the UNDP/GEF funded Tonle Sap Conservation Project. Phnom Penh (Cambodia): Wildlife Conservation Society Cambodia Program.

Danielsen F, Balete DS, Poulsen MK, Enghoff M, Nozawa CM, Jensen AE. 2000. A simple system for monitoring biodiversity in protected area of a developing country. Biodivers Conserv. 9(12):1671–1705.

Danielsen F, Burgess ND, Balmford A. 2005. Monitoring matters: examining the potential of locally-based approaches. Biodivers Conserv. 14(11):2507–2542.

Danielsen F, Burgess ND, Balmford A, Donald PF, Funder M, Jones JPG, Alviola P, Balete DS, Blomley T, Brashares J, et al. 2008. Local participation in natural resource monitoring: a characterization of approaches. Conserv Biol. 23(1): 31–42.

Danielsen F, Burgess ND, Jensen PM, Pirhofer-Walzl K. 2010. Environmental monitoring: the scale and speed of implementation varies according to the degree of people's involvement. J Appl Ecol. 47(6):1166–1168.

Danielsen F, Jensen AE, Alviola PA, Balete DS, Mendoza M, Tagtag A. 2005. Does monitoring matter? A quantitative assessment of management decisions from locally-based monitoring of protected areas. Biodivers Conserv. 14(11):2633–2652.

Feinsinger P. 2001. Designing field studies for biodiversity conservation. Washington (DC): Island Press.

[FiA] Fisheries Administration. 2007. Law on fisheries. Phnom Penh (Cambodia): FiA.

[FiA] Fisheries Administration. 2008. The compilation of legal instruments related to community fisheries in the Kingdom of Cambodia. Phnom Penh (Cambodia): FiA.

Gaidet N, Fritz H, Nyahuma C. 2003. A participatory counting method to monitor populations of large mammals in non-protected areas: a case study of bicycle counts in the Zambezi Valley, Zimbabwe. Biodivers Conserv. 12(8):1571–1585.

Gaidet-Drapier N, Fritz H, Bourgarel M, Renaud PC, Poilecot P, Chardonnet P. 2006. Cost and efficiency of large mammal census techniques: comparison of methods for a participatory approach in a communal area, Zimbabwe. Biodivers Conserv. 15(2):735–754.

Goes F. 2005. Four years of waterbird conservation activities in Prek Toal Core Area, Tonle Sap Biosphere Reserve (2001–2004). Phnom Penh (Cambodia): Wildlife Conservation Society Cambodia Program.

Gray M, Kalpers J. 2005. Ranger based monitoring in the Virunga–Bwindi region of East-Central Africa: a simple data collection tool for park management. Biodivers Conserv. 14(11):2723–2741.

Gray TNE, Hong C, Ro B, Collar NJ, Dolman PM. 2007. Habitat preferences of a globally threatened bustard provide support for community-based conservation in Cambodia. Biol Conserv. 138(3–4):341–350.

Hartanto H, Lorenzo CMB, Frio AL. 2002. Collective action and learning in developing a local monitoring system. Int Forest Rev. 4(3):184–195.

Joseph LN, Field SA, Wilcox C, Possingham HP. 2006. Presence-absence versus abundance data for monitoring threatened species. Conserv Biol. 20(6):1679–1687.

Katzner T, Milner-Gulland EJ, Bragin E. 2007. Using modelling to improve monitoring of structured populations: are we collecting the right data. Conserv Biol. 21(1): 241–252.

Kéry M, Schmid H. 2004. Monitoring programs need to take into account imperfect species detectability. Basic Appl Ecol. 5(1):65–73.

Lamberts D. 2006. The Tonle Sap Lake as a productive ecosystem. Water Resour Dev. 22(3):481–495.

Lim S, Sour V, Sirita U. 2004. The Mimosa Pigra report, State of Environment Report. National Capacity Development Project. Phnom Penh (Cambodia): Royal Government of Cambodia. Issue Paper No. 1

Margoluis R, Salafsky N. 1998. Measures of success: designing, managing, and monitoring conservation and development project. Washington (DC): Island Press.

McGeoch MA, Chown SL, Kalwij J. 2006. A global indicator for biodiversity invasion. Conserv Biol. 20(6): 1635–1646.

[MOE] Ministry of Environment. 2008. Law on Protected area management. Phnom Penh (Cambodia): MOE.

[MOE, DOF, WI] Ministry of Environment, Department of Fisheries, Wetlands International. 2002. Management plan for the Boeng Chhmar Ramsar Site in Cambodia, final draft. Phnom Penh (Cambodia): MOE.

[MOE, MAFF] Ministry of Environment, Ministry of Agriculture Forestry and Fisheries. 2007. Management Plan 2008–2012 for Boeng Tonle Chhmar, Stung Sen and Prek Toal core areas of Tonle Sap Biosphere Reserve. Phnom Penh (Cambodia): MOE & MAFF.

Neou B, Lane BD. 2002. Natural resources management for human security in Cambodia's Tonle Sap Biosphere Reserve. Environ Sci Policy. 5(1):33–41.

Nordic Agency for Development and Ecology, Department of Environment and Natural Resources. 2001. Biodiversity monitoring system manual for protected areas. 2nd ed. Manila (Philippines): DENR and NORDECO.

Noss AJ, Oetting I, Cuellar RL. 2005. Hunter self-monitoring by the Isoseno-Guaran in the Bolivian Chaco. Biodivers Conserv. 14(11):2679–2693.

Obura DO, Wells S, Church J, Horrill C. 2002. Monitoring of fish and fish catches by local fishermen in Kenya and Tanzania. Mar Freshwater Res. 53(2):215–222.

Rijsoort JV, Jinfeng Z. 2005. Participatory resource monitoring as a means for promoting social change in Yunnan, China. Biodivers Conserv. 14(11):2543–2573.

Royal Government of Cambodia. 2005. The designation of animals and plants as national symbols of the Kingdom of Cambodia; 2005 Mar 21; Phnom Penh, Cambodia. Royal Decree No. NS/RKT/0305/149.

Royal Government of Cambodia. 2009. Sub-decree No. 123 dated August 12, 2009 on national list of endangered species in Cambodia. Phnom Penh, Cambodia.

Seak S, Schmidt-Vogt D, Thapa GB. 2011. Biodiversity monitoring at the Tonle Sap Lake of Cambodia: a comparative assessment of local methods. Unpublished.

Sheil D. 2001. Conservation and biodiversity monitoring in the tropics: realities, priorities, and distractions. Conserv Biol. 15(4):1179–1182.

Steinmetz R. 2000. Ecological surveys, monitoring and the involvement of local people in protected areas of Lao P.D.R. Evaluating Eden Series. London (UK): IIED. Discussion Paper No. 13.

Stork NE, Samways MJ, Eeley HAC. 1996. Inventorying and monitoring biodiversity. Trends Ecol Evol. 11(1):39–40.

Sutherland W. 1996. Ecological census techniques: a handbook. London (UK): Cambridge University Press.

Teder T, Moora M, Roosaluste E, Zobel K, Pärtel M, Kõljalg U. 2007. Monitoring of biological diversity: a common-ground approach. Conserv Biol. 21(2):313–317.

Uychiaoco AJ, Arceo HO, Green SJ, Cruz MTDL, Gaite PA, Alino PM. 2005. Monitoring and evaluation of reef protected areas by local fishers in the Philippines: tightening the adaptive management cycle. Biodivers Conserv. 14(11): 2775–2794.

Van Zalinge R, Evans T, Sun V. 2008. A review of the status and distribution of large waterbirds in the Tonle Sap Biosphere Reserve. An output of the UNDP/GEF funded Tonle Sap Conservation Project. Phnom Penh (Cambodia): Wildlife Conservation Society Cambodia Program.

Vreugdenhil D, Terborgh J, Cleef AM, Sinitsyn M, Boere GD, Archaga VL. 2003. Comprehensive protected areas system composition and monitoring. Shepherdstown (WV): WICE.

[WCS] Wildlife Conservation Society. 2007. Tonle Sap biodiversity monitoring protocols. Technical output of the UNDP/GEF funded Tonle Sap Conservation Project. Phnom Penh (Cambodia): Wildlife Conservation Society Cambodia Program.

Yoccoz NG, Nichols JD, Boulinier T. 2003. Monitoring of biological diversity – a response to Danielsen *et al*. Oryx. 37(4):410.