The hollow drum: impacts of human use on the Tonle Sap flooded forest at Kampong Luong, Cambodia

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មូលន័យសង្ខេប

ព្រៃលិចទឹកនៅតំបន់បឹងទន្លេសាបនៃប្រទេសកម្ពុជា ផ្តល់ទីជម្រកដល់ជីវៈចម្រុះ ដែលមានលក្ខណៈពិសេសៗ ទាំងរស់នៅលើគោក និងក្នុងទឹក។ ប្រភេទព្រៃលិចទឹកទាំងនោះ ជួយរក្សាផលិតភាពដល់ផ្នែកជលផលទឹកសាបដ៏សំខាន់បំផុតមួយក្នុងពិភពលោក ហើយវាពិតជាមានសារៈសំខាន់យ៉ាងខ្លាំង សម្រាប់សន្តិសុខស្បៀងអាហារនៅក្នុងប្រទេសកម្ពុជា។ វាក៏ផ្តល់ផងដែរនូវប្រភពអុស អាហារ ឈើប្រើប្រាស់និងរុក្ខជាតិឱសថដល់ប្រជាជនក្នុងតំបន់។ តែយ៉ាងណាក្តី សកម្មភាពមនុស្សបាននឹងកំពុងបំផ្លិចបំផ្លាញ ឬ កែប្រែតំបន់ព្រៃលិចទឹកដ៏ធំទាំងនោះ តាមរយៈការទន្ទ្រានយកដីធ្លីធ្វើកសិកម្ម និង ការដកហូតឈើសម្រាប់ថាមពលចំហេះ និង សំណង់ជាដើម។ យើងបានធ្វើការពិនិត្យពីផលប៉ះពាល់របស់មនុស្សទៅលើគម្របព្រៃលិចទឹកនៅក្បែរកំពង់លួង ដែលវាជាតំបន់ភូមិអណ្តែតទឹកធំជាងគេនៅលើបឹងទន្លេសាប។ ដោយការប្រើប្រាស់ទូក ការសិក្សាពីប្រភេទរុក្ខជាតិព្រៃលិចទឹកត្រូវបានធ្វើឡើង នៅតាមខ្សែបន្ទាត់ត្រង់ស្ថិតនៅសងខាងភូមិអណ្តែតទឹកកំពង់លួង ក្នុងអំឡុងឆ្នាំ២០១៤។ ការសម្ភាសក៏ត្រូវបានធ្វើឡើងជាមួយប្រជាជននិងថ្នាក់ដឹកនាំភូមិ ដើម្បីសិក្សាពីរបៀបនៃការប្រើប្រាស់និងគ្រប់គ្រងព្រៃលិចទឹក។ ទោះជាតំបន់ព្រៃលិចទឹកនៅកន្លែងខ្លះ នៅរក្សាបាននូវលក្ខណៈដើមពីធម្មជាតិនៅឡើយ យើងក៏សង្កេតឃើញភស្តុតាងនៃការផ្លាស់ប្តូរយ៉ាងខ្លាំង ដោយឥទ្ធិពលនៃសកម្មភាពមនុស្ស។ ស្ទើរគ្រប់ចំណុចសិក្សាតាមខ្សែបន្ទាត់ត្រង់ គម្របព្រៃបានបាត់បង់សឹងតែគ្មានសល់ ហើយតាមរយៈការវិភាគរូបភាពទទួលបានពីផ្កាយរណបក៏បានបង្ហាញថា ទីកន្លែងនោះ និង កន្លែងមួយចំនួនផ្សេងទៀតត្រូវបានគេកាប់ឆ្ការតាំងពីឆ្នាំ២០០៤មកម្ល៉េះ។ ការខូច ខាតគម្របព្រៃលិចទឹកដោយសកម្មភាពមនុស្សនេះ គឺដោយសារគ្មានការហាមឃាត់លើការដកហូតធនធានព្រៃលិចទឹក និង កង្វះវិធានការគ្រប់គ្រង។ ប្រសិនបើលទ្ធផលនៃការសិក្សានេះ តំណាងឲ្យស្ថានភាពព្រៃលិចទឹកដទៃទៀតនៃតំបន់បឹងទន្លេសាបនោះ យើងអាចសន្និដ្ឋានបានថា តំបន់ព្រៃលិចទឹកនៅបឹងទន្លេសាបទាំងមូលត្រូវការការគ្រប់គ្រងយ៉ាងសកម្មជាចាំបាច់ ក្នុងគោលបំណងដើម្បីលើកស្ទួយប្រជាជនមូលដ្ឋាន ឲ្យបន្តទទួលបាននូវនិរន្តរភាពនៃការប្រើប្រាស់ធនធានធម្មជាតិ ព្រមទាំងចូលរួមអភិរក្សទីជម្រកធម្មជាតិដ៏សំខាន់នេះ។

Abstract

The floodplain vegetation of Cambodia’s Tonle Sap Great Lake provides habitat for a diversity of unique terrestrial and aquatic organisms. This vegetation helps maintain the productivity of one of the world’s most important inland

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fisheries which is vital to Cambodian food security. It also provides local people with wood, food and medicinal plants. However, human activities have destroyed or converted large areas of the Tonle Sap's flooded forest through land encroachment for agriculture and exploitation of wood for fuel and construction. We examined human impacts on the vegetation cover of flooded forests adjacent to Kampong Luong, the largest floating settlement on the lake. Vegetation surveys were undertaken along one transect on each side of the settlement by boat during the 2014 wet season. Interviews were conducted with villagers and village leaders to determine how the floodplain vegetation has been used and managed. While some of the vegetation retained natural characteristics, significant changes were also evident due to human impacts. Nearly all plots surveyed along one transect had almost no vegetation cover and analysis of satellite imagery revealed that these and other areas had been cleared since 2004. Vegetation changes caused by human activity were facilitated by unrestricted access to a common resource and lack of active floodplain forest management. If our results are applicable to other floating settlements on the Tonle Sap Great Lake, the vegetation of the lake's floodplain needs to be actively managed to ensure that local people have sustainable access to natural resources and to conserve this important habitat.

Keywords

Flooded forest, floodplain, human impact, Kampong Luong, Tonle Sap, vegetation cover.

Introduction

Located in the centre of Cambodia, the Tonle Sap Great Lake is one of the Mekong River's major tributaries. The Tonle Sap Lake is the biggest freshwater body in Southeast Asia and supports a highly productive fishery and large human population (Campbell *et al*., 2009). The floodplains that surround the lake experience large seasonal fluctuations in water level and are home to a diverse assemblage of unique terrestrial and aquatic organisms. The vegetation of the floodplains is a mix of forest, shrub land, grassland and agricultural land (Araki *et al*., 2007; Arias *et al*., 2012, 2013). The composition of these vegetation communities is structured by interactions between seasonal flood pulses, soil properties and human impacts (Araki *et al*., 2007; Arias *et al*., 2012, 2013). The floodplain vegetaton provides habitat for a wide range of species including water birds, mammals, reptiles, invertebrates and fishes (Nikula, 2005). The vegetation is also adapted to partial or full submergence and provides a crucial nursery for a wide variety of migratory fish species, while also providing excellent habitats for fish to feed, spawn, hatch and rear their young (Lamberts, 2006).

The huge production of fish supported by the Tonle Sap's floodplains, particularly its flooded forests, is central to Cambodia's food and livelihood security. Freshwater fish and other aquatic animals provide 80% of the protein consumed by people in Cambodia (Hortle, 2007). Approximately 4.1 million people live in the six provinces (Siem Reap, Pursat, Kampong Thom, Battambang, Kampong Chhnang and Banteay Meanchey) bordering Tonle Sap Lake. These depend on the lake and its floodplain for farming and fishing, while over 1.2 million people derive livelihoods from fishery activities (Oeur *et al*., 2014). Consequently, the Tonle Sap's floodplain vegetation not only plays a critical role in sustaining aquatic ecology and supporting numerous fish species, but also directly benefits local livelihoods and economic life (Roudy, 2002). Fishing and agriculture are the major occupations for people who live around the lake, particularly for people who live in Tonle Sap's floating communities (Keskinen, 2006). Compared to people who live further from the lake, they are often poorer, less well educated, and often do not own agricultural land (Keskinen, 2006). Alongside fishing, other livelihood activities link these people with the flooded forest. These include collection of wood for building materials and firewood for cooking and fish processing, and collection of other flooded forest products including wild foods and medicinal plants (Nikula, 2005).

The extent of the Tonle Sap's floodplain vegetation has declined due to human disturbance (Nikula, 2005; Campbell *et al*., 2009). Human activities including an increase in the number and size of human settlements, extensive agricultural conversion and exploitation of wood for fuel and construction materials have destroyed or converted large areas of floodplain vegetation (Roudy, 2002; Campbell *et al*., 2009). Fires, either accidental or intentionally lit for clearing or hunting, have also played an important role in modifying habitats throughout the floodplain (Campbell *et al*., 2006). The area of flooded vegetation declined from 791,000 ha in 2002 to 688,170 ha in 2005 and ca. 55,566 ha of flooded forest was lost between 2005 and 2010 (Mak, 2015; and references therein). Because the flooded forests play an important role in sedimentation, nutrient cycling, primary and secondary production and providing habitat for fish (Arias *et al*., 2012), their degradation threatens the livelihood and food security of millions of people who depend on the natural resources of the Tonle Sap Lake (MoE, 2001). The future productivity of the lake is also threatened by hydropower developments upstream, because these are predicted to change the seasonal pattern of flooding (Arias *et al*., 2013).

While degradation of the Tonle Sap's flooded forest is widespread, many of the drivers of degration occur at a local scale, and are replicated throughout the lake area. To investigate local drivers, we examined the impact of humans on the floodplain vegetation adjacent to Kampong Luong, the largest floating settlement on the Tonle Sap Lake (Mak, 2012). To determine the importance of environmental factors and human use in structuring the flooded forests in this area, we surveyed the vegetation on either side of the Kampong Luong settlement and interviewed local people to evaluate how the forest is used and managed. Given emerging threats to the system, we provide guidance on how management can mitigate future change.

Methods

Study area

The field survey was undertaken at the floating settlement of Kampong Luong (Fig. 1). Located on the southern shore of the Tonle Sap Lake, Kampong Luong has a population of approximately 10,000 people, who comprise Khmer and a large number of Vietnamese who catch and trade fish. Similar to many other floating settlements on the lake, Kampong Luong changes location throughout the year in response to the changing shoreline. Kampong Luong is located on the border of two communes, the Anlong Tnaot Commune, where it officially resides, and the neighbouring Kbal Trach Commune.

Canopy and floating vegetation survey

We surveyed canopy and floating vegetation during the wet season on 20–21 September 2014. Two transects were surveyed in the flooded forests adjacent to Kampong Luong. Each transect began at the outer (lakeward) edge of the flooded forest on either side of the channel leading out of Kampong Luong and proceeded landwards until the vegetation became impenetrable. The transects were located so that they encompassed the

Fig. 1 The Kampong Luong floating settlement and adjacent flooded forests. The main figure shows a landsat image of the area on 14 October 2014, the extent of the settlement (blue dotted lines) during the survey period and location of vegetation plots (light green dots) on the western and eastern transects. The small and large inset maps show the location of the settlement in Cambodia and the dark and light grey areas represent the minimum and maximum extent of the Tonle Sap Lake, respectively.

flooded forests closest to the floating settlement (Fig. 1). Thirty-two 314 m^2 vegetation plots were surveyed, 20 along the 1.9 km western transect in Anlong Tnaot Commune, and 12 along the 1.1 km eastern transect in Kbal Trach Commune. Vegetation plots were spaced at 100 m intervals and accessed using a boat. At each plot location, a tennis ball attached to a line was thrown in the four cardinal directions from the bow of the boat to establish a circular plot measuring 10 m in radius. We visually estimated total plant cover and the percentage cover of each species within each plot. Water depth (m) was recorded within each plot. Plant species were identified following Dy Phon (2000) and Campbell *et al.* (2006), and local names were employed for plant species that could not be identified.

Statistical analyses

Multivariate data analyses were conducted using the Vegan 2.3 package (Oksanen *et al*., 2015) in the R statistical program (R Core Team, Austria). Relationships between vegetation plots were examined using nonmetric multidimensional scaling (NMDS) via the *metaMDS* procedure, and hierarchical clustering via the *hclust* procedure. NMDS represents the position of communities in multidimensional space as accurately as possible using a reduced number of dimensions that can be easily plotted and visualized. Objects closer together in NMDS plots are more similar, whereas objects further apart are more dissimilar. In hierarchical clustering, all samples begin as single objects and are aggregated into progressively larger clusters based on their similarities. For both the NMDS and hierarchical clustering, similarities between survey plots was determined using the square root of Bray-Curtis similarity values. A dendrogram was generated using Ward's grouping method for clustering.

We used two methods to determine if there was a relationship between water depth and vegetation structure. The *envfit* procedure was used in Vegan to examine the relationship between water depth and the position of vegetation plots in the ordination space (Oksanen *et al*., 2015). Differences between water depth and vegetation plots were examined using similarity percentages (SIMPER: Clarke & Warwick, 2001) via the *simper* command. In *simper* analysis, the water depths of vegetation plots were arranged into three categories: shallow water samples (2.0–3.99 m), medium depth samples (4.0–4.99 m) and deep water samples (5.0–7.0 m). These categories were chosen to ensure that numbers of samples in each were roughly even. Use of SIMPER facilitated identification of plant species contributing most to pairwise differences between categories. Three pairwise comparisons were examined to this end: deep vs. medium depth water, deep vs. shallow water, and medium depth vs. shallow water. Discriminating species were selected based on the average contribution of each plant species to overall dissimilarity, the ratio of average contribution to standard deviation, and the greatest differences between average plant cover.

Forest loss

We examined the extent of forest loss adjacent to Kampong Luong between 2000 and 2014 using the Global Forest Watch Dataset (Hansen *et al*., 2014) and Google Earth Engine (Gorelick *et al*., 2017). A 1,846 ha polygon was assessed around Kampong Luong which comprised 0.09 ha of flooded forest in the year 2000. Following Hansen *et al*. (2014), forest loss was defined as removal or mortality of vegetation greater than 5 m height at a resolution of 30x30 m between the years 2000–2014. Changes in forest cover were explored visually for each year.

The role of fire in forest degradation was examined using the Fire Information for Resource Management (FIRMS) dataset in the Google Earth Engine (2017). Daily FIRMS data were derived from MODIS satellites at a resolution of 1 km^2. FIRMS provides the brightness temperature of a fire pixel and a confidence rating that each event was a fire on a scale of 0–100. For each year from 2000 to 2014, areas within the Kampong Luong forests which displayed a high confidence (<50) of having had a fire were identified and displayed graphically.

Semi-structured interviews

We conducted semi-structured qualitative interviews with knowledgeable locals to gather data regarding traditional knowledge, and current use, management and threats to the flooded forest around Kampong Luong. Purposeful sampling methods were adopted (Suri, 2011) and interviewees were chosen to obtain as much information as possible in the short time span available. These comprised six local informants, namely: the head and sub-head of the Kampong Luong settlement, two traditional medicine practitioners, one policeman and one fisherman. All interviews were conducted verbally and recorded with the consent of the participants. Efforts were made to retain the original ideas of each respondent interviewed. Important points voiced by the respondents were recorded and assessed as direct quotes.

Results

Canopy and floating vegetation of the flooded forest

Fourteen plant species belonging to 11 families were recorded in the two survey transects during the study. Thirteen of these were identified to species level and 11 were native: *Barringtonia acutangula* (Lecythidaceae), *Utricularia aurea* (Lentibulariaceae), *Polygonum barbatum* (Polygonaceae), *Combretum trifoliatum* (Combretaceae), *Merremia hederacea* (Convolvulaceae), *Gmelina asiatica* (Lamiaceae), *Bridelia cambodiaria* (Phyllanthaceae), *Impomoea aquatica* (Convolvulaceae), *Oryza rufipogon* (Poaceae), *Diospyros cambodiana* (Ebenaceae), *Derris* sp. (Fabaceae) and a single unidentified taxon known locally as Ronhia. The remaining two species, *Eichhornia crassipes* (Pontederiaceae) and *Mimosa pigra* (Fabaceae), were non-native invasive species.

There appeared to be little relationship between canopy and floating vegetation cover and water depth along either of the two transects (Fig. 2). Our western transect had high vegetation cover at either end, but was largely bare in the middle. Our eastern transect showed an almost opposite pattern, with generally sparser vegetation at either end and higher cover in the middle.

Our NMDS ordination produced a two-dimensional solution with moderate stress (0.13) (Fig. 3). Vegetation plots from the eastern and western transects tended to separate along the second axis, with western transect plots located towards the top of the ordination, and eastern transect plots towards the bottom. This corresponded with a weak depth gradient, whereby shallow water plots (2.0–3.99 m) were loosely grouped at the top and medium water plots (4.0–4.99 m) at the bottom. Deep water plots (5.0–7.0 m) tended not to group together. Vegetation plots from position 9 to 14 on the western transect formed the closest group and occurred in medium depth and shallow water. The *envfit* procedure produced a statistically significant but weak depth gradient (r^2=0.08; p<0.02) and suggested that water depth only explained around 8% of the variation in our vegetation plots.

Our hierarchical classification produced six clusters (Fig. 4). The dendrogram initially split into two groups, these comprising one group (A–B) which was confined to vegetation plots from the western transect, and another larger group (C–F) containing plots from both transects. Group A contained samples from the outer (lakeward) edge of the western transect, whereas group B contained plots from the middle and landward sections of the transect. Group D comprised plots in medium water depths on the eastern transect. The remaining groups (C, E and F) could not be assigned according to transect location, position on the transect or water depth.

SIMPER analysis identified seven plant species as being good discriminators of water depth (Table 1). *Barringtonia acutangula* contributed the most to overall dissimilarity and had the highest cover in deeper water plots. Cover of *E. crassipes* was lower in plots with medium water depth than plots in deeper or shallower

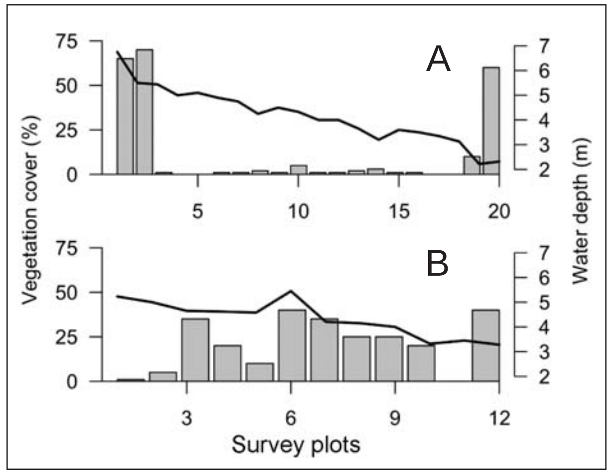

Fig. 2 Vegetation cover (bars) and water depth (black line) in survey plots along the A) western and B) eastern transects at Kampong Luong.

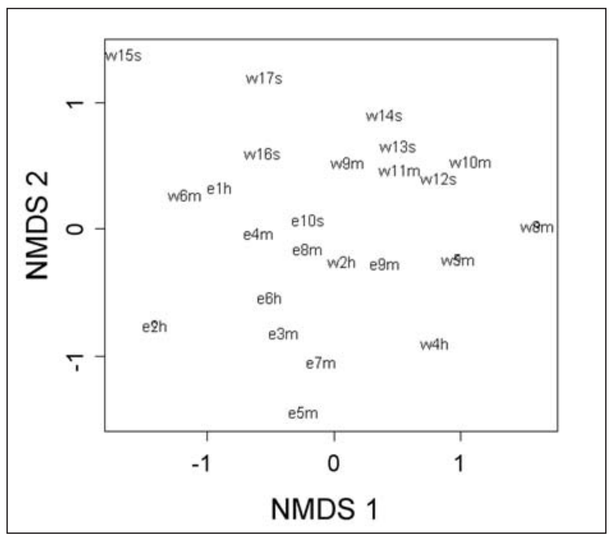

Fig. 3 Two-dimensional NMDS ordination of vegetation survey plots from the eastern and western transects at Kampong Luong. Plot labels denote transect (W=West, E= East), transect position (each transect began in deep water) and water depth (s=shallow, m=medium, h=deep).

Table 1 Similarity percentages (SIMPER) output for plant cover across different water depths. HD=deep water (5.0–7.0 m), MD=medium depth (4.0–4.99 m), SD=shallow water (2.0–3.99 m).

Species	Contribution	Standard deviation	Ratio	Average plant cover		
				HD	MD	SD
Deep vs. medium depth water						
Barringtonia acutangula	0.314	0.322	0.974	17.142	0.923	-
Eichhornia crassipes	0.089	0.122	0.734	3.285	0.692	-
Combretum trifoliatum	0.080	0.156	0.511	0.142	2.0	-
Ronhia (Local name)	0.070	0.164	0.426	0.714	1.923	-
Merremia hederacea	0.067	0.148	0.453	0.142	2.615	-
Deep vs. shallow water						
Barringtonia acutangula	0.302	0.322	0.939	17.142	-	2.857
Eichhornia crassipes	0.114	0.138	0.826	3.285	-	3.0
Merremia hederacea	0.144	0.132	1.091	0.142	-	6.571
Gmelina asiatica	0.091	0.162	0.562	0.0	-	4.571
Medium depth vs. shallow water						
Barringtonia acutangula	0.081	0.125	0.648	-	0.923	2.857
Eichhornia crassipes	0.080	0.107	0.749	-	0.692	3.0
Combretum trifoliatum	0.087	0.161	0.538	-	2.0	0.285
Merremia hederacea	0.193	0.163	1.179	-	2.615	6.571
Gmelina asiatica	0.109	0.167	0.654	-	0.384	4.571
Oryza rufipogon	0.088	0.134	0.660	-	0.384	0.857

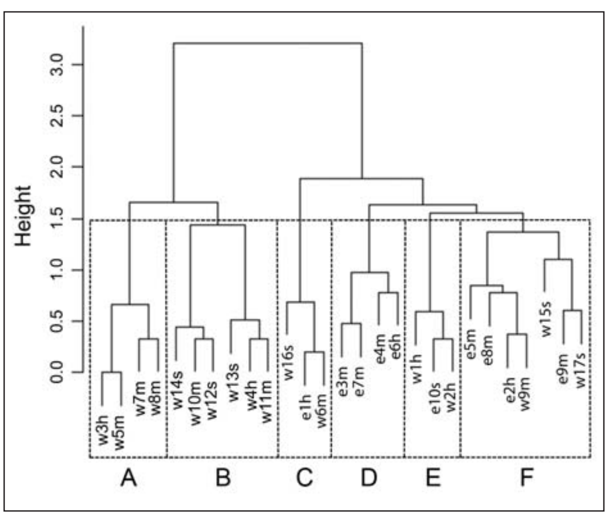

Fig. 4 Hierarchical dendrogram of vegetation plots from Kampong Luong. Plot labels denote transect (W=West, E= East), transect position (each transect began in deep water) and water depth (s=shallow, m=medium, h=deep).

water. Cover of *C. trifoliatum* and Ronhia was higher in plots with medium water depth than those in deeper or shallower water. Cover of *M. hederacea*, *G. asiatica* and *O. rufipogon* was greater in shallow water compared to medium depth and deep water. *Gmelina asiatica* was not found in deep water. These results suggest that similarity was greater within than between the two transects and that plots in deeper water on the western transect were more similar than those from lesser depths. There appeared to be little to differentiate plots from the eastern transect, although plots in medium depth waters did bear some similarities.

Forest loss

From 2000 to 2014, 1,187 m^2 (13%) of forest was lost around the Kampong Luong settlement, whereas forest cover increased by 49 m^2 (0.5%) in previously deforested areas. In the year 2000, the area surrounding the settlement was extensively forested (Fig. 5). Although only a small amount of forest was lost by 2003, large areas were deforested in 2004. This corresponded with a high probability of large fires in the adjacent area, which was believed to have been illegally cleared to provide wood for use in fishing activities (Heng S., pers. comm.). Steady forest loss occurred each year until 2014, mostly through enlargement of areas already cleared. Potential fires were detected in 2004, 2007, 2008, 2011 and 2013 (Fig. 5). Although many trees in the shallower portion of the eastern transect were defoliated and local reports indicated that this area had been burnt during the preceding dry season, this was not detected in satellite imagery. This indicates that small fires may have occurred more frequently than our analysis of satellite imagery would suggest.

Flooded forest use, management and threats

According to local informants, flooded forests surrounding Kampong Luong settlement are extensively used by local residents and outsiders for fishing during the wet season and for collection of timber, medicinal plants, vegetables, fruit and bark.

Informants reported that local residents and outsiders from the mainland both fish around Kampong Luong. Use of illegal fishing gear was attributed to the latter. Forest vegetation was actively managed during the dry season to facilitate fishing in the wet season and involved burning the forest so that gill nets could be set and retrieved without getting caught in submerged vegetation and becoming damaged or lost. This activity was also attributed to outsiders and local informants reported that efforts to hinder and prosecute these activities by local law enforcement officials were ineffective. Local informants described the importance of a complex floodplain habitat for fish and recognised the importance of conserving the flooded forests to maintain a healthy ecosystem and high fish yields. They also expressed beliefs that reductions witnessed in fish diversity and harvests were related to forest degradation. Despite this, locals evidently extract wood from the flooded forests, and one informant revealed that most wood is extracted during the dry season (although this increases the likelihood of being observed by the police) because access to the forest during the wet season requires a boat. The local police official interviewed emphasised that the forest was protected and that timber extraction and burning were both prohibited. Locals caught breaking these rules were reportedly turned over to officials from the Ministry of Environment or the Fisheries Administration, although locals were allowed to cut small amounts of wood for construction of fish traps. Burning of cleared land prior to the wet season for rice cultivation was also permitted.

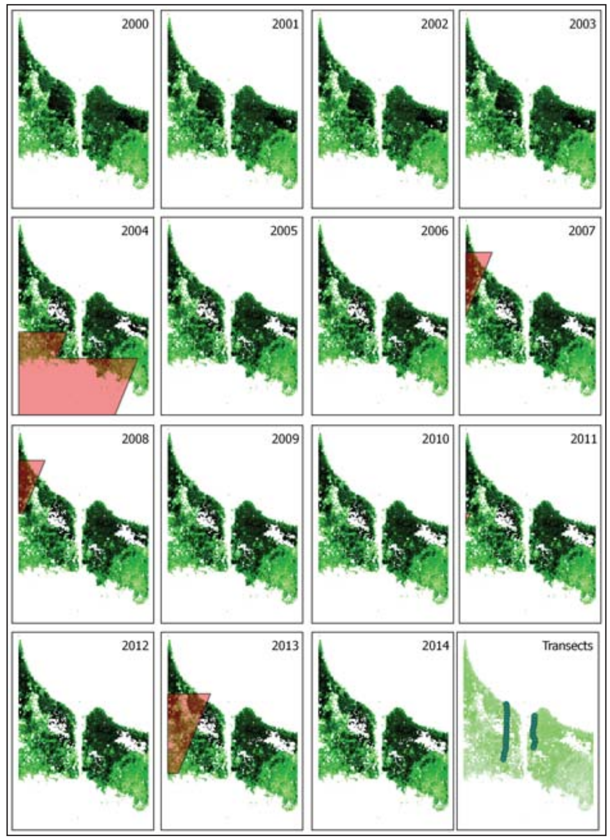

Fig. 5 Yearly forest loss and fire occurrence around Kampong Luong settlement. Green shading represents forest areas, with darker shading representing denser forest. White denotes no forest cover. Red polygons in 2004, 2007, 2008, 2011 and 2013 represent areas with a high likelihood of fire. The settlement occupies the white, non-forested strip dividing the two blocks of forest. The dark dots in the bottom-right panel show the locations of the study transects.

Our informants confirmed that locals were aware of the location of Kampong Luong on the boundary of two communes. Locals reportedly use a shrine located on the edge of the flooded forest as a marker beyond which they do not fish, as they claim it marks the boundary of the neighbouring Kbal Trach Commune. Kampong Luong is situated within Anlong Tnaot Commune for most of the year, but floating houses may occasionally cross into Kbal Trach Commune, particularly during the wet season. The location of a nearby and state-enforced fish sanctuary was poorly demarcated however. Some villagers reported that this sanctuary began "where the forest ends", whereas others believed that it was located deeper within the forest. We could not determine how much fishing activity occurs within the fish sanctuary, but the boundaries of fish sanctuaries supported by NGO's appeared to be better known and protected.

Connections between Kampong Luong and the wider world were revealed in interviews. Kampong Luong is a popular source of fish for traders who sell these to the rest of Cambodia. One fisherman interviewed revealed that he earned 2,000 riel (ca. US$ 0.50) for 1 kg of small, gutted and decapitated fish. These were sold to Cambodian traders who in turn sold the fish in bulk for export to Thailand, where they were dried and then re-imported to Cambodia.

The two traditional medicine practitioners we interviewed stated that a range of floodplain plants were used in traditional medicine (Table 2), and that many locals were aware of the medicinal properties of many plants. Use of such plants for medicine was reported to have decreased due to the availability of modern pharmaceutical medicines. Notwithstanding this, the flooded forest reportedly continues to be important to local spiritual beliefs. Tales of evil spirits reportedly abound and locals obtain protective talismans from the medicine men before they venture into the forest to extract timber or non-timber forest products (Fig. 6).

Table 2 Medicinal and food plants in the flooded forest surrounding the Kampong Luong settlement and their traditional uses and associated beliefs.

Species	Traditional uses
B. acutangula	Bark boiled in water can prevent a loose bladder. After harvesting the bark from the tree, one must 'soothe' the tree wound with soil.
B. cambodiaria	The stem and root are used to treat gynecological conditions and reduce temperature.
D. cambodiana	The fruit can prevent diarrhoea, but as it is bitter it is commonly eaten with prahoc.
E. crassipes	White roots can be ground and drunk with coconut juice to prevent diabetes and abnormal swelling of body parts.
G. asiatica	Roots boiled in water can reduce fever.
I. aquatica	Commonly known as morning glory, this species is extensively cultivated for sale as a vegetable.
M. hederacea	Used to treat gynecological conditions, and to reduce temperature.
Ronhia (Local name)	Cannot be used alone. Must be mixed with other plants for medicinal effects which depend on the latter.
C. trifoliatum	Fruit and bark boiled in water can prevent diarrhoea.

Discussion

The canopy and floating vegetation adjacent to the Kampong Luong settlement shows signs of being structured by environmental factors and human interactions. Human interactions appear to be the dominant driver. A weak water depth gradient in vegetation composition was apparent in our study, with different species characterizing the outer (lakeward) edge of the forest, medium water depths and shallower waters closer to the shore line. Consistent with previous studies (Araki *et al*., 2007; Arias *et al*., 2013), the outer edge of the forest was characterised by a band of mature *B. acutangula*. Cover of the early successional liana *C. trifoliatum* was greatest in medium depth and shallow waters and this species was previously associated with disturbed forest (Araki *et al*., 2007). In many cases, dead shrubs presumably killed by burning during the previous dry season were covered with *C. trifoliatum*. Plants indicative of shallow waters such as *M. hederacea* are associated with cultivated or fallow fields, and the early successional liana *G. asiatica* is associated with shrub communities (Araki *et al*., 2007).

The extensive clearance of forest evident in satellite data from 2000 to 2014 reveals the extent of human impacts on the forest. In interview, the head of Kampong Luong summarised relationships between humans and forest cover surrounding the settlement as follows: *"The villagers are smart. Outside, the forest looks untouched – so when the environment officers from Phnom Penh check by boat, it looks protected! But actually, inside it is all cut! The forest is hollow like a drum!"*. This pattern was most evident to the west of Kampong Luong and was detected in our transect there (Fig. 2a). It was not detected in the eastern transect (Fig. 2b), although an area of cleared forest and open water further to the east also fit this pattern (Fig. 1, Fig. 5). As such, further surveys would undoubtedly reveal more regarding the composition and extent of vegetation surrounding Kampong Luong. As our study took place during the wet season, much of the floral diversity of the flooded forest was not sampled. Because many small shrubs, grasses and herbs would occur in the forest understorey and bare patches during the dry season, additional sampling would undoubtedly reveal this diversity and facilitate comparisons with other published surveys (e.g., Araki *et al*., 2007; Arias *et al*., 2012). As a consequence, our results are localised and cannot be extrapolated to the rest of the floodplain, where we anticipate environmental factors may play a greater role in structuring vegetation (Araki *et al*., 2007; Arias *et al*., 2012). Irrespectively, it would be interesting to test if the 'hollow drum' pattern revealed by our study occurs around other floating settlements on the Tonle Sap Great Lake.

Humans extensively use the natural resources of the flooded forests surrounding Kampong Luong. This resource use is open access and non-exclusive as residents of Kampong Luong and outsiders from the mainland freely access the forest. Local forest resources are also inevitably subject to rivalry because timber cut by one person means less for another. Fishermen from outside of Kampong Luong reportedly fished in the forest during the wet season and were alleged to frequently use illegal fishing gear and burn the forest in the dry season to avoid their gear getting tangled. Although the residents of Kampong Luong understand that the flooded forest provides important spawning grounds for fish, they apparently feel powerless to restrict access to those who either do not understand this or have no qualms about destroying the forest for short term gains.

Kampong Luong is located near the boundary of the Anlong Tnaot and Kbal Trach communes and seasonal movements can shift the settlement between these. Our interviews indicated that local residents are aware of the commune boundaries and this may partly explain why many of our survey plots on the western transect retained almost no vegetation cover. This area is located within the Anlong Tnaot Commune (where the settlement officially resides) and is consequently likely to be considered safer to access by locals. During the field work, greater fishing activity was observed to the west of Kampong Luong compared to the east. Perceptions of the flooded forest as open access are spatially limited by commune boundaries. For political delineations established only 13 years ago (Romeo & Spyckerelle, 2004), this indicates success and faith in the current regulatory regime. However, this must be compared against more recent forest degradation observed to the east, caused by the dry season burning of the flooded forest, allegedly by outsiders. The reported lack of response to this burning by local officials could also partly be due to this activity occurring in the adjacent commune and therefore outside of the bounds of their responsibility.

Fig. 6 A talisman prepared by the local medicine man at Kampong Luong settlement to protect villagers entering the forest against evil spirits.

The transboundary nature and movement of the Kampong Luong settlement defies the clearly-structured commune system, making management of activities difficult through this system. This may be why government enforcement of laws related to flooded forest use has been seemingly lackadaisical; many interviewees reported that areas of forest under NGO jurisdictions are better protected. Kampong Luong bears testimony to the process of centralised power weakening at peripheries in Cambodia, commune boundaries in this case (Grundy-Warr, 1993; Battersby, 1999). Although jurisdictional uncertainties caused by the movement of Kampong Luong may not be typical of all settlements on the Tonle Sap Great Lake, it nonetheless represents one of the many challenges the Cambodian government faces in managing resource-based populations on the lake.

Significant changes are predicted in the natural flow regime of the Tonle Sap Lake in the coming decade due to construction and operation of dams upstream. The operation of these dams for hydropower will flatten the flood pulse of the Mekong River: peak flood levels will be lower during the wet season (Arias *et al*., 2013), while lake levels will be higher during the dry season (Kummu & Sarkkula, 2008). This will affect the vegetation of the surrounding floodplains. The vegetation closest to the centre of the lake, the outer wall of the drum, will become permanently inundated and unlikely to survive, while landwards vegetation will be threatened by clearance for agriculture. Thus, the walls of the hollow drum may collapse. Local communities can do little to alter hydrological changes that would originate as far upstream as the headwaters of the Mekong in China. For the Tonle Sap's flooded forest to continue to provide natural resources to local people and those further afield, improvements in forest management are needed, not only to protect what is left, but to ensure that a productive forest can emerge from forthcoming changes.

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