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Where do people vulnerable to deforestation live? Triaging forest conservation interventions for sustainable non-timber forest products

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ABSTRACT

Rural households in developing countries often depend on non-timber forest products (NTFPs), including foods, traditional medicines, fuelwood, fodder, and construction and craft materials such as bamboo and rattan, for their livelihoods, but the forests that supply NTFPs are subject to competition from other land uses. NTFP collectors who are unable to sustain their livelihoods because of changes caused in the NTFP collection environment by deforestation and degradation may even convert surrounding forests to agricultural land to compensate for their reduced incomes. This feedback loop of deforestation and degradation can create further conflicts among natural resource users and undermine long-term development goals. Here, we aimed to advance the discussion of forest conservation interventions in protected areas in developing countries—particularly the discussion of patrolling strategies in and around existing wildlife sanctuaries—by presenting a new approach that uses the case of NTFP collection and a human geography perspective. We used a structured questionnaire composed of closed questions to measure the awareness of village households of the impacts of deforestation and/or illegal extraction of trees on NTFP collection over a short period of time (2014–2016) near the Prey Long Wildlife Sanctuary in the eastern part of the Kampong Thom Province, Cambodia. Our survey was based on the conceptual framework of Bohensky and Lynam (Ecol. Soc. 10, 11; 2005) that people in complex adaptive systems change their behaviour after becoming aware of the impact or consequences of a change. The probability of a village having an affected household (i.e., a household that was aware of the impact) was predicted by using generalized linear mixed models. By using identified geospatial indicators of environmental and socioeconomic aspects, including distance between the village and the wildlife sanctuary, size of deforested area per capita in 2014–2016 within a 10-km radius of the village and proportion of households in the village that collect NTFPs for cash income, we predicted the spatial distribution of villages with affected NTFP-collecting households. Priority areas for NTFP collection were then mapped with reference to the identified indicators. By using these results, we present an approach to breaking the deforestation feedback loop by identifying priority areas for patrolling and other forest conservation interventions in the wildlife sanctuary.

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1. Introduction

The livelihoods of rural households in developing countries often depend on non-timber forest products (NTFPs), including foods, traditional medicines, fuelwood, fodder, and construction and craft materials such as bamboo and rattan, to maintain their livelihoods. In rural areas where credit and insurance options are limited, NTFPs have been seen as a so-called safety net that helps households to avoid poverty and smooth their overall consumption by supplementing incomes during off-farm periods (Albers and Robinson, 2013; Baland and Francois, 2005; Delacote, 2007; Fisher and Shively, 2005; Pattanayak and Sills, 2001; Sunderlin et al., 2001). Furthermore, Jakobsen (2006) found that, in a transition phase of land-use policy in Laos where food shortages occurred because of a severe decrease in hill rice production, farmers mitigated the impact of the food shortages by purchasing food items with money earned from the sales of NTFPs. In the case of NTFPs connected to larger markets in Brazil, Lopes et al. (2019) reported that NTFP collection in the state of Acre was the third-highest contributor to the annual incomes of their sample families, after agriculture and livestock, and that the growing market for açaí production could be an important source of income in the future if it receives financial assistance through subsidies and other development programs. Antunes et al. (2021) found that, in north-eastern Pará, NTFP collection and membership of co-operatives based on enterprise–community partnerships has led to an increase in total income at the household level.

However, sustainable NTFP collection is less feasible if there are many competing land uses (e.g., logging, livestock grazing, fire, agriculture) (Ticktin and Shackleton, 2011, p. 157). By using a household model of land-use choice, Delacote (2007) predicted that, if the risk of crop failure were to be reduced, forests would potentially be more likely to be converted to agricultural land because of a reduced need to rely on NTFPs as an insurance and safety net in case of crop failure. For this reason, they suggested that, when agricultural development is promoted as a development policy, agricultural risk-reduction policies should be combined with environmental and forest management policies.

NTFPs are exposed not only to forest versus other land-use competition, but also to conflicts with different uses by others in the forest. Different resource uses of the same species among local stakeholders can cause conflict over the use of that species (Guariguata et al., 2010; Herrero-Jáuregui et al., 2009). For example, in a study in a biosphere reserve located in the rainforest region of south-eastern Mexico, Navarrete-Segueda et al. (2017) found that more than half of 165 identified species had one or more potential forest products, and 57% of timber species had also supplied NTFPs.

Moreover, households that have made a living from NTFPs may even convert forests to agricultural land if they cannot tolerate the changes in socioecological conditions caused by deforestation (i.e., competing land use) or illegal extraction of trees (i.e., competing resource use in the forest). Ehara et al. (2018) found a feedback loop in Cambodia whereby some NTFP collectors who could no longer sustain their livelihoods because of changes in the NTFP collection environment caused by deforestation and/or illegal extraction of trees converted the surrounding forest to agricultural land to compensate for their reduced incomes. Such residents' coping strategies are maladaptive to land-use change because they can create conflicts among natural resource users and undermine long-term development goals (Suckall et al., 2014).

For land and agricultural development policies and projects entailing land-use change, stakeholder analyses need to be conducted during the environmental and social impact assessment stages, followed by the application of measures to mitigate the impacts. However, in developing countries, financial, human, and other constraints can hamper assessments (Duffy, 2004; Pasgaard, 2013; Trethanya and Ranjith Perera, 2008). Similarly, in natural resource management projects, a biased stakeholder analysis can cause conflict among stakeholders and lead to further marginalisation of certain groups (Reed et al., 2009; Robards et al., 2010). Therefore, policies to slow or prevent deforestation and forest degradation in developing countries often combine explicit spatial policies, such as the provision of parks and buffer zones, with non-spatial policies, such as poverty reduction projects and payments for environmental services (e.g. REDD+, Reducing Emissions from Deforestation and Forest Degradation) (Albers and Robinson, 2013). The success or failure of such policies in those countries depends on the behaviour of forest resource users, such as their choice of the type and number of forest products they collect, and the intensity and location of the collection (Wells, 2003; White and Martin, 2002).

However, according to Albers and Robinson (2013), who conducted a review of the spatial economics of NTFP extraction, relatively few studies in the literature on NTFPs have explicitly considered the spatial decision-making of NTFP collectors and the spatial outcomes of forest degradation prevention policies. They categorized the empirical and modelling studies examining spatial patterns of NTFP collection and forest degradation into those that 1) spatialised market scenarios by including distance to markets; 2) examined the impacts of the time and labour costs of traveling back and forth through the forest for collection; and 3) analysed the relationship between the collection and spatial policies such as establishing parks and buffer zones. In the third category (see Albers and Robinson (2013) for more information on the first and second categories), some papers have discussed the spatial interactions between illegal loggers and enforcement, such as patrolling in reserves and parks, and the associated differences in patterns of forest degradation (Albers, 2010; Albers and Robinson, 2011; Robinson et al., 2011). However, according to the abovementioned review by Albers and Robinson (2013), even though enforcing property rights through access restrictions is the most widely used means of reducing deforestation and forest degradation, there has been little consideration of how enforcement changes collection behaviour and thence spatial resource patterns when determining patrol locations, and few data exist to inform models of spatial enforcement strategies.

Therefore, through this study, our goal was to help develop research that explicitly considers the spatial outcomes of deforestation and forest degradation prevention policies, especially regarding topics such as the spatial decision-making of NTFP collectors and the selection of priority areas for patrolling in protected areas in developing countries, from the perspective of human geography. As an approach to this, we focused on the 'awareness' of NTFP collectors toward deforestation and illegal extraction of trees; such awareness has not been examined much in the context of the spatial patterns of NTFP collection and the deforestation or degradation described above. Meyfroidt (2013), by using a local case study of forest transition in Vietnam, emphasized that knowledge of how local actors perceive, interpret, and evaluate forest scarcity and degradation is a prerequisite for changing their next actions and land-use practices. Few studies in the NTFP literature have used geospatial information to examine how different degrees of surrounding deforestation alter the behaviour of NTFP collectors over short periods of time, with the exception of the work of Ehara et al. In an area adjacent to a wildlife sanctuary in Cambodia, Ehara et al. (2016) found that households whose main livelihood was NTFP collection were more likely to consider that they were negatively affected by NTFP collection the more severe the degree of deforestation within a 10 km-radius of their village centre. Ehara et al. (2018) also found that 20% of the affected households subsequently opted for coping strategies that converted the surrounding forest to agricultural land to compensate for the decrease in income that had previously been earned from the collection of the NTFPs. Our aim was to contribute to the discussion of spatial enforcement strategies (especially patrol strategies in and around an existing wildlife sanctuary) and to the discussion of other spatial forest conservation interventions. We achieved this aim by examining the local people's patterns of NTFP collection and the next possible coping strategies they were likely to take, by using their awareness of the impacts or consequences of deforestation and/or illegal extraction of trees on NTFP collection.

This paper is structured as follows. First, the context of the study site, an area adjacent to the Prey Long Wildlife Sanctuary (PLWS) in the eastern part of Kampong Thom (KT) Province, Cambodia, is introduced. Next, the conceptual framework used in this study is introduced. This is followed by a section explaining the materials and methods used 1) to predict the spatial distribution of villages with NTFP-collecting households that were aware of the impacts or consequences of deforestation and/or illegal extraction of trees (in other words, that were affected by these events) by using their awareness data and statistical models, and 2) to identify *priority areas for NTFP collection*. The Results section has three components. First, we describe the types of NTFPs collected in the case study area and the NTFPs that were the sources of cash income. Secondly, we present the modelling outcomes that predicted the spatial distributions of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees between 2014 and 2016. Thirdly, on the basis of the modelling outcomes, we show the identified *priority areas for NTFP collection*. In the Discussion, first, with reference to previous studies of the spatial patterns of NTFP collection and on the basis of the statistical modelling outcomes, we discuss the spatial patterns of the NTFP-collecting households' awareness of deforestation and/or illegal extraction of trees. Secondly, on the basis of the predicted spatial distributions of villages with affected households and the identified *priority areas for NTFP collection*, we discuss the implications for patrolling in and around the existing wildlife sanctuary. Thirdly, we discuss some implications for implementing policies for reducing deforestation and forest degradation, which will be of interest to an international audience. Finally, on the basis of the findings of our study, we propose refinements to Bohensky and Lynam's (2005) three scopes of the conceptual framework that we used.

2. Materials and methods

2.1. Study site

In our study country—the Kingdom of Cambodia—all forest areas are owned by the state and exploitation of forest resources is permitted under concessions for timber logging, agribusiness and residential areas, as well as agricultural land in the case of poorer communities (Schmidt and Theilade, 2010). All logging concessions have been under a moratorium since 2002 owing to problems with illegal logging (Ministry of Agriculture, Forestry and Fisheries Cambodia, 2010). Because of the moratorium and ineffective alternatives for managing past concession areas, the forest areas in Cambodia have been labelled as being in a 'management vacuum' by some researchers (Hansen and Top, 2006; Nathan and Boon, 2012).

We conducted this study to the east of a provincial town in KT Province (105°14'43''–105°36'19''E, 12°30'27''–13°15'35''N), which is one of the seven provinces in Cambodia considered to be particularly poor (Asian Development Bank, 2014) (Fig. 1). The province has an area of 12,447 km^2. In KT Province, the annual average temperature is 27 °C and the annual average rainfall is 1300–1900 mm; the dry season runs from November to February (Araki et al., 2007; Kabeya et al., 2008). The total population was 690,414 in 2013, and its growth rate from 2008 to 2013 was 1.79% (National Institute of Statistics, 2013). In 2016 approximately 38.4% of the land in KT Province was forested (Ministry of Environment Cambodia, 2018), with four dominant forest types: evergreen, deciduous, mixed (evergreen and deciduous), and inundated forest. Forest cover was 49.8% in 2010 (Forestry Administration Cambodia, 2011), showing the recent rapid deforestation in the province from 2010 to 2016. Most of the forest occurs in lowlands or on plateaus less than 100 m above mean sea level.

At the study site, many villages are located along National Road 6 and on the eastern side of the Stung Sen River (Fig. 1). Rural people in the study area depend on oleoresin (liquid resin) extracted mostly from *Dipterocarpus* species, used for lighting, sealing boats, paints, varnishes and perfume fixatives, for cash income, and on other NTFPs for subsistence (Ehara et al., 2016; Evans et al., 2003; Dyrmose et al., 2017; Hayes et al., 2015). For residents in or near Permanent Forest Reserves, the government assures their subsistence consumption of forest products and byproducts, including the right to barter or sell forest byproducts, as long as they do not pose a substantial threat to the sustainability of the forest (RGC, 2002), although 'sustainability' is not defined in the Law on Forestry. In addition, residents can manage part of the state forest demarcated and registered as Community Forestry (CF) by the Forestry Administration (FA) for both commercial and subsistence purposes under certain conditions (RGC, 2002). CF members are required to protect and plant species for the conservation of the forest (RGC, 2003). The FA registers community forests by assessing community requests for their establishment, with the involvement of local authorities or the local Commune Council. The registration process requires the proposed area to be mapped by FA officials, and a written application and a forest management plan are developed by the community with FA support (RGC, 2003).

The area, however, has experienced severe deforestation since the 2000s (Ehara et al., 2016; Matsuura et al., 2013). 20% of the households whose main livelihood was NTFP collection and that have been evaluated as affected by deforestation (within a 10-km radius of the centres of their villages) and/or illegal extraction of trees have subsequently chosen the coping strategy of converting the surrounding forest to agricultural land to compensate for the reduced income they were earning from NTFP collection (Ehara et al., 2018). This deforestation feedback loop created by local actors is a typical example of the phenomenon caused by actions labelled by Suckall et al. (2014) as 'maladaptive coping strategies'. They argue that these local people's coping strategies in response to land-use changes can be evaluated as 'maladaptive', because they can create conflicts among natural resource users and undermine long-term development goals.

To address deforestation pressures and mitigate their impacts on local people in Cambodia, earlier studies have proposed interventions, including cautious allocation of economic land concessions (Ministry of Agriculture, Forestry and Fisheries Cambodia, 2010); justification of forests' and forest programs' substantial economic and social benefits (Dyrmose et al., 2017; RGC, 2010); recruitment of forest-dependent residents as CF guards by using the Commune Development Fund (Persson and Prowse, 2017); and identification of marketable NTFPs and improvement of the management of commercial NTFPs (Boissière et al., 2013; Ministry of Agriculture, Forestry and Fisheries Cambodia, 2010). In response to these challenges, in 2016, the Prey Lang Wildlife Sanctuary (PLWS, 431,683 ha) was established across four different provinces: KT, Stung Treng, Kratie, and Preah Vihear (RGC, 2016). The PLWS is considered to be a Protected Area. Under the Law on Natural Protected Areas, NTFP collection by local ethnic minority communities to support their livelihoods is legal in the conservation zone and community zone, provided that the access has the prior consent of the administrative body and the impacts of collection on biodiversity are taken into account (RGC, 2008). Moreover, to reduce greenhouse gas emissions from deforestation and forest degradation and thus mitigate global climate change, two REDD+[1] projects have been implemented: the Prey Lang REDD+ Project in the PLWS and the adjacent area to its north-east; and the Tumring REDD+ Project to the south-west of the PLWS.

2.2. Conceptual framework

Social-ecological systems in which all human-used resources are embedded (Ostrom, 2009) are increasingly understood as complex

[1] REDD+ (Reducing Emissions from Deforestation and forest Degradation, plus the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) has been recognized as one of the key climate change mitigation measures under the Paris Agreement adopted at the 21st Conference of the Parties in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC, 2015).

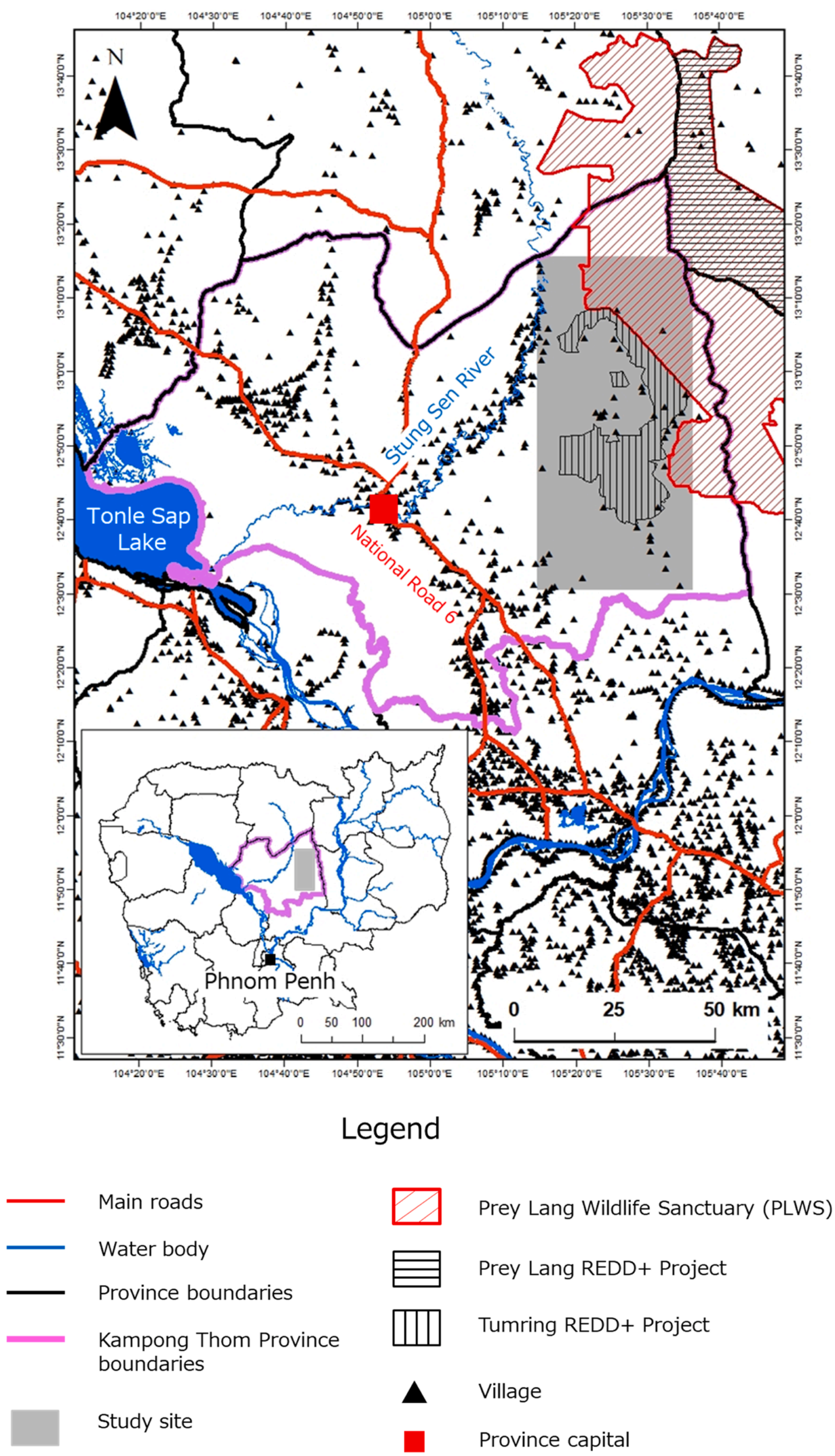

Fig. 1. Location of the study site in Kampong Thom Province, Kingdom of Cambodia.

adaptive systems (Levin et al., 2013). To evaluate the effectiveness of human responses in maintaining social and ecological resilience or withstanding changes in complex adaptive systems, Bohensky and Lynam (2005) used three scopes: *the scope of an impact*; *the scope of awareness of the impact*; and *the scope of the power or influence to respond*. We used the first two scopes as a conceptual framework in our study to examine local people's NTFP collection patterns by using the impacts or the consequences of a change (i.e., deforestation and/or illegal extraction of trees) and the people's awareness of the impacts or the consequences. Bohensky and Lynam (2005) argue that the same situation can affect different groups or locations differently, either in space, in time, or both. People in complex adaptive systems have a good chance of selecting and implementing effective responses if they are fully aware of the impacts or consequences, and the causes, of a change and have the power to alter the processes driving those changes (Bohensky and Lynam, 2005). According to Bohensky and Lynam, the scope of the awareness further consists of two elements. The first element is the awareness of the impact or consequences of a change and the second element is the awareness of the direct and indirect drivers of the observed or expected change. We paid particular attention to the first element in our application of the framework, because people in complex adaptive systems will not consciously respond to a change unless they are aware of it (Bohensky and Lynam, 2005). Similarly, Meyfroidt (2013) argues that understanding the perception, interpretation, and evaluation of forest scarcity or degradation by local actors is a prerequisite to changing their land-use practices.

Here, we argue that the spatial distribution of villages with NTFP-collecting households that were aware of the impacts of deforestation and/or illegal extraction of trees, including those who might implement maladaptive coping strategies, needed to be understood to achieve the aims of our study (i.e., to contribute to the discussion of spatial enforcement strategies—especially patrol strategies in and around the existing wildlife sanctuary—and the discussion of other spatial forest conservation interventions). This is, first, because spatial information on where local residents use NTFPs is required for better management of forest ecosystem services (Matsuura et al., 2014; Sheil and Salim, 2012). Secondly, residents may differ in their awareness and perception of an environmental problem and the suitable countermeasures, depending on where they live and whether they are affected by the problem (Bradford et al., 2012; Marshall et al., 2005; Meyfroidt, 2013). Thirdly, although individual coping strategies may be limited in their temporal and spatial scales, they may influence the drivers of environmental change at longer and larger scales if they are aggregated (Carr et al., 2007). Thus, policy interventions that are not informed by the spatial distribution of residents who are particularly vulnerable to the impacts of deforestation and/or illegal extraction of trees on NTFP collection may impede the implementation of effective land development; they may also continue to create a population that implements maladaptive coping strategies and may not break the feedback loop of deforestation.

2.3. Data collection

Our data collection consisted of three components. First, we acquired 2014–2016 deforestation data at the study site by overlaying two forest-cover maps derived from satellite imagery and by examining the change in land cover (Section 2.3.1). Secondly, to select sample villages, data on the locations of villages, waterbodies, and main roads, available at Open Development Cambodia (ODC, 2022), CF (FA, unpublished) and the PLWS (Ministry of Environment of Cambodia, unpublished), were collected (Section 2.3.2). Thirdly, we conducted face-to-face interviews with the occupants of 404 households in the sampled villages by using a structured questionnaire from December 2016 through February 2017 (Section 2.3.3). The procedures used are explained in the following sections.

2.3.1. Delineation of the deforested area

To ascertain the area deforested from 2014 to 2016, we examined the change in land cover by overlaying two forest-cover maps. These maps were obtained from object-based image classification of cloud-free Landsat 8 imagery taken early in the dry season (on 12 January 2014 and 2 January 2016), by using eCognition 8.8 software (Trimble Co., Inc., Sunnyvale, California, USA). In the classification, the Landsat imagery was first segmented into small polygons with similar colour, brightness, and texture. After the exclusion of waterbodies by using a land and water mask, the remaining land covers were classified into three classes, i.e., evergreen forest (including evergreen–deciduous mixed forest), deciduous forest, and non-forest. For the classification, we used a threshold of mean NDVI (normalized difference vegetation index) values in each segment for each land-cover class. As there were burned areas in the Landsat imagery taken on 2 January 2016, we added this class for 2016, and later merged it into non-forest. We took sample segments with a minimum area of about 3 ha in every 3-km cell within the study area and visually interpreted their land-cover classes by using the Landsat imagery and other ancillary satellite imagery of finer resolution available from Google Earth. Pixel values in half the sample segments were used for supervised classification (i.e., nearest-neighbour classification), whereas pixels in the other half of the sample segments were used for verification. The overall accuracies of the land-cover maps for 2014 and 2016 were 93% and 96.7%, with kappa statistics of 0.85 and 0.94, respectively. Owing to the difficulty in recognizing deciduous forest from Landsat imagery taken in the dry season, deciduous forest areas, covering approximately 11.8% of the KT Province, were further excluded from our analysis by using a manually interpreted forest cover map from 2010[2] (Forestry Administration Cambodia, 2011). We also visually delineated large-scale rubber plantation areas of various ages, mainly in economic land concessions. These rubber plantations have the typical appearance of homogeneous land cover with a regular grid of farming roads in the Landsat imagery.

2.3.2. Village and household sampling

A staged sampling method (Shively, 2011) was applied to select villages from which households were randomly sampled; the process used is shown in Fig. 2. As a commune, which is an administrative subdivision of a district in Cambodia, consists of several villages, we used the commune as the first unit from which villages were sampled. Communes are administrative units where vital decision-making at the local level takes place through the election of commune councils; they are part of Cambodia's decentralization process, which aims to deepen democracy and help to reduce poverty (Higginson et al., 2013).

Communes that had National Road 6 within their administrative boundaries were excluded from potential samples. Both Ehara et al. (2015) and our field observation indicated that few households within the highly populated strip within 10 km of the road depended on NTFPs. Communes that had forest cover of less than 100 ha in 2016 were also excluded from the study, because one of our aims was to identify *priority areas for NTFP collection* where the proposed interventions should be preferentially implemented; this required a greater area of forest. Next, we checked whether or not the commune had a community forest within

[2] This map had eight land-cover classes: evergreen forest, deciduous forest, mixed (evergreen and deciduous) forest, evergreen scrub, deciduous scrub, other forest (i.e., plantation, inundated or degraded forests), bamboo thicket, and non-forest. The overall accuracy of the preliminary version of this map with two additional classes (mangrove forest and rubber plantation) for all of Cambodia was 85%, which was based on 304 stratified random sample points (Forestry Administration Royal Government of Cambodia, unpublished). About one-third (104) of these sample points were taken in the field, whereas other points (particularly the more homogeneous land covers distant from roads) were interpreted from the Landsat imagery by a skilled image analyst, independently of the map interpreter.

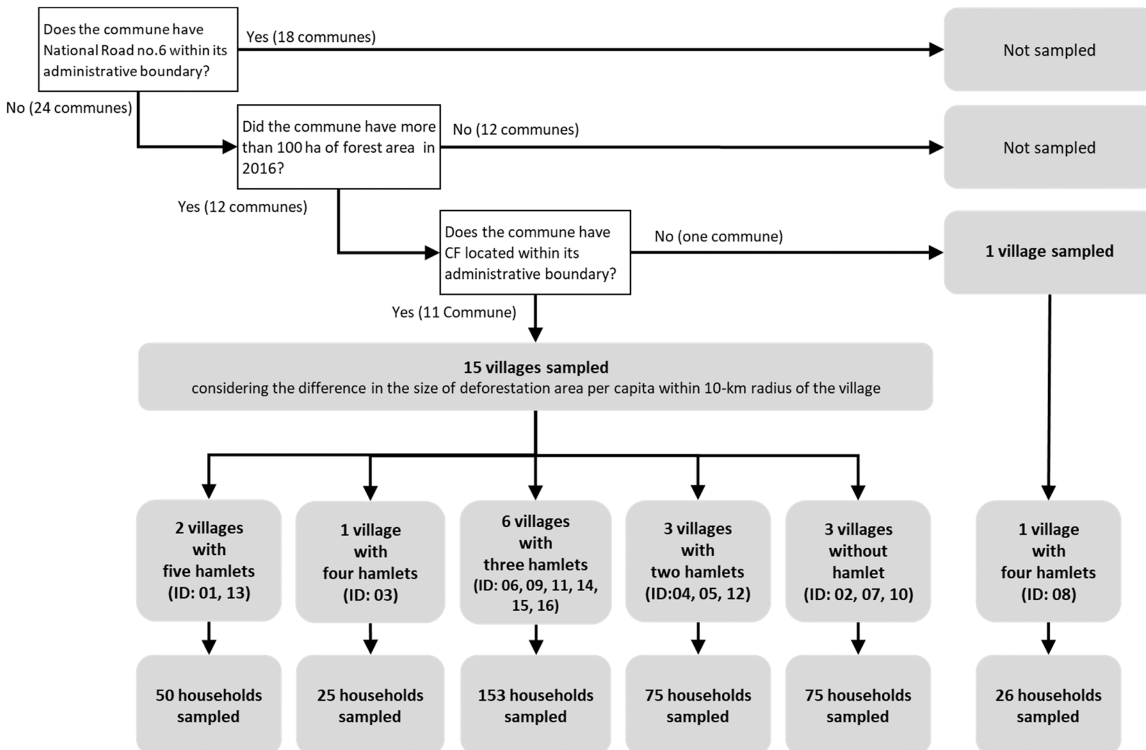

Fig. 2. Sample village selection process.

its administrative boundary. Ehara et al. (2015) reported that, although a village might have relatively high deforestation per capita within a 10-km radius, if the forest environment for NTFP collection inside its community forest was maintained, the villagers were less affected by deforestation. There were 11 communes with community forests and one commune without a community forest; in total, 15 villages were sampled from the former and one village from the latter. In the sample selection, villages located on the western side of the Stung Sen River were excluded, because there were few bridges crossing the river and households in those villages had few land-use activities in our study site on the eastern side of the river. Ehara et al. (2016) found that households whose main livelihood activity was NTFP collection before deforestation were more likely to be affected by larger areas of deforestation per capita within a 10-km radius of the village than by smaller areas. Therefore, we sampled villages considering differences in the size of the 2014–2016 deforestation area per capita within a 10-km radius of the village. We created a circular buffer (a 10-km-radius circle) from the centre point of each sample village and calculated the 2014–2016 deforested area within the circle. To calculate the deforested area per capita, the deforested area was divided by the population of all the villages whose centre points were within the circle. The population was estimated by using the total population of villages within a 10-km radius of the sample village, which was obtained from a national census conducted in 2008 (ODC, 2022), and the population growth rate for KT Province between 2008 and 2013, as reported by the National Institute of Statistics, Cambodia (National Institute of Statistics, 2013). We regarded this 2013 population estimate as the best available dataset to represent the population during 2014–2016 at the study site, as it allowed us to calculate the spatial distribution of the population. These calculations were conducted by using a geographic information system (GIS), ArcGIS10.6 (ESRI Co., Ltd., Redlands, California, USA). Although we tried to sample villages by considering the proportion of villages in each group as much as possible, we also had to consider the accessibility of the villages for household interviews by the authors.

In each sampled village, we determined the complete distribution of hamlets and households by asking the village chief or vice chief, or both, to draw a hamlet and household distribution map before household sampling took place. This mapping showed that the number of hamlets in that village varied, ranging from none to five. We sampled households from all the hamlets. The Poverty Environment Network[3] Technical Guidelines suggest, as a rule of thumb, that the minimum sample should be 25–30 households from each village if the village size is in the range of 100–500 households (PEN, 2007). As all our sample villages had fewer than 500 households, we sampled 25 households per village. The first household in each village was randomly selected from the map, and we visited every third household in the village in the period from December 2016 to January 2017, when the field survey was conducted. In the case of absence or rejection, we moved to the next third household. This resulted in 404 sampled households from 16 villages (45 hamlets). Table S1 gives an overview of the sampled villages with hamlets.

2.3.3. *Questionnaire survey*

We conducted structured interviews of sample households by using a questionnaire developed by Ehara et al. (2016). Our goal was to obtain data from NTFP-collecting households that were aware of the impacts of deforestation and/or illegal extraction of trees. The survey was conducted from December 2016 through February 2017. The questionnaire asked about the household size and household members' ages, education levels, migration experience, and membership of CF. The questionnaire also asked about participants' historical (2014) and current (2016) collection of NTFPs and about their awareness of changes in NTFP availability. For each year, we asked where they collected NTFPs (e.g., the direction and distance from their houses and the type of local vegetation in the area), the reasons for (causes of) the changes (if the

[3] The Poverty Environment Network (PEN) is an international network and research project on poverty, environment and forest resources, organized by the Center for International Forestry Research (CIFOR). It collects tropics-wide uniform socioeconomic and environmental data at the household and village levels in 25 countries.

availability changed), the importance of the changes to the household (see next paragraph for details), and the reason why the change was important or unimportant. NTFPs were classified into 19 categories in accordance with earlier studies (Boissière et al., 2013; Ehara et al., 2016; Ra et al., 2011). The NTFPs referred to here are only those collected in forests (evergreen, semi-evergreen, and deciduous forests); products collected from areas with other types of vegetation were not referred to as NTFPs in this study. The questionnaire also asked about household assets (land, livestock, durables, and housing), the main livelihood activities of household members in 2014 and in 2016, and their experience of forest clearance (for other land uses) between 2014 and 2016.

We measured the importance of the changes in the availability of NTFPs to the household by using a scale consisting of four ordinal-level categories ranked along a continuum (Neuman, 2010), where a score of 1 indicated that the household was unaffected, 2 slightly affected, 3 affected and 4 strongly affected. These impacts of changes in availability were then categorized as either 'low' (1 or 2) or 'high' (3 or 4). If a household identified at least one NTFP category as affected or strongly affected by deforestation and/or illegal extraction of trees providing NTFPs during the 3 years, this household was categorized as 'highly affected'. We then labelled households that were categorized as 'highly affected' into two categories depending on resin collection status: *affected resin-collecting households* and *affected other-NTFP-collecting households*. Additional information that helped to determine the pure impacts of deforestation and/or illegal extraction of trees providing NTFPs was recorded but not included in our analysis. This information included the abandonment of NTFP collection owing to aging of household members and reduced market demand for NTFPs.

Although there were limitations in relying on the interviewees' recollection of historical facts [i.e., we could not assess the accuracy of recalled data in terms of time (2014 historical data) and space (travel distance and direction of collection)], we believe that the recalled data were reliable for our purposes. Previous studies show that highly salient life events, such as changes in livelihood patterns, are likely to be consistently reported up to 12 years later (Beckett et al., 2001). Moreover, residents in our study area were used to being asked similar questions in an annual complete household survey that was used to construct the Commune Database (National Committee for Subnational Democratic Development, n.d.), which supports provincial planning.

2.4. Data analysis

2.4.1. Distribution prediction models and their validation

The information-theoretic approach described by Burnham and Anderson (2002) was used to model the data. Variables used in model selection are explained in the following paragraph, and their descriptive statistics are presented in Table 1. All possible subsets of explanatory variables shown in Table 1 were modelled to predict the occurrence probability of *affected households* in a village or hamlet by using generalized linear mixed effect models (GLMMs, binomial distribution and logit link function): $g(p_i) = \beta_1 + \beta_2 X_i + \beta_3 f_i \ldots + r_i$, where p_i is the probability of encountering an *affected household* at sample village/hamlet i; g is the logit link function between p_i and each term provided in the right side of the equation; and r_i is village/hamlet ID as a random term. The response variable was the proportion of *affected resin-collecting households* in the sample villages or hamlets in the case of the resin models (*RESIN*), and the proportion of *affected other NTFP-collecting households* in the sample villages or hamlets in the case of the other NTFP collection models (*OTHER*).

The explanatory variables used for model construction were as follows. The variance inflation factor between these explanatory variables in both the *RESIN* and *OTHER* models was less than 2, and non-significant multicollinearity was found in each model.

DefoPercap10km (the deforested area per capita within a 10-km radius of a village or hamlet) was used for the *OTHER* models, and *DefoPercap20km* (the deforested area per capita within a 20 km-radius of a village or hamlet) was used for the *RESIN* models. According to Albers and Robinson (2013) in their review of the spatial economics of NTFP extraction, extractors live at the edge of the forest and the extractors determine the one-dimensional distance at which forest degradation occurs. In the review, they introduce their previous work (Albers and Robinson, 2011), which found that, if we aggregate or extrapolate these one-dimensional determinations to cover the entire landscape, we need to assume a distribution of villagers, and if there is a homogeneous landscape and one central village or market, one way of extrapolating this is to draw concentric land-use circles around that central point. Woodward et al. (2021), who conducted remote-sensing analyses focusing on NTFP collection and grazing in a southern African landscape, recommended the inclusion of covariates reflecting proxies of population density and mobility in studies attempting to characterize communal resource use when Landsat's spectral signatures alone do not adequately capture resource-use intensity. At our study site, we found previously that the probability of households that collected NTFPs being affected by deforestation within a 10-km radius of their village increased with increasing deforested area per capita within this radius if NTFP collection was a principal livelihood activity before the deforestation (Ehara et al., 2016). We also knew that some resin collectors travelled farther than 10 km from their villages in the study area (Ehara et al.,

Table 1
Variables used in model selection.

Used for	Name of variable	Description	Mean value	Standard error	Maximum value	Minimum value
Response variable						
RESIN model	*RESINaffected*	Proportion of *affected resin-collecting households* in the sample villages or hamlets	0.05	0.01	0.50	0.00
OTHER model	*OTHERaffected*	Proportion of *affected other NTFP-collecting households* in the sample villages or hamlets	0.12	0.02	0.50	0.00
Explanatory variable						
RESIN model	*DefoPercap20km*	Area deforested per capita (ha) during 2014–2016 within a 20-km radius of a village/hamlet	0.92	0.12	3.16	0.07
RESIN model	*ProportionR14*	Proportion of resin-collecting households in our sample in each sampled village or hamlet in 2014	0.09	0.02	0.84	0.00
OTHER model	*DefoPercap10km*	Area deforested per capita (ha) during 2014–2016 within a 10-km radius of a village/hamlet	0.87	0.09	3.43	0.08
OTHER model	*ProportionO14*	Proportion of households collecting other NTFPs for cash income in our sample in each sampled village or hamlet in 2014	0.15	0.03	0.72	0.00
RESIN and *OTHER* models	*PLWSdist*	Linear distance (km) between PLWS and the centre point of a sampled village/hamlet	12.01	1.47	33.50	0.10
RESIN and *OTHER* models	*ProportionCFmember*	Proportion of households with a CF member or members in our sample in each sampled village or hamlet in 2016	0.36	0.05	1.00	0.00

2018) and in other areas of Cambodia (Mckenney et al., 2004). From these findings, we assumed that the impacts of deforestation and/or illegal extraction of trees on NTFP collection, in terms of the awareness of NTFP collectors, occurred within a 20-km radius of the village for resin collection and within a 10-km radius of the village for other types of collection. We drew circles of 10-km radius and 20-km radius from the centre point of each sampled village or hamlet and calculated the deforested area per capita for the 2014–2016 period by following the same steps as those described in Section 2.3.2.

ProportionR14 (the proportion of resin-collecting households in our sample in each sampled village or hamlet in 2014) was used for the *RESIN* models, and *ProportionO14* (the proportion of households collecting other NTFPs for cash income in our sample in each sampled village or hamlet in 2014) was used for the *OTHER* models. These two variables were based on the results of a preliminary analysis of data comparing the percentages of *affected households* in household groups with (yes) and without (no) members whose primary or secondary occupation was NTFP collection (Fig. 3). The former ('yes' group) was more likely to be *affected* than the latter ('no' group). In the former group, 23 households were *affected households* (resin-collecting and other NTFP-collecting households combined); 70% of them ($n = 16$) collected resins, and all 16 of them said that cash income from resin collection decreased. In the latter ('no' group), 45 households were *affected households* and 69% of them ($n = 31$) said that they were affected because cash incomes from resin, rattan, or tarantula (for food) collection had decreased.

PLWSdist (the linear distance between the PLWS and the centre point of the sample village or hamlet) was used in both the *RESIN* and the *OTHER* models. Resin collection is an important source of cash income for the region (Ehara et al., 2016; Dyrmose et al., 2017; Hayes et al., 2015). If we apply *the scope of impact* part of the conceptual framework to our case, people who largely depend on resin collection for their livelihoods will be more aware of the impact or consequence of forest destruction on resin. In a managed common property regime, less labour and extraction occurs at each point in space, resulting in the same pattern of resource degradation as in the unmanaged case, but with lower levels of degradation at each point (López-Feldman and Wilen, 2008). Despite the continuous deforestation and illegal extraction of trees around the villages (Ehara et al., 2018), we assumed that most resin-yielding trees remained in and around the PLWS, where forest resource exploitation pressures were lower than in other areas. Therefore, we considered *PLWSdist* as an important variable for both the *RESIN* and the *OTHER* models.

ProportionCFmember (the proportion of households with a CF member or members in our sample in each sampled village or hamlet in 2016) was used for both the *RESIN* and the *OTHER* models. Communities with open-access forests have more regular spatial and temporal resource extraction patterns, with higher levels of degradation near villages, whereas communities with strong property rights and the ability to plan for the future have spatial patterns of resource extraction that vary dramatically over time and space (Albers and Robinson, 2013). If the latter were the case at our study site—i.e., if the forest environment for NTFP collection inside the community forest were maintained and the household members were CF members, then the households might have been less affected by deforestation and/or illegal extraction of trees. Therefore, this variable was created to examine whether differences in the proportion of households with a CF member or members in the sampled village or hamlet had an influence on the probability of households being affected.

To select the best-fit models for the *RESIN* and the *OTHER* models, from the full suite of possible models, we used a theoretical information approach based on the corrected Akaike information criterion (AICc). To determine the important independent variables in the GLMMs, we applied model averaging because of its practical and theoretical advantages, particularly in terms of prediction (Burnham and Anderson, 2002). All statistical analyses were performed in R v. 4.2.1 (R Core Team, 2022) with the lme4 package for GLMMs (Bates et al., 2015) and the MuMIn package for model averaging (Bartoń, 2022), both available in the R library.

The area under the curve (AUC) value, which was derived from the receiver operating characteristic (ROC) analysis, was used to assess the prediction accuracy of the two types of models. The AUC values range from 0.5 for models with no discrimination ability to 1 for models with perfect discrimination (Swets, 1988). A model with an AUC between about 0.70 and 0.90 has an accuracy that is useful for some purposes, and higher AUCs represent more accurate models (Swets, 1988). AUCs were calculated by using the 'auc' function in the PresenceAbsence package (Freeman and Moisen, 2008) available in the R library.

2.4.2. Predicting the distribution of villages with affected households

Considering the results of the AICc-based *RESIN* and *OTHER* candidate models, and the relative importance of the explanatory variables derived from model averaging (Table 2 and Table S2), the top-ranked models for resins and the other NTFPs were selected as the best models. We used the kriging function, which is an interpolation method in ArcGIS, to obtain the predicted values of *ProportionR14* and *ProportionO14* for villages that we did not visit. Kriging is effective when the sample size is small or when data with measurements of low precision are interpolated. These values were used in the best models for *RESIN* and *OTHER*, respectively, to calculate the probabilities of having *affected households* in unvisited villages.

2.5. Identifying priority areas for NTFP collection

Identifying *priority areas for NTFP collection* facilitates the discussion of spatial enforcement strategies— particularly the implications for patrolling an existing wildlife sanctuary. To predict the spatial distribution of each *priority area for collection of resins and other NTFPs*, we used *ProportionR16* (mean: 0.06, maximum: 0.74, minimum: 0.00), which was the proportion of resin-collecting households in our sampled households in each sampled village/hamlet in 2016 and *ProportionO16* (mean: 0.14, maximum: 0.64, minimum: 0.00), which was the proportion of households collecting other NTFPs for cash income in our sampled households in each sampled village/hamlet in 2016, as socio-economic geographic indicators. We considered that these were important indicators because of the high relative importance of the variables for *ProportionR14* and *ProportionO14* in our models. The threshold for both *ProportionR16* and *ProportionO16* for selecting villages to be included in the priority area mapping was set at 0.05 (i.e., if a village/hamlet was predicted to have less than 5% of all households collecting resin or collecting other NTFPs for cash income, the village/hamlet was not considered in the priority area mappings). We used the

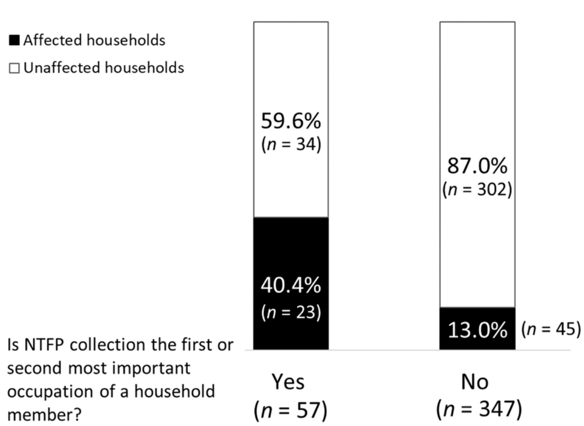

Fig. 3. Proportions of households with members who collected NTFPs as their main occupation (first or second most important occupation) (chi-squared test, $P < 0.001$).

Table 2
Results of model averaging for the *RESIN* and *OTHER* GLMMs.

Explanatory variable	β	SE	CI	RI
RESIN model				
ProportionR14	**3.086**	**0.862**	**1.344, 4.744**	**1.00**
PLWSdist	**− 0.123**	**0.059**	**− 0.243, − 0.004**	**0.88**
DefoPercap20km	− 0.083	0.326	− 1.538, 0.774	0.25
ProportionCFmember	0.111	0.513	− 1.421, 2.474	0.24
OTHER model				
ProportionO14	**4.184**	**0.800**	**2.582, 5.788**	**1.00**
DefoPercap10km	**0.923**	**0.448**	**0.285, 1.741**	**0.91**
PLWSdist	0.004	0.012	− 0.019, 0.052	0.28
ProportionCFmember	0.084	0.406	− 1.147, 1.940	0.23

β, coefficients; SE, standard error; CI, confidence interval (2.5–97.5%); RI, relative importance of variable; *ProportionR14*, proportion of resin-collecting households in our sample in each sampled village or hamlet in 2014; *ProportionO14*, proportion of households collecting other NTFPs for cash income in our sample in each sampled village or hamlet in 2014; *PLWSdist*, linear distance (km) between the PLWS and the centre point of the sample village/hamlet; *DefoPercap20km*, area deforested per capita (ha) during 20014–2016 within a 20-km radius of a village/hamlet; *DefoPercap10km*, area deforested per capita (ha) during 20014–2016 within a 10-km radius of a village/hamlet; *ProportionCFmember*, proportion of households with a CF member or members in our sample in each sampled village or hamlet in 2016. Variables selected in the best models are underlined, and β estimates for which the 95% CI excludes zero are presented in bold.

kriging function of Arc GIS to obtain the predicted value of *ProportionR16* and *ProportionO16* for villages that we did not visit. Because most of the villagers collect resins within a 20-km radius of their villages/hamlets and other NTFPs within a 10-km radius (see **Section 3.2**), we created circular buffers 20 km and 10 km from the village/hamlet centre point, and we extracted the forest areas that overlapped with those buffers. After minor modifications based on the distance and direction from the house to the collection sites identified by the questionnaire, the extracted areas were defined as *priority areas for collection of resin* and *priority areas for collection of other NTFPs*.

3. Results

In this section, we first describe the types of NTFPs collected and the main cash-generating NTFPs at our case study site. We then present the predicted spatial distributions of villages with NTFP-collecting households affected by deforestation between 2014 and 2016, and on the basis of these results, we show the identified *priority areas for NTFP collection*, which we use as information in the Discussion section to facilitate our examination of the strategies used to patrol the existing wildlife sanctuary.

3.1. NTFPs collected by sample households in 2014 and 2016

In 2014, the number of households that collected NTFPs (at least one category) in forests was 237 (58% of all samples). This number decreased to 199 (49%) in 2016. The NTFPs collected in forests by more than 10 households in both 2014 and 2016 included wild fruit, tarantulas, mushrooms, fuelwood, wild vegetables, liquid and dry resins, and medicinal plants (Fig. 4). The main NTFP cash income sources in both 2014 and 2016 were resins and tarantulas, which were most commonly collected for cash income (rather than for self-consumption) (Fig. 4). The average gross cash income of sampled households from the sale of liquid resins in 2016 was approximately $1400; for solid resins, $30; and for tarantulas, $50 (Table 3). Other NTFPs that were collected for cash income (although the numbers of households collecting these items for cash were relatively small) were fruit, mushrooms, wild vegetables, medicinal plants, vines (including rattan), honey, and mammals (Fig. 4).

3.2. Spatial distribution of villages or hamlets with NTFP-collecting households affected by deforestation, 2014–2016

The outcome of the best model for resin collection (Table 2) indicated that the closer the village's or hamlet's proximity to the PLWS (*PLWSdist*), or the greater the proportion of households that collected resins in 2014 (*ProportionR14*), the higher the probability that the village or hamlet had households affected by deforestation and/or illegal extraction of trees. Resins were collected by 36 households (9% of samples), and about 90% of them collected within 20 km of their homes. In the case of the other NTFPs, the outcome of the best model indicated that the larger the area of deforestation per capita within a 10-km radius of the village (*DefoPercap10km*), or the greater the proportion of households that collected NTFPs for cash income in 2014 (*ProportionO14*), the higher the probability that the village had households affected by deforestation and/or illegal extraction of trees. Other NTFPs were collected by 194 households (48% of samples), and more than 90% of them collected within a 10-km radius of their homes. The AUC value for the *RESIN* best model was 0.91, and that for the *OTHER* best model was 0.89.

We mapped the predicted spatial distributions of villages or hamlets with a high probability of the presence of *affected households* collecting NTFPs (Fig. 5). (See Table S1 for the calculated probability for each sample village or hamlet.) Villages with a relatively high probability of having *affected resin-collecting households* were concentrated near the PLWS, whereas *affected other-NTFP-collecting households* were more widely scattered.

3.3. Spatial distribution of priority areas for NTFP collection

We mapped the predicted spatial distributions of *priority areas for NTFP collection*, which were important sources of cash income (Fig. 6). Mapping was performed by superimposing polygons of the CF area and the PLWS, taking into account the traveling distances and directions from the villages to the collection sites of resin and other NTFPs. *Priority areas for resin collection* were confined mainly to the PLWS and surrounding areas. In contrast, *priority areas for other NTFP collection* were observed not only in and around the PLWS but also in the south-western parts of the study area.

4. Discussion

4.1. Spatial distribution of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees

In the *RESIN* model, but not in the *OTHER* model, the distance between the PLWS and the sample village or hamlet (*PLWSdist*) was a strong determinant of a village or hamlet having households affected by deforestation and/or illegal extraction of trees (Table 2). This finding may have been due to the relative abundance of resin-providing trees in and around the PLWS. Albers and Robinson (2011) modelled a two-dimensional forest with various collection 'rays' radiating from a single village consisting of many villagers. They assumed that enforcing access restrictions along one forest ray (or in one area) would deter fuelwood extraction on that ray and that extraction would then be

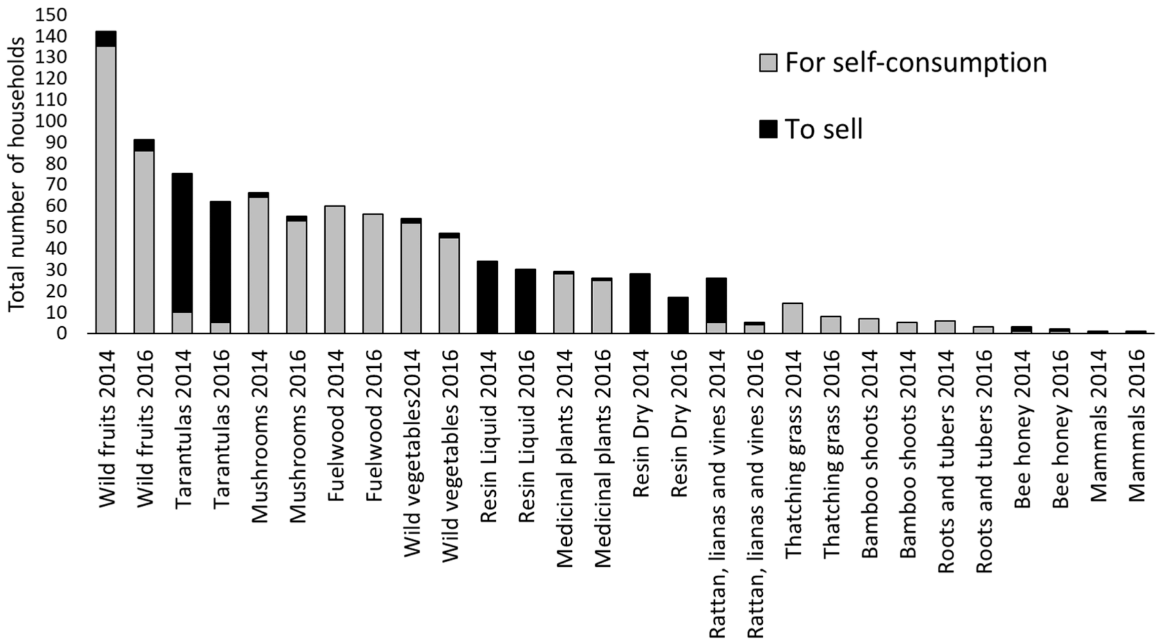

Fig. 4. Types of NTFPs collected in 2014 and 2016.

Table 3
Gross cash incomes of households from resin and tarantulas in 2016 (Units: USD; 1 USD = 4000 riel).

NTFP	Sample size[a]	Mean	Max.	Min.	Median	SD
Liquid resins	26	1393.8	6210.0	35.0	652.1	1475.7
Solid resins	11	31.3	60.0	5.0	28.0	19.2
Tarantulas	46	50.8	300	0.8	25.7	60.8

[a] The number of households from which data on the amount of the NTFPs collected was obtained

shifted to forest areas, represented by clusters (on the same rays or on different rays), that were subject to less (or no) enforcement. In this logic of '*I* rays of *J* equally sized resource clusters radiating from the village' (hereafter, the $I \times J$ cluster model), a circle in which the radius of the ray extends from the centre point of the village will include [1] undegraded forests with no extraction owing to distance costs and enforcement; [2] moderately degraded forests without enforcement at some distance from extractors; [3] moderately degraded forests with enforcement and near extractors; and [4] more heavily degraded forests without enforcement but near extractors (Albers and Robinson, 2013). The logic of the $I \times J$ cluster model, originally intended for application to illegal fuelwood extraction, could also be used to illustrate the difference between the abundance of resin-providing trees and the effect of deterrence of illegal extraction of those trees in our study area. The core of the PLWS is not easily degraded because of high distance costs. The edge of the PLWS that coincided with our study site has CFs positioned as if protecting the PLWS (see Fig. 5). Before the official establishment of the PLWS in 2016, the area was protected from illegal logging by the Ministry of Agriculture, Forestry and Fisheries and by voluntary community patrols, which focused on the protection of resin trees (Soueter et al., 2016). Therefore, the resin-producing species in the area should have remained in a better state than those in other forests where enforcement was much weaker. These forest areas correspond to [3] and [4] in the logic of the $I \times J$ cluster model. However, even so, enforcement is costly and rarely perfect (Albers, 2010; Robinson and Albers, 2006; Rode et al., 2015). Therefore, this would mean that resin collectors were affected by deforestation and/or illegal extraction of trees in 2014–2016 because of the imperfect enforcement. On the other hand, earlier studies have reported that there were few resin-yielding species left by 2014 in the forested areas located relatively far from the PLWS (this corresponds to [4] in the logic of the $I \times J$ cluster model) (Ehara et al., 2016, 2018). In fact, the resin-yielding trees (*Dipterocarpus* spp.) are also important as sources of valuable hardwood and are subject to legal and illegal extraction for timber in Cambodia and other Southeast Asian countries (Dyrmose et al., 2017). Therefore, it is reasonable to assume that, before 2014, the forest in the areas far from the PLWS and not included in *Priority areas for resin collection* was already degraded to a point at which resin extraction was not possible. Even in highly degraded forests far from the PLWS (corresponding to [4] in the logic of the $I \times J$ cluster model), it was still possible to collect NTFPs such as tarantulas, an important source of cash income. For this reason, the distance between the PLWS and the sample village or hamlet (*PLWSdist*) was less important in the *OTHER* model.

In the *RESIN* model, area deforested per capita during 2014–2016 within a 20-km radius of a village or hamlet (*DefoPercap20km*) was not a strong determinant of a village or hamlet having households affected by deforestation and/or illegal extraction of trees, whereas in the *OTHER* model, area deforested per capita during 2014–2016 within a 10-km radius of a village or hamlet (*DefoPercap10km*) was a strong determinant (Table 2). The reason for the relative unimportance of deforestation per capita within a 20-km radius of the village or hamlet (*DefoPercap20km*) compared with the distance between the PLWS and the sample village or hamlet (*PLWSdist*) in the case of resin collection was that, as noted above, our samples included villages or hamlets that, in 2014, already had few resin trees left within a 20-km radius. On the other hand, as also noted above, even in degraded forests (corresponding to [2−4] in the logic of the $I \times J$ cluster model) it was still possible to collect NTFPs such as tarantulas. The importance of deforestation area per capita within a 10-km radius of the village (*DefoPercap10km*) for predicting *affected other-NTFP-collecting households* is supported by similar findings in other studies (Ehara et al., 2016). The area within a 10-km radius of a village is the daily activity area for the villagers. For example, according to Ehara et al. (2018), at the same site, about 65% ($n = 106$) of total sampled households ($n = 161$) had, at some time, cleared forest for agricultural land, and for most of them ($n = 100$) their farthest agricultural land was within 10 km of their homes.

From these findings, we can imagine that villagers collect NTFPs as part of their daily activities around the village where they also have their own agricultural land. This setup was labelled by Albers and Robinson

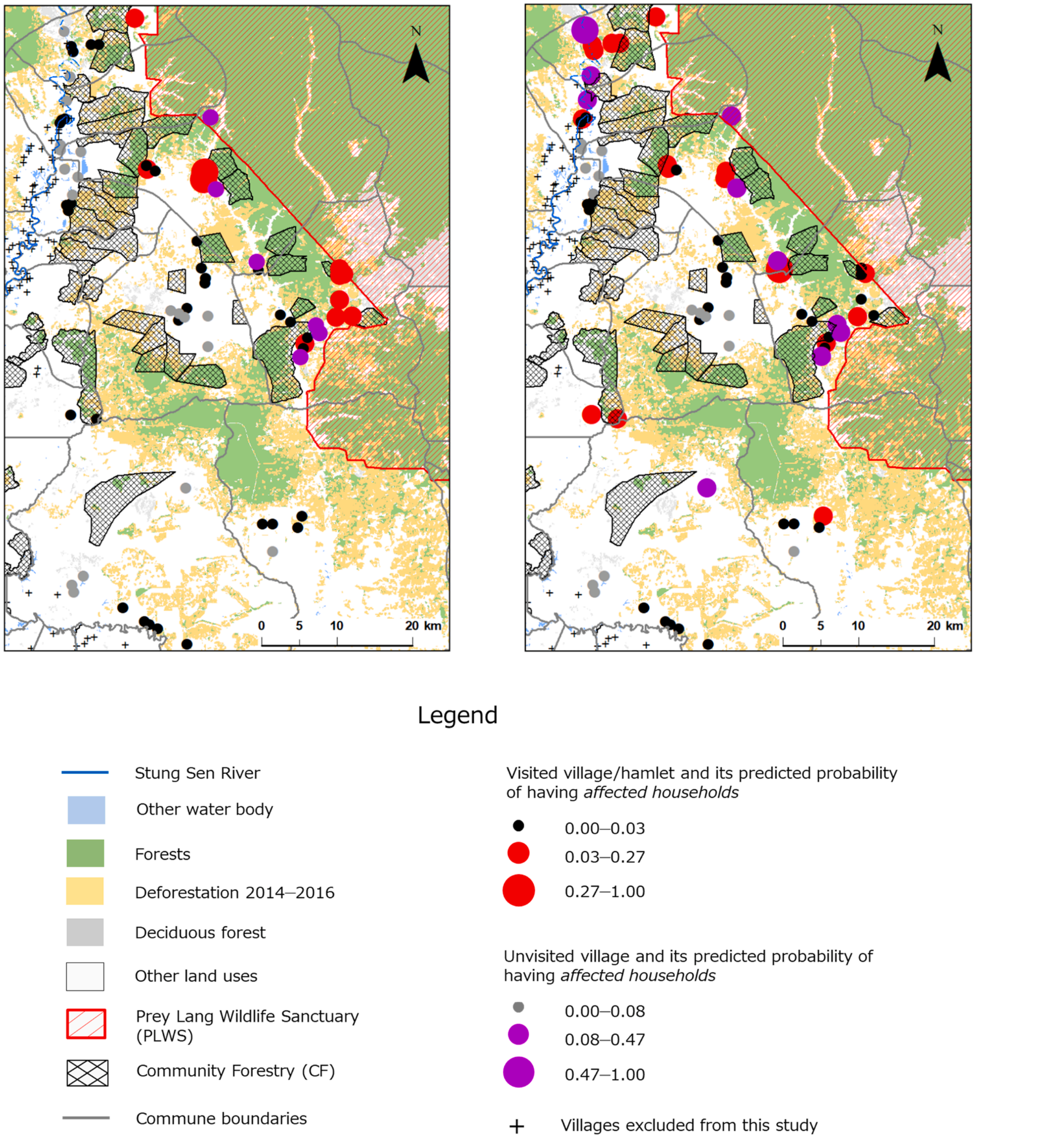

Fig. 5. Predicted spatial distributions of villages with households that were involved in resin collection (left) or other NTFP collection (right) and had been affected by deforestation and/or illegal extraction of trees. The minimum threshold of the scale for the largest circle was based on the observed prevalence (i.e., observed sensitivity, 0.27 for resin collection and 0.47 for other NTFP collection). The minimum threshold of the scale for the medium-sized circle was set as the distance from the ROC curve to the upper left corner of the ROC plot (0.03 for resin collection and 0.08 for other NTFP collection).

(2011) as 'joint action'. However, some villagers make long trips to collect resin, because most collection sites are limited to the PLWS and the surrounding area. Therefore, in the conceptual framework of Bohensky and Lynam (2005) applied to our current study, the environmental geographic indicators that are useful for understanding the varying degrees of awareness of NTFP collectors about the impacts or consequences of deforestation and/or illegal extraction of trees are (1) the distance to the PLWS for resin collection and (2) the area of deforestation per capita within a 10-km radius of the village or hamlet in the case of the collection of other NTFPs.

The proportion of households collecting NTFPs as a source of cash income in a village or hamlet (*ProportionR14*, *ProportionO14*) was an important variable in both the *RESIN* model and the *OTHER* model (Table 2). The first reason for this finding would be that some of these NTFPs contributed directly to the household economy by generating cash income. Given that the average household income in rural Cambodia is about US$4000 (National Institute of Statistics, 2016), liquid resins, solid resins, and tarantulas were important sources of cash income for harvesting households (Table 3). The second reason is that, for NTFP collectors, the decrease in cash income from NTFP collection is easy to recognize. The third reason would be the shift from a subsistence lifestyle based on traditional slash-and-burn agriculture to a lifestyle more dependent on the money economy. For example, at our study site, an increasing number of farmers were selling nuts from cashew trees

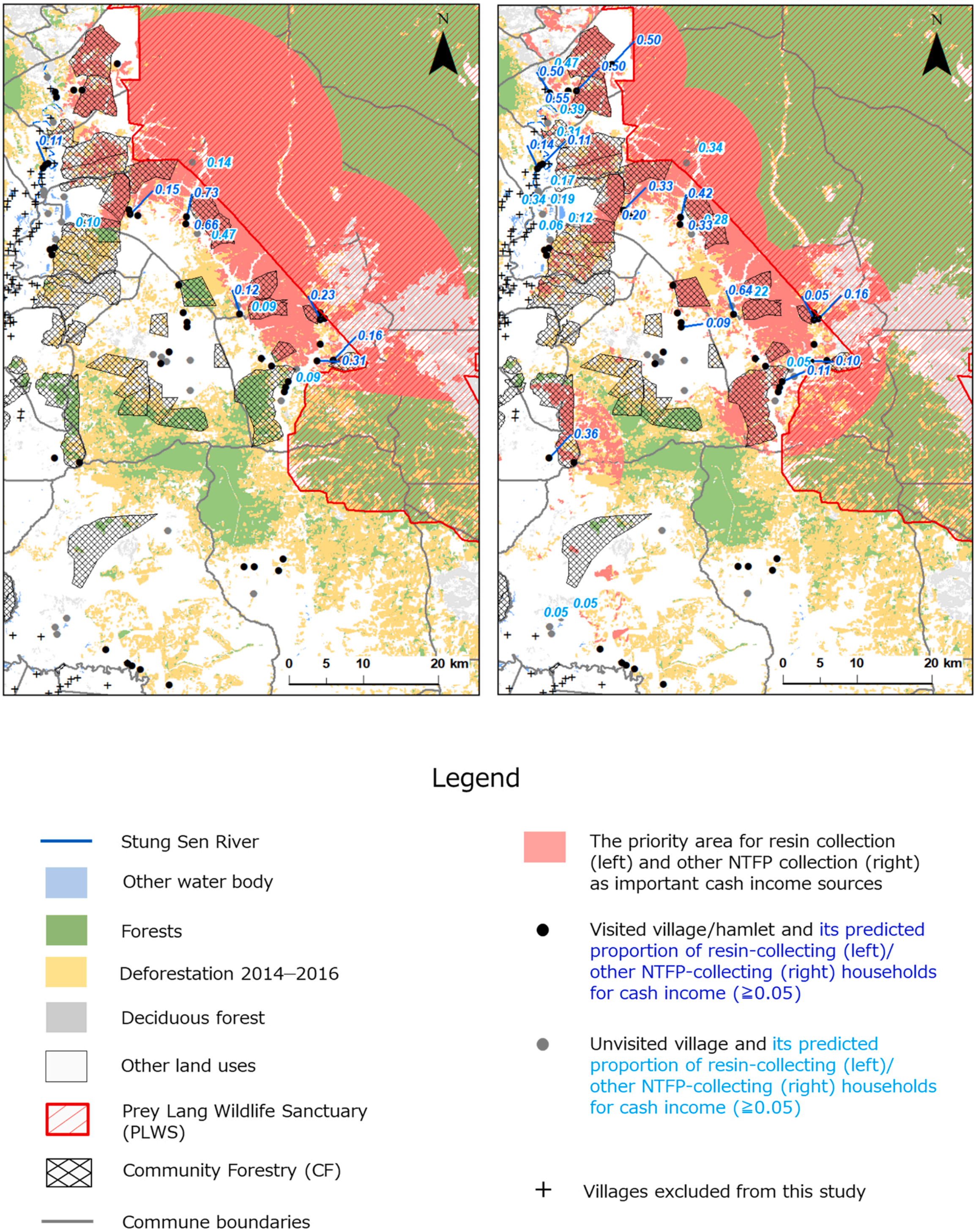

Fig. 6. Predicted spatial distributions of *priority areas for resin collection* (left) and of *priority areas for other NTFP collection* (right) as cash income sources.

planted on their agricultural land or on fallow land (source: the authors' field observations). A similar case of lifestyle shift has been reported in neighbouring Laos. The Laos government policy allocating farmers reduced areas of land for shifting cultivation has led to a severe decrease in hill rice production, and NTFP collection is becoming more commercially oriented (Jakobsen, 2006). These may be the reasons why households collecting NTFPs as a source of cash income more easily became aware that they had been affected by deforestation than did those who did not collect NTFPs as a source of cash income. Therefore, the socioeconomic geographic indicators that are useful for understanding the varying degrees of awareness of NTFP-collecting households about the impacts or consequences of deforestation and/or illegal extraction of trees are (1) the proportion of households collecting resin in the village or hamlet in the case of resin collection and (2) the proportion of households collecting NTFPs in the village or hamlet as a source of cash income in the case of other NTFP collection.

In both the *RESIN* model and the *OTHER* model, the proportion of households with a CF member or members in the sampled village or hamlet in 2016 (*ProportionCFmember*) was not an important variable. In Fig. 5, it appears that some forest areas were protected, without deforestation, during 2014–2016 because of the presence of community forests, and some were not. From this, we can infer that not all community forests are effective in reducing deforestation. Of the total of 404 sampled households, 201 had CF members and 203 did not, but even in the latter group 40 households (19.7%) in 2014 and 28 households (13.7%) in 2016 collected NTFPs in the community forests, indicating that there was no strict exclusivity [75 non-CF-member households (36.9%) collected outside the community forests in 2014, and 61 (30.0%) in 2016]. Even in the former group, 97 households (48.2%) in 2014 and 83 households (41.2%) in 2016 collected outside the community forests [67 CF-member households (33.3%) in 2014 and 45 (22.3%) in 2016 responded that they collected both inside and outside the community forests]. These findings indicate that, although the establishment of a community forest may itself have forest conservation benefits in some cases, knowing whether residents are CF members is not necessarily useful for understanding the varying degrees of awareness of NTFP-collecting households about the impacts or consequences of deforestation and/or illegal extraction of trees.

4.2. *Implications for patrolling strategies in and around the existing wildlife sanctuary and for other spatial forest-conservation interventions*

Although there have been a few attempts to identify the characteristics of local residents whose collection of NTFPs is vulnerable to deforestation within a short time frame, such as 5 years or less (e.g., Ehara et al., 2016; Schoneveld et al., 2011), to the best of our knowledge, no study has estimated the spatial distribution of households vulnerable to such deforestation. By using environmental geographic information (the distance of each village or hamlet to the PLWS and the area deforested per capita within a 10-km radius of the village or hamlet) and the socioeconomic information linked to village location (the proportion of households collecting NTFPs as a source of cash income in a village or hamlet), which were useful in predicting people's awareness, we developed maps showing the distribution of villages or hamlets according to the degree of awareness—in other words, the probability of the presence of affected households (Fig. 5) and *priority areas for NTFP collection* (Fig. 6). Previous studies integrating remote sensing and socioecological studies have also produced relevant maps of locally important ecotypes and places (e.g., Robiglio and Mala, 2005; Shrestha and Medley, 2016; Woodward et al., 2021). However, the methods used to generate these maps and the outcomes produced differ substantially from ours. These previous studies combined remote-sensing data with data from participatory mapping of local actors who assigned some sort of meaning to the distribution and location of 'as-is' resources. In contrast, in accordance with the conceptual framework that local actors change their behaviour after becoming aware of impacts and their consequences, we linked information on the degree of the impacts and the consequences of which local households could be aware *only* after the loss of forests and trees with households' attribute information, and we applied this information to the remaining forests to map locally important places. The map was then supplemented with information on the distribution of households that were vulnerable to deforestation and/or illegal extraction of trees—in other words, those that were more likely to be aware of the impacts and consequences on NTFP collection in the future. We argue that these new mapping methods and their outcomes, based on local actors' awareness, are particularly useful for discussing spatial enforcement strategies—especially patrol strategies in and around the existing wildlife sanctuary—and for discussing other spatial forest conservation interventions.

To facilitate this discussion, we next classified the forests into 12 areas. Our classification was based on the identification of *priority areas for NTFP collection*, existing CF areas, the PLWS area, and the predicted spatial distributions of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees over the 3 years of the study (Table 4). In conjunction with this, the $I \times J$ cluster model of Albers and Robinson (2011), can be used to examine the NTFP collection patterns of local residents, as well as the residents' coping strategies. In the $I \times J$ cluster model, a so-called 'leakage' event—the displacement of deforestation and degradation activities to other forests—occurs when restriction is enforced along a forest ray (or in a forest area); illegal fuelwood extraction on that ray is deterred, and the extraction moves to other forest rays or areas with less enforcement. This leakage is usually concentrated in the unprotected forest closest to the extractors (Albers and Robinson, 2013). In our case, the situation was more complicated because we were dealing with multiple villages in reality, but if we assume that leakage occurs according to this theory, then the leakage would be concentrated in the unprotected forest closest to the tree extractors, i.e., where the Non-CF/Non-PLWS area and *priority areas for NTFP collection* overlap (i.e., **Area 3** and **Area 6** in Table 4). Therefore, patrols should be strengthened to maintain these areas as *priority areas for NTFP collection*.

The relationship between the cause of the leakage and the location of its occurrence resembles the relationship between the cause of the maladaptive coping strategies and the location of their occurrence. Albers and Robinson (2011, 2013) discuss only the event of deterrence of illegal extraction by access restrictions enforced by a local authority along a forest ray (or in a forest area) as the cause of leakage. However, if we replace this cause or event with the event of deforestation or illegal extraction of trees by local actors and/or allocation of land concessions by the government, then NTFP collectors who are affected by this event would implement coping strategies (i.e., new deforestation and/or extractive activities) to compensate for their lost incomes. If the coping strategies further create a conflict in forest resource use with other parties, the coping strategies become maladaptive. For this reason, the logic of response measures against leakage can also be used as the logic of response measures against maladaptive coping strategies. Under this theory, if we consider the context in which displacement or coping strategies that could be maladaptive occur, we find that the displacement occurs in the unprotected forests closest to the collectors, i.e., where the Non-CF/Non-PLWS area and *priority areas for NTFP collection* overlap (**Area 3** and **Area 6** in Table 4). Therefore, response measures against maladaptive coping strategies, such as strong patrolling by recruiting forest guards from the villages, establishing new CF areas or expanding the PLWS area, should be considered. In addition, villages that are considered to have relatively large numbers of residents who could adopt maladaptive coping strategies are located within, or adjacent to, **Area 1**, **Area 2**, and **Area 3**, where the probability of the presence of *affected households* in the villages or hamlets is already high, and **Area 6**, where forest degradation is likely to increase in the future owing to the absence of CFs and the PLWS. As there are already *affected households*, as well as households likely to be affected in the future, in these villages or hamlets, immediate relief or prevention measures, such as providing alternative livelihoods for NTFP-dependent households that use the areas, are needed to avoid the adoption of maladaptive coping strategies.

One possible relief or prevention measure is to recruit residents who have been, or are, dependent on forest resources as CF guards (Persson and Prowse, 2017) or government rangers. This measure is likely to be particularly effective in villages in and around *priority areas for NTFP collection*. There are two factors behind this effectiveness: the aptitude of the person being recruited, such as their motivation and ability, and the urgency of the need to patrol the area. Regarding the former, Evans et al. (2003), in their study of resin-dependent communities in Mondulkiri province, Cambodia, concluded that, if income from resin collection were lost, other alternatives would be unlikely to fully replace that income. The same is true in our study area, where the *priority areas* overlapping with, or adjacent to, the PLWS have concentrated populations that collect resin as a source of cash income. It makes sense to recruit resin collectors and their household members as CF guards or rangers because they are likely to have the motivation and the land intuition to sustainably manage the *priority areas for resin collection* in

Table 4
Triaging of areas for forest-conservation intervention for sustainable NTFP collection. The triaging was based on the relationship between the locations of villages or hamlets in the study site that had a high or low probability of having households affected by deforestation and/or illegal extraction of trees in 2014–2016, as well as on priority areas for NTFP collection and the locations of households in relation to existing CF areas and the PLWS.

		Inside *priority areas for NTFP collection*			Outside *priority areas for NTFP collection*		
		CF area	PLWS area	Non-CF/Non-PLWS area	CF area	PLWS area	Non-CF/Non-PLWS area
For resin collection: Area neighbouring PLWS **For other NTFP collection: Area within a 10-km buffer of village or hamlet**	**Location of village or hamlet with high probability of having affected households**	**Area 1** (Urgency 4) • Strengthening of CF patrols to tackle illegal forest clearing and illegal extraction of trees, with forest guards recruited from the villages by REDD+ projects • Provision of relief/ prevention measures for NTFP-dependent CF members to avoid adoption of maladaptive coping strategies	**Area 2** (Urgency 4) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees, with support from Ministry of Environment and Provincial Department of Environment, including recruitment of rangers by REDD+ projects • Provision of relief or prevention measures for NTFP-dependent households that use the conservation zone and community zone to avoid their adoption of maladaptive coping strategies	**Area 3** (Urgency 4) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees in collaboration with FA and Provincial Department of Environment, including the recruitment of rangers by REDD+ projects • Examination of whether it is feasible to establish new CF areas or expand the PLWS conservation zone and/or community zone; recruitment of forest guards from villages • Provision of relief or prevention measures for NTFP-dependent households that use the area to avoid their adoption of maladaptive coping strategies	**Area 7** (Urgency 2) • With FA support, improvement of forest management plans developed by the community	**Area 8** (Urgency 2) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees with support from Ministry of Environment and Provincial Department of Environment, including recruitment of rangers by REDD+ projects	**Area 9** (Urgency 2) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees, with support from FA and Provincial Department of Environment
	Location of village or hamlet with low probability of having affected households	**Area 4** (Urgency 3) • Strengthening of CF patrols to tackle illegal forest clearing and illegal extraction of trees, with recruitment of forest guards from villages by REDD+ projects • Provision of relief or prevention measures for NTFP-dependent CF members to avoid their adoption of maladaptive coping strategies	**Area 5** (Urgency 3) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees, with support from Ministry of Environment and Provincial Department of Environment, including recruitment of rangers by REDD+ projects • Provision of relief or prevention measures for NTFP-dependent households that use the conservation zone and community zone to avoid their adoption of maladaptive coping strategies	**Area 6** (Urgency 3) • Strengthening of law enforcement against illegal forest clearing and illegal extraction of trees in collaboration with FA and Provincial Department of Environment, including recruitment of rangers by REDD+ projects • Examination of whether it is feasible to establishing new CF areas or expand the PLWS conservation zone and/or community zone; recruitment of forest guards from villages • Provision of relief or prevention measures for NTFP-dependent households that use the area to avoid their adoption of maladaptive coping strategies	**Area 10** (Urgency 1) • Maintain the status quo of CF management for NTFP collection	**Area 11** (Urgency 1) • Maintain law enforcement	**Area 12** (Urgency 1) • Maintain law enforcement

CF: Community Forestry; FA, Forestry Administration; PLWS: Prey Long Wildlife Sanctuary; Urgency 4: Very urgent action required; Urgency 3: Urgent action required; Urgency 2: Act if it is affordable to do so; Urgency 1: Maintain the status quo.

Table 5
Classification of actors, impacts, and drivers in terms of *the scope of the awareness of the impact*.

Society	Scope of awareness	
	Impact (of a change) that the actors are aware of (*I*)	Direct and indirect drivers (of an observed or expected change) that the actors are aware of (*D*)
Individuals and groups that are aware of (affected by) an impact or consequences of a change (*a*)	*I-a*	*D-a*
Individuals and groups that are not aware of (not affected by) an impact or consequences of a change (*b*)	*I-b*	*D-b*
Governments and NGOs (*c*)	*I-c*	*D-c*

Elaborated by the authors on the basis of Bohensky and Lynam (2005)

order to maintain their cash incomes. Chou (2018), in another wildlife sanctuary in Cambodia, found that the greater the income received by households from NTFP collection, the more likely they were to join the community patrol team, mainly because local people were aware of the consequences of deforestation, wildlife poaching, and inappropriate resource extraction and were motivated to maintain their incomes from NTFPs. Chou (2018) also reports that most of the community forest patrollers were former hunters and traders, so they knew the geography of the forests well. Regarding the latter factor, Albers and Robinson (2013) argue that 'modeling the spatial reaction to enforcement activities can enable forest managers to identify areas of wasteful enforcement spending, such as patrolling in the remote interior of the park'. Agreeing with this, our study identified spatially the locations where patrols are urgently needed (i.e., **Area 1**, **Area 2**, **Area 3**, and **Area 6**), and where patrol activities should, as far as possible, not be 'wasteful'. On the other hand, areas of 'remote interior' that do not fall into the *priority areas* in the PLWS can be defined as being outside the NTFP collectors' areas of action (i.e., **Area 11**). This is not to say that patrolling there is 'wasteful', but it is less urgent than in the areas mentioned above.

4.3. Implications for implementing local policies to reduce deforestation and forest degradation

The methods we applied to identify *priority areas for NTFP collection*, and the outcome of that identification, also provide some practical implications for implementing local policies to reduce deforestation and forest degradation. Although these suggestions apply to Cambodia, they should be of interest to other countries in similar situations.

First, CCB (Climate, Community and Biodiversity) project design standards and other global safeguard standards for REDD+ programs expect the proponents to map or describe and prioritise areas important for ecosystem services (Ehara et al., 2014). The *priority areas for NTFP collection* that we predicted here are important for both the Prey Lang REDD+ project and the adjacent Tumring REDD+ project, not only to maintain and enhance carbon stocks but also to maintain income sources for residents. When proponents both plan and implement their projects, their close cooperation is required in considering the *priority areas* and the intervention activities that are effective for each area.

Secondly, the government seeks information that will demonstrate the forests' and forest programs' substantial economic and social benefits (Dyrmose et al., 2017; RGC, 2010). Our findings on the numbers and spatial distribution of households depending on NTFP collection as a cash income source enabled us to identify the areas and villages where the socioeconomic importance of resin and other NTFPs should be measured in order to secure local economies and welfare. The methods that we used here can also be used to contribute to REDD+ project certification processes. By using these methods, REDD+ projects can predict the number of villages where project implementation could have protected the NTFP collection environment, compared with the scenario in which there was no project. For example, the Tumring REDD+ project, which is certified by CCB standards, is required to present its predicted outcomes by comparing scenarios with and without the REDD+ project in the project design document (Bird and Williams, 2018). The information we obtained here should be useful as reference information for this comparison.

Thirdly, the Ministry of Agriculture, Forestry and Fisheries, in the National Forest Programme 2010–2029, considers the cautious allocation of economic land concessions (Ministry of Agriculture, Forestry and Fisheries Cambodia, 2010). At the landscape level, we consider that concession allocations should be avoided in *priority areas for NTFP collection*, especially **Area 3** and **Area 6** in Table 4, where there is relatively weak enforcement owing to the absence of CF and the PLWS. This is because, as predicted above, these areas are close to villages with relatively high concentrations of people who may adopt maladaptive coping strategies, and concession allocation to these areas will create a feedback loop of deforestation.

4.4. Improving on the scopes of Bohensky and Lynam (2005)

Bohensky and Lynam (2005) used three scopes to evaluate the effectiveness of responses to changes in complex adaptive systems: *the scope of an impact*, *the scope of awareness of the impact*, and *the scope of the power or influence to respond*. Although, in their case study of water management in international river basins, Bohensky and Lynam (2005) implicitly answered the question of who should *be aware of* the impact, they did not answer the question in such a way that the actors were explicitly classified and organized in a conceptual framework. We attempted to classify and organize the actors (Table 5).

The actors in a society of interest can be allocated to three categories: the individuals and groups who are directly affected (*a*); those who are not directly affected (*b*); and the governments (in some cases supported by non-governmental organisations (NGOs)) that adopt policies and measures to address the impacts (*c*). Here, we argue that there should be effective means for actors (*c*) to be aware of the impact. This is because, without the means of transmitting the information (such as who is in category (*a*), their number, and where they live) upward, local knowledge will remain in the community and will thus not influence the causal processes operating at higher levels (Bohensky and Lynam, 2005). In addition, as we saw in our case study area, some residents in category (*a*) may adopt maladaptive coping strategies that can create conflict among other natural resource users in both categories (*a*) and (*b*) and thus undermine long-term development goals. To avoid such risks, the conceptual framework of Bohensky and Lynam (2005) should explicitly categorize individuals and groups into the three classes described above.

Our findings allow actors (*c*) to better understand the importance of the impacts (*I*) and their consequences (i.e., of *I-a* in Table 5) by demonstrating the spatial distribution of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees between 2014 and 2016; they also allow a common awareness of the impacts to be shared among the actors in all three categories. On the basis of this shared awareness of the impacts, actors (*c*) in society need to be aware of the direct and indirect drivers that are causing the problem (*D-a*, *D-b*, and *D-c*). Although it is beyond the scope of this paper to identify such drivers, earlier studies have attempted to do so by dividing the drivers of deforestation in Cambodia into *direct drivers* and *indirect drivers* (Ehara et al., 2021) at the national level or *pressures* and *drivers* (Ehara et al., 2018) at the landscape level. By using such findings, governments and NGOs should be able to develop a comprehensive understanding of drivers and to prioritise resources to implement response actions. This will help achieve to the situation of 'congruence between the impact, awareness, and power scopes', which Bohensky and Lynam (2005) argue is exhibited by the most effective responses.

5. Conclusions

Although the success or failure of policies to slow or prevent deforestation and forest degradation in developing countries depends on the behaviour of forest resource users in terms of which forest products, how many, how intensively, and from which parts of the forest they collect, relatively few studies have explicitly considered the spatial decisions of NTFP collectors or the spatial outcomes of forest degradation prevention policies. Here, we aimed to contribute to the development of research that explicitly considers these spatial outcomes, particularly in terms of topics such as the spatial decision-making of NTFP collectors and the selection of priority areas for patrolling in parks in developing countries.

We believe that this study makes the following important contributions. First, the logic of previous studies of the spatial economics of NTFPs (which suggests that the gradation of forest quality from undegraded to heavily degraded is produced by differences in distance cost and enforcement) was empirically demonstrated from the perspective of human geography by using the awareness of local residents regarding the impacts or consequences of deforestation and forest degradation on NTFP collection. By using a case study of NTFP collection in an area adjacent to the PLWS in the eastern part of KT Province, Cambodia, as well as data on the local villagers' awareness and statistical models, we presented a novel method of predicting the spatial distribution of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees. This was accomplished by measuring the residents' awareness of the impacts of deforestation and/or illegal extraction of trees on NTFP collection over a short period of time (2014–2016) through a questionnaire and the use of GLMMs. The results showed that, in environmental and geospatial terms, in the case of resin collection, the closer a village or hamlet was to the PLWS, and in the case of other NTFP collection, the larger the deforested area per capita in 2014–2016 within a 10-km radius of the village or hamlet, the higher the probability that households in that village or hamlet would be aware of the impacts or consequences of deforestation and/or illegal extraction of trees on NTFP collection. We considered that the reasons for these findings were that 1) resin-providing trees in and near the PLWS were more likely to remain than other forested areas not included in *Priority areas for resin collection* owing to differences in location and previous forest management history, and 2) the area within 10 km of the village or hamlet was the area in which villagers were engaged in daily activities such as agriculture and non-resin-NTFP collection, and NTFP collection was possible before the deforestation covered by this study period. This logic, obtained by using a human geography perspective, was consistent with the logic of the previous NTFP spatial economics literature, which considers that the gradations in forest quality from undegraded to heavily degraded forests are produced by differences in distance costs and enforcement.

In socioeconomic and geospatial terms, for resin collection, the greater the proportion of households that were collecting resin in 2014, and for other NTFP collection, the greater the proportion of households collecting NTFPs for cash income in that year, the higher the probability that households in that village or hamlet would be aware of the impacts or consequences of deforestation and/or illegal extraction of trees. The main reason for this was the relative perceived importance of cash-generating NTFPs by residents in the study area, where residents' livelihood strategies today are more dependent on the money economy than in the past.

Secondly, our study has advanced the discussion of spatial enforcement strategies (especially patrol strategies in and around the existing wildlife sanctuary) and of other spatial forest conservation interventions by examining the local people's patterns of NTFP collection and the possible coping strategies they may adopt in the face of deforestation and/or illegal extraction of trees. We used the results of the statistical models described above to predict the spatial distributions of villages with NTFP-collecting households affected by deforestation and/or illegal extraction of trees (Fig. 5). By using the geospatial indicators identified in the prediction models as a reference, as well as the information and methods presented in **Section 2.5** , *priority areas for NTFP collection* were mapped (Fig. 6). By following the conceptual framework of Bohensky and Lynam (2005), we showed that information shown in Fig. 5 (the distribution of villages or hamlets according to the degree of probability of the presence of affected households) and Fig. 6 (which roughly shows the extent of forest areas used by residents for NTFP collection) can be used to design efficient spatial enforcement or patrolling strategies. By using these results, we classified the forests into 12 areas (Table 4). We argued that the logic of previous studies in the spatial economics of NTFPs, that leakage is usually concentrated in unprotected forests closest to the extractors, can be applied to the logic of maladaptive coping strategies, which generate a feedback loop of deforestation. We then presented an approach to break the deforestation feedback loop by identifying areas within these 12 categories where response measures against leakage and maladaptive coping strategies should be prioritized for implementation.

The third important contribution of our study is the identification of room for improving the utility of the conceptual framework proposed by Bohensky and Lynam (2005). We focused specifically on the scopes of impacts and awareness of the impacts, and showed that these scopes can help to make a response more tailored to the local context if: 1) it clearly distinguishes between those who are affected by the change (e.g., deforestation) and those who are not, by examining their spatial distribution; and 2) the governments and NGOs in the society are aware of this distribution and of the direct and indirect drivers of the problem.

The methodology and the improved conceptual framework that we used are applicable to similar studies in Cambodia and other countries. However, there are areas for future improvement. First, within Cambodia, some of the questions in our questionnaire were the same as those in the Ministry of Planning's Cambodia Socio-Economic Survey (a sample survey of villages and households across the country), and others referred to the Commune Database that supports provincial planning (all households are surveyed annually). Ideally, information on whether households collect NTFPs, and on whether they collect them for self-consumption or for sale, could be collected regularly and more comprehensively under these existing information collection systems. Another more general area of improvement is the accuracy of information on NTFP collection sites. In this case, information on the locations where household members collected NTFPs (direction and distance from home, type of vegetation) was collected by asking them. Recently, GPS devices have become smaller and more affordable, and more residents are carrying smartphones. In the future, we expect that the quality of information will be improved by asking NTFP collectors to carry GPS loggers and take pictures of their collection sites, as well as by using location information from smartphones.

Declaration of interest statement

The authors have no conflicts of interest directly relevant to the content of this article. The funding sources had no roles in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Data Availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2023.106637.

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