

# Development trade-offs and socio-ecological feedbacks in the Mekong

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## ***ABSTRACT***

This paper provides an analysis of development trade-offs in the Nam Xong catchment in the Mekong basin. Development strategies considered by government agencies involve expansion of mining, rubber and banana plantations, agriculture and tourism. The analysis of potential trade-offs requires considering complex socio-ecological interactions. Results from this participatory modelling exercise emphasise the relevance of two mechanisms: (1) human migration and (2) ecosystem services. People adapt to changes in livelihood conditions and inevitably the spatial dynamics of trade-offs emerges as critical. People migrate and with that spatial poverty patterns change and pressure on natural resources shifts. Changes in ecosystem services impact on local conditions (e.g. forest) and remote conditions (e.g. fish, water). From a development perspective, these two types of complex dynamics create close connections between rural locations and between rural and urban

areas. Several scenarios involve replacing a forest economy many households depend on by paid labour few can depend on. Consequently, poverty is driven from rural into urban areas. Another trade-off revealed during this study is that the expansion of tourism is providing a more sustainable alternative to other development strategies. But water quality decline requires mitigation measures to make this strategy sustainable and avoid adverse impacts on fisheries.

## 1. INTRODUCTION

Economic development often involves trade-offs as activities by one sector are likely to cause environmental impacts that shift constraints for other sectors (Biggs et al., 2015; Folke et al., 2002). Ecosystem services provide essential inputs for and links between economic activities (De Groot, 1992; Fisher et al., 2009). Climate change and other external factors often influence these complex socio-ecological interactions and their inherent trade-offs and synergies (Bohensky et al., 2013; Smajgl et al., 2015a; Tol, 2005). Sustainable development strategies require a robust understanding of these ecosystem-based cross-sector trade-offs. The assessment of ecosystem services and their role in economic development and spatial planning is evident, although incorporating ecosystems faces a series of challenges, see the discussion provided by De Groot (1992) and by Butler et al. (2013). Many studies focused on the link between agricultural activities and ecosystem services (Smajgl, 2006; Verburg et al., 2002), between tourism and ecosystem services (Lankford, 1994; Sun and Walsh, 1998) and between conservation investments and ecosystems services (Brown, 2004; Chan et al., 2006; Larson and Smajgl, 2006; Lunney et al., 1997).

Fewer studies assess more complex dynamics between ecosystem services and multiple economic sectors and how trade-offs can be avoided or synergies nurtured. Understanding these trade-offs and synergies is critical for the design of sustainable development strategies, specifically for spatial planning (de Groot et al., 2010; Margules and Pressey, 2000; Wilkinson et al., 2013). This study investigates a complex multi-sector planning context in the Mekong, involving several economic activities and numerous ecosystem services. The assessment aims to identify which dimensions are most critical for the understanding and the management of development trade-offs.

In the context of the Nam Xong (also known as Nam Song) – a Lao tributary to the Mekong – local stakeholders observed trade-offs between upstream mining and rubber and banana plantations, mid-stream tourism and agriculture, and downstream fishing and agriculture (Bartlett et al., 2012; Bush and Hirsch, 2005). The substantial income generated by tourism activities in and around Vang Vieng (Harrison and Schipani, 2007) were perceived to be endangered due to changes in water levels and water quality. Thus, stakeholders invited and engaged in a participatory research process to understand some of these development trade-offs (Smajgl and Ward, forthcoming).

The research design involves a mixed method approach that was implemented during a participatory process, the Challenge and Reconstruct Learning (ChaRL) approach (Smajgl and Ward, 2013). The methods included a household survey, a hydrological model (Kallio, 2014), and the agent-based model MerSim (Smajgl et al., 2015b). This paper summarises results from the agent-based approach (for methodological details on agent-based modelling see Axelrod et al., 2006; Gilbert, 2008; Grimm et al., 2005; Matthews et al., 2007), which genuinely links livelihood related behaviours with their underpinning

agricultural growth, hydrological dynamics, various ecosystem services, and labour and commodity markets.

The results emphasise that taking a narrow sector perspective is likely to provide wrong recommendations. For instance, mining expansion strategies that aim for developing new employment and increasing revenue, reduce poverty in the target upstream areas only slightly. Concurrently, due to land-use change and the resulting consequences for ecosystem services other livelihoods face losses that substantially outweigh the direct income gains in the mining sector. Importantly, most mining employment is likely to be taken up by persons from outside the district, which were beforehand not under the poverty line. Widening the spatial area emphasises further consequences that add to the local trade-offs. Two types of downstream effects prove critical for the province and national perspective: changes in ecosystem services (water flow) and human migration. Changes in water flow, in particular an increase in flood peaks, trigger agricultural income losses in downstream districts that drive families to migrate out of the Province. The level of poor households in the remaining populations increases as most out-migrating families were not under the poverty line.

From a methodological perspective, it becomes evident that the understanding of development outcomes and related trade-offs require a sophisticated approach that captures the socio-economic and bio-physical feedbacks. Two aspects seem particularly important, first the link between livelihoods and ecosystem services, and second migration, which stresses the importance of spatial and temporal dynamics of poverty (Bohensky et al., 2013; Smajgl and Bohensky, 2013).

## **2. THE MERSIM MODEL**

The description of the agent-based Mekong region simulation (MerSim) model follows the ODD (Overview – Design concepts – Details) protocol (Grimm et al., 2006; Grimm et al., 2010; Müller et al., 2014) and model details including Java code can be found in (Smajgl et al., 2013).

### **2.1. Purpose of the model**

The model design was embedded in a participatory process, which follows the Challenge and Reconstruct Learning approach as outlined by Smajgl and Ward (2013) and Smajgl and Ward (2015). This participatory process helped eliciting the policy indicators and policy scenarios.

- Climate change and increase in flash floods
- Continued deforestation
- Rubber expansion and rubber price increase
- Mining expansion
- Tourism drop
- Tourism expansion

The results aim to inform the basin development plan and specific sector strategies for mining, forest management and agriculture.

### **2.2. State variables**

The participatory process placed the stakeholder priorities at the core of the model design and determined the state variables as: poverty, forest cover, rubber production, water flow, water quality (dissolved oxygen), rice production, migration, land use, household livelihoods and fish catch.

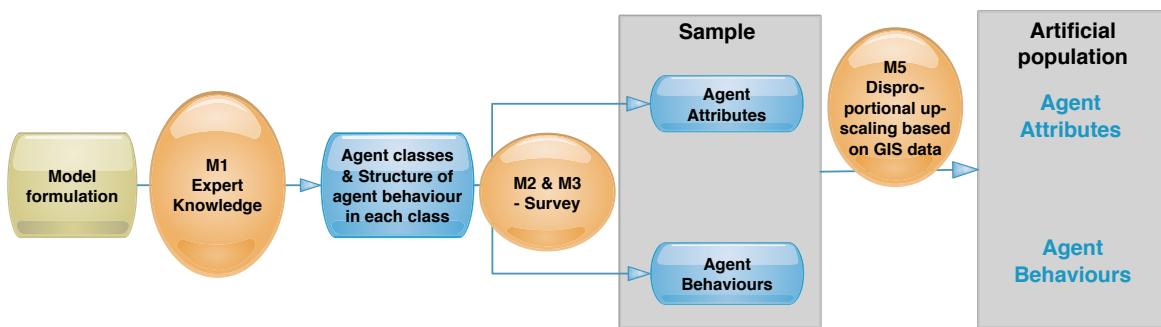
### **2.3. Emergence**

Corresponding with stakeholder-defined modelling goals, emergent phenomena include the temporal and spatial poverty patterns, the spatial extend of forest cover and rubber plantations, and

water quantity and quality changes in response to the expansion of mining and rubber plantations upstream. One core policy focus is the trade-offs between upstream investments and mid-stream tourism income, which is emerging from modelled interactions.

#### 2.4. Household data for parameterisation

The parameterisation process is described based on the framework provided in Smajgl and Barreteau (2017).



**Figure 1: Parameterisation Sequence for the MerSim model, adapted from Smajgl and Barreteau (2017)**

Figure 1 shows the principle parameterisation steps required in an empirical model (boxes) and which particular options were implemented for this study (arrows). The MerSim model formulation is based on theory articulated by Castellani and Hafferty (2009) that conceptualises social-ecological complexity, in particular the focus on a disaggregated systems approach that allows non-linear system components to interact and, thereby allowing for emerging phenomena, i.e. Funtowicz and Ravetz (1994) and Sawyer (2005).

Experts helped to identify principle agent classes, such as household agents, government agents and spatial agents. This expert-based process also identified principle agent behaviour such as the harvesting of tea and the tapping of rubber. These livelihood-related activities were put into annual calendars and linked to associated regions and altitudes where necessary.

The next step involved the specification of household attributes and household behaviours. A random sample of 1,000 households (20 randomly selected households from 50 randomly selected villages) across the Nam Xong sub-basin were surveyed to elicit their key characteristics (i.e. location, household size, livelihoods, production, and income), their self-selected attributes of subjective wellbeing, the principle human values that guide their lives, and their adaptation intentions. Intentions represent responses to questions that frame a specified hypothetical change.

In this case the change households were asked to imagine:

- Flash floods started to occur frequently
- Deforestation continued
- Rubber prices would increase
- More mining jobs would be available
- Tourist numbers would drop
- More jobs in the tourism sectors would be available

Households had four principle response options: either

- To maintain their livelihood activity in their current household location;
- To change their livelihood in their current household location;
- To migrate out but maintain their current livelihood; or
- To migrate out and change their livelihood activity.

In each of these categories, responses to follow-on question informed estimates of the magnitude or type of livelihood response, the impediments to adaptation and/or the location for migration. The intentional data and behavioural changes elicited from household survey responses delimited the cognitive complexity of household agents to a more parsimonious depiction of largely reactive agents in the model.

The sample data for attributes and behavioural rules was mapped into the total agent population by disproportional up-scaling. Proportional up-scaling refers to a technique in which the proportions

of responses in the sample is maintained to parameterise the whole population by simply replicating (or cloning) each response by sample size divided by population size (in this case multiplied by about 200). Disproportional up-scaling on the other hand changes proportions as some responses are used more often than others due to some scaling factors. In this case, the proportions were amended to match the actual land use, in particular rubber plantations, rice paddy and the urban population. Otherwise a random approach would map intentional data from a tourism-dependent household into a non-tourism area and responses from a rubber farming household into an urban area. This GIS-based adjustment was intended to represent a more realistic spatial distribution of simulated household behaviour.

## **2.5. Adaptation & Objective**

Given the way we reduced agent cognition, agents step through a simple adaptation process, which allowed a reduction in the run time of the model so that live runs were able to be performed during the participatory modelling process (Smajgl et al., 2015b). Household agents respond to income levels derived from paid labour or agricultural activities. Households' objectives are implicit to their behavioural response functions (or rules). Modelled agents respond to livelihood related changes based on intentional data derived from the household survey responses. No additional optimisation or satisficing assumption is implemented. As a corollary, household expectations and learning are not explicitly represented but implicitly captured by the empirically derived response strategies.

Most parameters are assumed to be stochastic to resemble more realistic model assumptions, including crop prices, productivity, and wages. The ranges were developed by experts in conjunction with time series data (Smajgl et al., 2011).

## **2.6. Initialisation and Submodels**

The MerSim model utilises five sets of GIS data: (1) administrative boundaries down to administrative villages, (2) soil data, (3) land cover data, (4) rainfall projections, and (5) a digital

elevation model. These datasets were used to specify the artificial landscape while the household survey provided the necessary data on household attributes and behavioural responses.

Five essential submodels were integrated to deliver the processes stakeholders had requested: hydrology, crop growth, water quality, livelihood, and income. The hydrology module calculates in daily time steps the run off for each spatial polygon based on rainfall, slope, inlet and outlet node, land cover and soil type. Based on this method flood and drought risk for the tourist town of Vang Vieng can be estimated, which triggers tourism numbers to divert from a projected trend. Based on rainfall, soil type and land cover livelihood-relevant crops (e.g. rice, rubber, trees, grass) grow following established growth algorithms. The combination of water flow and particular land cover provides the necessary information for calculating dissolved oxygen, which is calculated for Vang Vieng town and for Hinheup where the Nam Xong is partly diverted into the Nam Ngum 1 dam and partly continues its flow into the Mekong. The livelihood module follows crop and job specific calendars, which involves, for instance planting and harvesting. Household livelihoods only change based on intentional data elicited through the household survey. The income module calculates the weekly income for all household members and assigns how many are below the poverty line. This calculation includes the monetisation of subsistence production to avoid a misleading, under-estimated quantification of poverty.

### **3. SCENARIOS, INDICATORS AND RESULTS**

#### **3.1. Scenario definitions**

The analysis of development trade-offs is based on a participatory process during which stakeholders defined a set of five scenarios that reflect their current expectations or options for the further development of the Nam Xong catchment:

- The expansion of the mining sector is the first scenario and implies a doubling of mine sites in Kasy district and in Vang Vieng district;

- the expansion of rubber plantations, which assumes a doubling of the area under rubber across the Nam Xong district; and
- the expansion of tourism beyond the current trend.

### **3.2. Assessment Indicators**

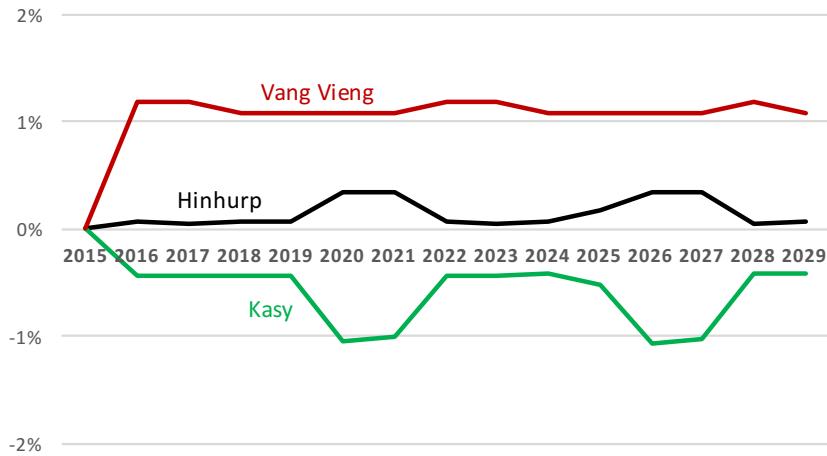
The participatory process revealed also a set of core assessment indicators decision making agencies employ to rank development options. The following indicators were defined as the most critical by the Nam Xong working group:

- Poverty rate
- Water flow in tourism areas around Vang Vieng
- Water quality, in particular dissolved Oxygen

Poverty rate was chosen due to the national development agenda to leave behind the least development status by 2025. Water flow was considered due to the observed trade-offs between upstream development and water needs to further develop tourism in Vang Vieng. Water quality was selected due to the Government's commitment to improve water quality. Here dissolved oxygen was identified as a key indicator that links to fish and broader ecosystem health.

### **3.3. Results for the mining expansion scenario**

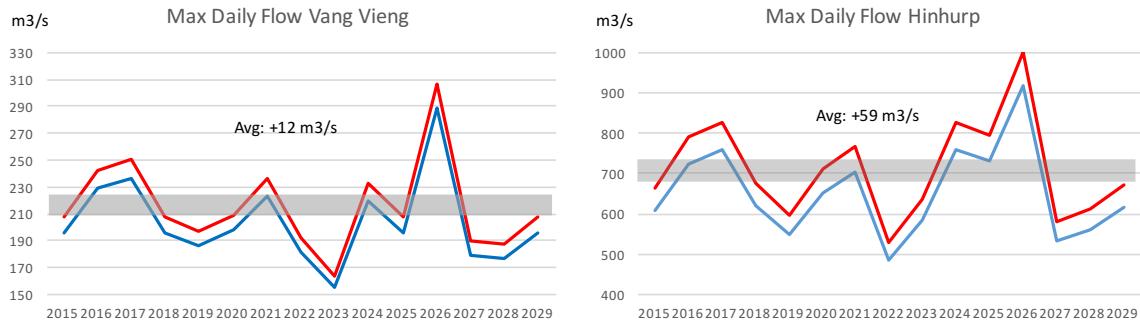
Poverty rates in the districts Kasy, Hinlarp and Vang Vieng vary for the baseline around 24%, 36% ad 28% respectively. This indicates how many households in percent are below the national poverty line.



**Figure 2: Impacts of the mining expansion scenario on poverty rate in Kasy, Vang Vieng and Hinhpur.**

Figure 2 shows the impact of the mining expansion scenario on poverty rate in the three districts of the Nam Xong catchment. The impacts in the upstream district Kasy is slightly positive. The pattern indicates that poverty reduction during very wet or very dry years are larger than during years with ideal climatic conditions for agricultural activities. Consequentially, poverty levels are likely to become less climate dependent. In the mid-stream area of Vang Vieng poverty levels are likely to increase by an average of 1% of the population. While poverty in downstream district of Hinhpur is likely to increase only marginally.

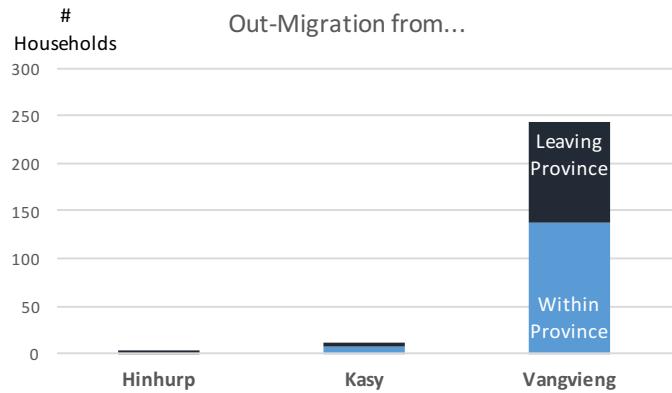
The understanding of these poverty impacts requires the consideration of three main socio-ecological feedbacks. First, mining provides livelihoods but also replaces existing livelihoods that depend on agricultural land and forests. This effect limits the positive effects mining income would have in Kasy and Vang Vieng. Second, water flow is also responding to the land use change this scenario implies. These hydrological effects involve an increase in peak flows, which triggers flood related consequences for households and their livelihoods.



**Figure 3: Impacts of the mining expansion scenario on water flow in Vang Vieng and in Hinhurp.**

Figure 3 shows the impact on annual peak flow for the projected fifteen-year period in  $\text{m}^3$  per second. The lower line depicts the peak flow conditions during the baseline while the higher line results for the mining expansion scenario. In average across all years the peak flow increases for Vang Vieng by about  $12 \text{ m}^3/\text{s}$  and for Hinhurp by about  $59 \text{ m}^3/\text{s}$ . Due to lack of data it cannot be determined which flow rate converts into actual flooding of the townships and the surrounding agricultural production or industrial sites (i.e. cement production). However, the few data points available suggest that the Nam Xong breaches its banks within the grey shaded areas. This means that one in ten year events are likely to occur in four to five years. It also means that unprecedented flood levels are likely to occur based on these CCAM predictions. From a socio-economic perspective, many livelihoods, including tourism and agricultural activities, are likely to experience income losses, which is contributing to the poverty results in Vang Vieng and Hinhurp, shown in Figure 2.

The third socio-ecological feedback is linked to migration. The loss of the forest economy and of agricultural land (effect 1) and the loss of income in tourism and agricultural production (effect 2) is likely to trigger households to adapt. This involves three types of migration.

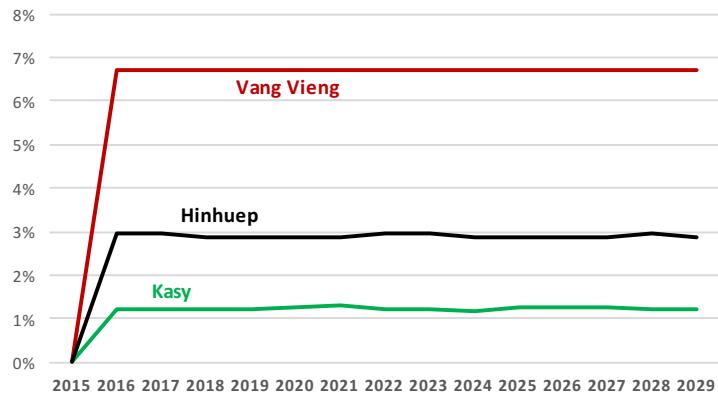


**Figure 4: Impacts of mining expansions on out-migration from Kasy, Vang Vieng and Hinlarp.**

In total, up to 14% of households are likely to out-migrate from their initial village. The vast majority of these households are likely to leave Vang Vieng, see Figure 4. More than two thirds are likely to leave the province and move to urban and peri-urban areas, including the capital Vientiane. Nearly one third will move within the province, partly to be employed in the mining industry and partly to move to less flood prone areas. These results emphasise the importance of understanding spatial dynamics of poverty. Results shown in Figure 2 would be considerably higher if households would migrate. This means that poverty is likely to shift to urban areas in consequence of the mining expansion in the Nam Xong.

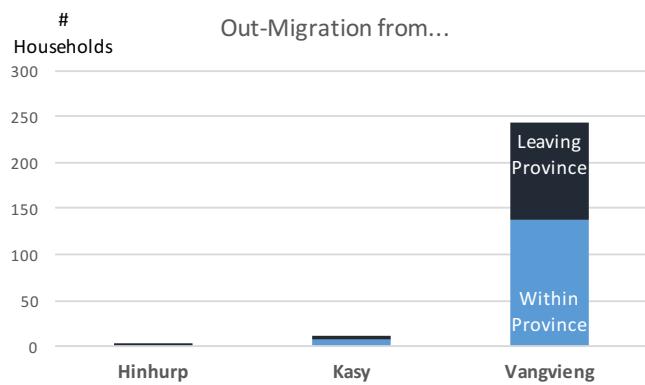
### 3.4. Results for the rubber expansion scenario

The second scenario assumes a doubling of the area under rubber plantations. The livelihood related design assumes the currently dominating model of Chinese investments instead of small holder rubber. Most of the rubber expansion would occur in Vang Vieng. Under these assumptions, poverty increases by more than 1% in Kasy, by 3% in Hinlarp, and by nearly 7% in Vang Vieng. This would push the poverty rate in Vang Vieng district to about 40%.



**Figure 5: Impacts of the rubber expansion scenario on poverty rate in Kasy, Vang Vieng and Hinhpur.**

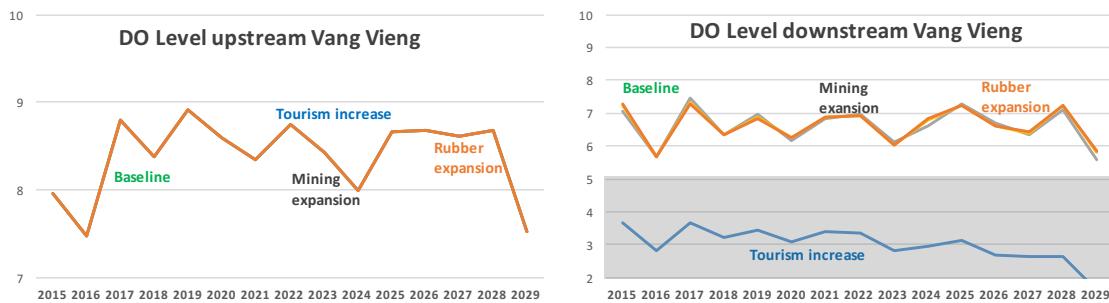
The socio-ecological mechanisms relevant for this emergent phenomenon are mainly linked to land use change, which erodes forest-based and agricultural livelihoods. Changes to flood peaks are marginal. Migration numbers are about 50% of the mining scenario as Figure 6 shows. In this scenario, the majority of migrants would decide to re-settle within the province.



**Figure 6: Impacts of the rubber expansion scenario on out-migration from Kasy, Vang Vieng and Hinhpur.**

### 3.5. Results for the tourism expansion scenario

The expansion of tourism triggers a drop of the poverty rate by about 1% in Vang Vieng. Effects on the poverty rate in Hinhurp and Kasy are marginal. These results are again linked to migration dynamics. About one percent of the population in Kasy would move to the Vang Vieng region to work in the tourism sector. Equally, about 1% of the population in Vang Vieng would move away from the Nam Xong into urban areas. Only few migrate from Hinhurp. The majority of new employment in the tourism sector is taken up by people from outside the Nam Xong catchment. The outmigration in Vang Vieng and Hinhurp is not linked to land use change but to the effects on water quality. Figure 7 shows the impact of the tourism sector expansion on lowest annual levels of dissolved oxygen in comparison to the baseline and the two other scenarios.



**Figure 7: Impacts of the tourism expansion scenario on levels of dissolved oxygen upstream and downstream of Vang Vieng.**

On the left, Figure 7 shows the lowest level of dissolved oxygen per year for an area upstream of Vang Vieng town and all tourism accommodation. There is no visible difference between any of the four scenarios. It is important to emphasise that dissolved oxygen is only one water quality indicator. The additional hydrological modelling focused on other water quality indicators and projected decreasing water quality due to mining and rubber expansion triggering increasing sediment loads and heavy metals. On the right,

Figure 7 shows the lowest level of dissolved oxygen per year downstream of Vang Vieng's tourism area. The shaded area highlights levels of dissolved oxygen that are fatal for fish. The tourism expansion scenario triggers a drop of dissolved oxygen levels below levels that are fatal for fish, which is highlighted by the grey area. Consequentially, livelihoods concerned with fishing are affected and migration as one of the adaptation strategies (Bohensky et al., 2013; Smajgl and Bohensky, 2012).

#### 4. DISCUSSION AND CONCLUSIONS

The simulations reveal a few socio-ecological feedbacks critical for the set of development strategies considered by decision makers, including

- Loss of forest ecosystems diminishes existing livelihoods to a larger extend than incoming mining employment, which results in outmigration and export of poverty into urban areas.
- Loss of agricultural production and tourism income due to an increasing frequency and magnitude of floods triggered by upstream mines and plantations, which results in outmigration and increasing poverty.
- Loss of fish production due to declining water quality triggered by tourism expansion.

From a policy perspective, considering these feedbacks is important to design development strategies that effectively alleviate poverty. The emerging simulation results reflect dominating spatial patterns in Asia, as poor households lose their livelihoods in rural areas and are being forced to move to peri-urban or urban areas where often a mismatch of skills and experiences reinforce their poverty cycle and cause social hotspots.

The design of more sustainable development strategies could involve a very selected approval of mining concessions and rubber plantations at places where there are no direct impacts on existing livelihoods and where the indirect impact through ecosystem services such as effects on water flow and erosion are minimal. In parallel, local households would

need to be trained to fill the new employment opportunities in the mining sector. This would further reduce the shift of poverty into urban areas.

The expansion of tourism activities could also be aligned with investment in water treatment, either decentralised as the responsibility of each hotel or as a centralised option for Vang Vieng town. This would help mitigating the water quality decline and thereby reduce the effect on fish population and related livelihoods.

From a modelling perspective, the integration of hydrological, social, ecological and economic dynamics at a highly-disaggregated level helped revealing some important feedbacks in the socio-ecological system. The results challenged pre-existing assumptions among policy makers, which leads in many applied research situations to further fuelling of contested values in the decision making context (Smajgl, 2010; Smajgl et al., 2015b).

Implementing the integrated simulation modelling in a participatory process that aims specifically for learning – or improved systems understanding – among policy makers and planners, helped bridging research and policy effectively (Smajgl and Ward, 2013, 2015). Consequentially, action plans were developed in response to this research evidence that focused on effectively enforcing the implementation of Environmental Impact Assessments and Social Impact assessments. Additionally, national decision makers were approached to request water treatment for Vang Vieng town to allow for a sustainable development of its tourism sector.

Improving capacity to further integrate policy relevant indicators in an empirical agent-based model faces a series of challenges, including

- data for model parameterisation and the validation;
- more modular approaches to develop models that respond to particular concerns of policy makers in reasonable time;

- better process designs to better bridge research and policy and translate evidence into policy action on the ground.

Integration requires data for a wide range of parameters, which establishes considerable constraints in developing countries. This requires stochastic modelling approaches that employ value ranges to capture the inherent uncertainty (Smajgl et al., 2011).

The ability of applied research to respond to policy needs depends not only on data but also on the availability of adaptable models or modules. Each context is likely to require a different focus, depending on the policy focus, existing ecosystems, and dominating socio-economic characteristics. Ideally, modules would be available for each livelihood (i.e. rice, mining, tourism, or fishing) and a calendar of activities the modelling could adjust to the context at hand. Ideally, each ecosystem service (i.e. forest, water flow, or water quality) would be available and implementable through the loading of the GIS data for the target area of the modelling exercise. Ideally, researchers could follow recipes for the design of their engagement process that takes into account the particular characteristics of the context at hand. This would make it more likely that the often resource-intense modelling exercises lead to actual changes on the ground.

In summary, this paper documents a case of empirical agent-based modelling that links ecosystem services such as water flow and water quality with ecological variables such as fish, and with social variables such as livelihoods and migration. This reveals important socio-ecological feedbacks that guided the policy discussion and shaped the design of revised development strategies in the Nam Xong catchment in lao PDR.

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