**Discussion**

Understanding the drivers and proximate causes of forest cover loss and land use change is critical for the development of sustainable environmental policies and forest conservation initiatives. Studies need to target multiple scales to build a cohesive picture of the social-ecological systems within which deforestation occurs, so that policy development is appropriate and effective. Importantly, researchers need to select the appropriate method to answer specific questions at specific scales, and the complexity of the system must be understood. In this study, we have modelled the relationships between macroeconomic and socioeconomic variables and forest loss, forest cover, and the development of new ELCs. We have investigated these relationships at multiple scales using a variety of approaches and have revealed some important relationships from which we can make cautious inferences regarding direct and indirect drivers of forest loss. Furthermore, we have revealed key methodological issues, particularly around scale and model variance, that are likely to be common in these types of analyses, but which often remain unexplored or unreported in the literature.

*Macroeconomic analysis*

There were very few significant effects in the macroeconomic analysis with forest loss as the response variable. Some of the predictor variables have been shown to correlate with LUC in other studies, such as GDP (Ewers, 2006; Fan and Ding, 2016; Gong et al., 2013; Kuang et al., 2016), the contribution of economic sectors to national GDP (Gong et al., 2013), human population growth and density (Bonilla-Bedoya et al., 2018; Fan and Ding, 2016), and agricultural output (Fan and Ding, 2016). There are several possible explanations for the lack of effects in this study. First, previous studies have been at different scales to this study, such as global (e.g., Ewers, 2006), or sub-national (e.g., Gong et al., 2013), and therefore the drivers which are operating at those scales may be different to the drivers operating at the national scale in Cambodia. Second, Cambodia’s economy is unique within Asia because of the civil unrest and war, economic collapse, and subsequent rapid economic revival. This may render comparison of macroeconomic drivers of forest loss and LUC with other Asian countries ineffective. For example, Cambodia’s economy is in its infancy relative to many other countries in the region, and therefore forest loss during the study period may have been driven more by local drivers such as poverty, insecure land tenure, and land speculation by migrants, rather than national-level economics. Third, we did not include predictor variables covering institutional factors, land rights or tenure, or environmental policies, which have been shown to be important (Culas, 2007). Fourth, we only investigated up to two years of time lag between changes in predictor variables and changes in forest cover. It is possible that the effects of macroeconomics on forest cover and LUC operate at a larger temporal scale than considered in this study.

In contrast, the macroeconomic variables were effective at predicting the allocation of new ELCs. Although ELCs do not guarantee deforestation (indeed not all ELCs are awarded on forested land), the deforestation rates within ELCs are up to 105% higher than comparable areas with no ELCs (Davis et al., 2015). There has also been widespread allocation of ELCs within forested community land and protected areas, resulting in the loss of important forest habitat, rural livelihoods, and indigenous land rights (Global Witness, 2013; Watson et al., 2014). Therefore, ELCs themselves can be considered direct drivers of forest loss, rendering the macroeconomic predictors indirect drivers. Our results have demonstrated that during the study period, the economic development of the country was closely linked to the increase in ELCs, which in turn have driven forest loss. There were clear relationships between the size of the agricultural sector, the rates of foreign investment, and the number of new ELCs. The process of awarding ELC contracts in Cambodia has been criticised for lacking transparency and for corruption (Neef et al., 2013; Vrieze and Kuch, 2012), and so it is not always possible to identify who owns a particular concession. Nevertheless, of those identified, 48% were foreign owned (Licadho, 2019). Despite real and perceived benefits of attracting foreign investment and expanding the production of cash crops, there are numerous negative effects on local people and the environment. Development of potential agricultural land by investors comes with opportunity costs for local people, who otherwise may have had access to the land, water, and other resources, and could have themselves developed agriculture that would have alleviated poverty more effectively than a commercial agricultural enterprise. Furthermore, agro-industrial production of cash crops for international markets leaves the country open to price shocks and other suboptimal market fluctuations (De Schutter, 2011).

Changes in new ELC allocation can also be effectively predicted by several key agricultural commodity prices, both on the international market and internally at the farmgate scale. Rubber, sugar, corn, and rice we all important variables in the models, and increases in the market prices of these commodities can predict increases in the allocation of ELCs. Importantly, there were differences in the effects of commodity and producer prices on ELC allocation at different time lags, suggesting that either investors will delay investing in a new crop for up to two years after the prices increase, or that the process of purchasing land and establishing an ELC venture can in some cases be a slow process. International market forces are known to drive LUC, and globally, land conversion for commodity production is the single largest driver of deforestation (Curtis et al., 2018). Grogan et al (2015) provide an empirical example of how the international market price of rubber can drive deforestation in frontier areas of Cambodia and Vietnam. Understanding which commodities are driving land conversion, the strength of the effects, the time lags, and the legal and institutional mechanisms that facilitate the link between prices and forest loss, is critical for predicting future forest loss. The Cambodian Prime Minister issued a moratorium on new ELCs in 2012, which drastically reduced (although did not eliminate) ELC allocation. Although this has had a positive effect on forests, rural livelihoods, and indigenous land tenure, it is unclear how long this reprieve will last (Davis et al., 2015), or whether a new mechanism will emerge to replace ELCs. The opaque legal mechanisms and weak institutional frameworks that governed ELCs in the past are likely to continue to hinder the development of sustainable agricultural policies. The relationships between macroeconomics, commodity prices, and industrial-scale agriculture identified in this study are likely replicated across the region, and therefore these results will be of use to researchers and policy makers outside Cambodia.

*Socioeconomic analysis*

The commune-level model revealed that population density was the only non-control variable with any effect, and that effect was very weak. We were limited in the socioeconomic variables that were available, and it is possible that the variables selected were poor predictors of forest cover. However, the modelling process revealed huge between-commune variation in both predictor and response, which combined with many random effect levels (between 1,317 and 1,512) could suggest that it was the estimation of the effects from amongst the noise that was the problem, rather than a lack of effects.

Province-level

Differences in effects between scales

Socioeconomics. Discuss the few effects that I did find at commune level and province level. Huge differences in socioeconomics across the country – different stages of development. Challenging to identify national-level effects.

Methodological issues. Social-ecological systems are infinitely complex and operate at different scales. When looking at an entire country, it is difficult to identify relationships at a fine scale – there is too much noise/variation. Our commune-level models perform badly and are not good enough to be able to make meaningful predictions across the country. This should serve as a warning for other researchers. If you are looking at the broad scale you are likely missing a lot of variation and nuance, but if you look at too fine a scale you may be swamped by variation and lose the signal. The province-level models are better, but don’t reveal any strong relationships between forest cover and socioeconomics.

Alternative approaches to this kind of analysis. Non-hypothesis testing – cellular automata, neural networks.

Cluster analysis. When the models above performed badly, we decided to try different approach. Specifically removing hypothesis testing – describe the data rather than trying to explain it. Not enough to just keep looking at increasingly complex data - simulations and machine learning can isolate our thinking and help to increase understanding. Talk about cluster results. What can be said about the country? How do the results relate to the modelling results? What are the similarities, what are the differences? Do we learn anything new?

Conclusions. What forest transition pathway is Cambodia on (lambin & Meyfroidt papers)? Linking forest cover and forest loss to economic and social factors is challenging. This is particularly true of a country like Cambodia which has changed and developed extremely rapidly over the last 30 years – does not conform to development trends of the region. The governance of the country also means that natural resource exploitation is difficult to pin down through official metrics – opaque legal mechanisms and processes (e.g. ELC allocation). Nevertheless, there are analytical tools to use. Which ones you choose will depend on the data you have and the questions you are trying to ask. Final point of optimism - something about the Environmental Kuznet curve and hoping that Cambodia can reduce forest loss before its too late.