Applied Geography 62 (2015) 294–300

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Combining national forest type maps with annual global tree cover maps to better understand forest change over time: Case study for Thailand

Brian A. Johnson

Institute for Global Environmental Strategies, 2108-11, Kamiyamaguchi, Hayama, Kanagawa, 240-0115, Japan

ARTICLE INFO

Article history:
Received 3 April 2015
Received in revised form
26 May 2015
Accepted 26 May 2015
Available online xxx

Keywords:
Forest monitoring
Data fusion
Deforestation
Land use change
Landsat
REDD+

ABSTRACT

National and global land use/land cover (LULC)/LULC change (LULCC) data sets often have different strengths and weaknesses for monitoring forest change over time. For example, a national-level map may be very detailed in terms of number and type of forest-related LULC classes, but infrequently updated compared to a global map with fewer LULC classes (e.g. percent tree cover maps or forest/non-forest maps). So, additional useful information might be gained by integrating national and global LULC data sets. As a demonstration, in this study a national forest type map of Thailand from the year 2000 was combined with annual global tree cover maps for the years 2000–2012 to obtain multi-temporal information on forest change in Thailand and to create a baseline estimate of forest change to 2020 (i.e. with no new policy interventions). Results showed that all forest types experienced declines in area from 2000 to 2012, with the greatest area losses for Mixed Deciduous Forests (−137,765 ha) and the greatest percentage losses for Swamp Forests (−5.8%). Annual forest losses, in general, increased at a near-linear rate from 2000 to 2012, and are projected to increase from 39,290 ha/year in 2012 to 51,775 ha/year by the end of 2015 (an increase of 31.8%) and 66,945 ha/year by 2020 (an increase of 70.4%) based on linear extrapolation of the historical trend. For comparison, net forest loss is currently around 5,211,000 ha/year at the global level and 677,000 ha/year at the South and Southeast Asia regional level (Food and Agriculture Organization of the United Nations, 2010b). The methods presented here provide a computationally-simple approach to annually update existing forest maps and estimate future forest change using free global tree cover data.

1. Introduction

1.1. *National and global land use/land cover change mapping efforts related to forest monitoring*

The loss and degradation of natural forests has significant impacts on the broader terrestrial, atmospheric, and aquatic environments, and Southeast Asia has been identified as a region with high natural forest loss (Sodhi, Koh, Brook, & Ng, 2004; Sodhi et al., 2010). Frequent measurements of natural forest extent are needed to assist national/sub-national land use planning, monitor compliance with international environmental agreements (e.g. Kyoto Protocol, Convention on Biological Diversity), and implement conservation-based incentive programs (e.g. REDD+). To support these and other efforts, many national and global land use/land cover change (LULCC) mapping studies have been conducted using satellite imagery and remote sensing image processing techniques. Previous LULCC studies vary greatly in terms of their mapping methodologies (e.g. automated vs. manual mapping approaches, choice of classification algorithm for automated mapping), spatial resolutions, temporal resolutions, classification systems (i.e. number/type of LULC classes), and classification accuracies, and many examples of different approaches can be seen in the Country Reports of FAO's (2010a, b) Global Forest Resources Assessment (FRA) (http://www.fao.org/forestry/fra/67090/en/, last accessed May 11, 2015). This variety of methodologies makes it difficult to aggregate the national-level maps for regional-to-global scale assessments (Food and Agriculture Organization of the United Nations, 2010b; Hansen, Stehman, & Potapov, 2010). So, a major advantage of global LULCC maps are their high consistency across space (Hansen et al., 2013). On the other hand, national-level LULCC mapping

---

E-mail address: johnson@iges.or.jp.

http://dx.doi.org/10.1016/j.apgeog.2015.05.011
0143-6228/

studies have typically been conducted using finer spatial resolution imagery (e.g. 30 m or finer in many of the FAO Country Reports) than global mapping studies, which have mainly used imagery with spatial resolutions of 250 m or coarser (Bellot, Bertram, Navratil, Siegert, & Dotzauer, 2014; Bontemps et al., 2011; Friedl et al., 2010; Hansen et al., 2003; Hansen et al., 2010; Wang et al., 2014), so often the national maps could detect finer-scale changes that the global maps could not. The use of the finer resolution data for global LULC mapping (and LULCC mapping) is difficult due to the limited availability of high-quality (e.g. cloud-free) imagery covering the entire land surface, the high spectral and textual variability of global landscapes, and the high computation requirements (Chen et al., 2015). Only in the last couple of years have global LULCC studies been conducted at resolutions of 30 m (Chen et al., 2015; Hansen et al., 2013) or finer (Shimada et al., 2014), and these fine resolution LULCC products still have some limitations compared to many national LULCC data sets, such as lower temporal resolution (e.g. only two years of LULC maps for Chen et al. (2015)) or less detailed land use information (e.g. only one (Hansen et al., 2013) or two (Shimada et al., 2014) LULC classes).

Given the different strengths and weaknesses of national and global LULCC mapping efforts, there seem to be some possibilities to combine national and global data sets for more effective LULCC monitoring and/or modeling, especially if the data sets have similar spatial resolutions. For example, if a national data set has very detailed LULC information (e.g. many LULC classes) but a low temporal resolution, it may be useful to combine it with a global data set having a higher temporal resolution (but less detailed LULC information) to better assess the rates of change of at least some types of LULC of interest (e.g. forests). In comparison, previous studies on LULC map integration have mainly focused on combining existing maps to generate a more accurate single-date LULC map (Clinton, Yu, & Gong, 2015; Schepaschenko et al., 2011; Song et al., 2014).

To demonstrate how existing national and global LULC data sets can be combined for improved forest change monitoring, here a national LULC map of Thailand (Wichawutipong, 2006) having very detailed forest type information (12 forest type classes) but a low temporal resolution (only one map date) was combined with a global tree cover data set (Hansen et al., 2013) having less detailed LULC information (percent tree cover/tree cover change) but a high temporal resolution (annual maps). By combining the two data sets, multi-temporal information on deforestation/forest degradation (DFD) was obtained, and a baseline level of future LULCC related to forests was generated to 2020. To the author's knowledge, this is the first study to combine existing national and global LULC products to predict future LULCC.

1.2. *Overview of annual global tree cover (AGTC) maps and Thailand forest type map*

The annual global tree cover (AGTC) maps recently produced by Hansen et al. (2013) have a great potential for monitoring forest cover and forest cover change at national, regional, and global scales due to their high spatial (30 m) and temporal resolutions (annual maps from 2000 to 2012 using a temporally-consistent methodology). However, these maps do not differentiate between natural forest and other tree habitats (e.g. plantations), or between different natural forest types, which have different implications for climate change (Intergovernmental Panel on Climate Change, 2006), biodiversity (Schnittler & Stephenson, 2000), and other ecosystem services (Sohngen & Brown, 2006). For example, Tropical Evergreen Forests and Mixed Deciduous Forests provide habitat for different species (Forest Carbon Partnership Facility, 2013; Roy & Tomar, 2000) and have different levels of carbon storage (Forest Carbon Partnership Facility, 2013; Intergovernmental Panel on Climate Change, 2006), so for habitat modeling or quantification of ecosystem services, it is necessary to understand the forest area/forest area change by forest type. Additionally, the AGTC maps have been found to incorrectly show non-forest and/or non-tree lands (e.g. shrublands and agricultural lands containing pineapple, soybeans, tea, bananas, etc.) as containing tree cover/tree losses/tree gains due to automated mapping errors (Bellot et al., 2014; Tropek, 2014), leading to significant overestimates of forest extent and forest loss (i.e. "phantom deforestation") (Bellot et al., 2014). To overcome the limitations of the AGTC maps, a previous study combined the AGTC maps with a global "Intact Forest Landscapes" map (Potapov et al., 2008) (i.e. a map of forested areas 50,000 ha or larger with no significant human activity) and a landform map of Indonesia (i.e. a map of wetland, other lowland, upland, and montane formations) to assess primary forest loss by landform type in Indonesia (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014). However, the previous work did not take into account smaller forested areas (only 52 of the total 38,672 natural forest areas in Thailand were ≥50,000 ha) and did not discriminate between the different forest types which may exist within a single landform type. In many cases it is useful to monitor changes in all natural forested areas rather than just large primary forests, as small, fragmented forest patches can also provide important ecosystem services (e.g. habitat provisioning for animals that pollinate crops and disperse seeds) (Bodin, Tengö, Norman, Lundberg, & Elmqvist, 2006).

As discussed in Section 1.1., many countries prepare detailed national land use and/or forest maps, and these data sets can potentially be integrated with the AGTC maps (or other global maps) for improved LULCC monitoring. As one example, Thailand's Royal Forestry Department produced a detailed national forest type map for the year 2000 in which polygons of 12 different forest types were manually-digitized based on Landsat TM image interpretation and ground verification (Wichawutipong, 2006). The polygons in this map delineate the general outer boundaries of the forest lands, but some areas within these boundaries lack tree cover due to human (e.g. logging) or natural (e.g. fire) disturbances, and these non-tree areas do not provide the same ecosystem services as the tree-covered areas, e.g. they provide less erosion protection and runoff mitigation (United States Department of Agriculture, 1986) and store less carbon (Intergovernmental Panel on Climate Change, 2006), so the ecosystem services provided by forests would be overestimated if these non-tree areas are not removed. The AGTC maps could be used to separate these tree and non-tree areas within the areas designated as natural forest. The national forest type map has not been updated since the year 2000, but more general forest/non-forest maps of Thailand (i.e. maps without forest type information) have been produced (Food and Agriculture Organization of the United Nations, 2010a; The Royal Forestry Department of Thailand, 2013). However, the use of different types of imagery (with different spatial resolutions) and/or different definitions of forest in different years makes it difficult to assess trends in forest change over time (Forest Carbon Partnership Facility, 2013). The lack of forest type information in the forest maps produced since 2000 also reduces their usefulness for many types of environmental analysis (e.g. habitat modeling, climate modeling, ecosystem service quantification).

To summarize, the main limitations of the AGTC maps as related to this study is their lack of detailed LULC information and the main limitation of the national forest type map is its lack of update since the year 2000. These two data sets have the same spatial resolution (30 m, both being produced from Landsat imagery), but different numbers of LULC classes and temporal resolutions, so they seem to contain complementary information for LULCC monitoring. For