Remote Sensing of Environment 148 (2014) 42–57

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Review

Good practices for estimating area and assessing accuracy of land change

Pontus Olofsson [a,*], Giles M. Foody [b], Martin Herold [c], Stephen V. Stehman [d], Curtis E. Woodcock [a], Michael A. Wulder [e]

[a] Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA
[b] School of Geography, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[c] Laboratory of Geo-Information Science and Remote Sensing, Wageningen University, Droevendaalsesteeg 3, 6708 Wageningen, The Netherlands
[d] Department of Forest and Natural Resources Management, State University of New York, 1 Forestry Drive, Syracuse, NY 13210, USA
[e] Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, Victoria, BC 12 V8Z 1M5, Canada

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form 15 January 2014
Accepted 22 February 2014
Available online 12 April 2014

Keywords:
Accuracy assessment
Sampling design
Response design
Area estimation
Land change
Remote sensing

ABSTRACT

The remote sensing science and application communities have developed increasingly reliable, consistent, and robust approaches for capturing land dynamics to meet a range of information needs. Statistically robust and transparent approaches for assessing accuracy and estimating area of change are critical to ensure the integrity of land change information. We provide practitioners with a set of "good practice" recommendations for designing and implementing an accuracy assessment of a change map and estimating area based on the reference sample data. The good practice recommendations address the three major components: sampling design, response design and analysis. The primary good practice recommendations for assessing accuracy and estimating area are: (i) implement a probability sampling design that is chosen to achieve the priority objectives of accuracy and area estimation while also satisfying practical constraints such as cost and available sources of reference data; (ii) implement a response design protocol that is based on reference data sources that provide sufficient spatial and temporal representation to accurately label each unit in the sample (i.e., the "reference classification" will be considerably more accurate than the map classification being evaluated); (iii) implement an analysis that is consistent with the sampling design and response design protocols; (iv) summarize the accuracy assessment by reporting the estimated error matrix in terms of proportion of area and estimates of overall accuracy, user's accuracy (or commission error), and producer's accuracy (or omission error); (v) estimate area of classes (e.g., types of change such as wetland loss or types of persistence such as stable forest) based on the reference classification of the sample units; (vi) quantify uncertainty by reporting confidence intervals for accuracy and area parameters; (vii) evaluate variability and potential error in the reference classification; and (viii) document deviations from good practice that may substantially affect the results. An example application is provided to illustrate the recommended process.

Contents

* Corresponding author. Tel.: +1 617 353 9734; fax: +1 617 353 8399.
E-mail address: olofsson@bu.edu (P. Olofsson).
URL: http://people.bu.edu/olofsson (P. Olofsson).

http://dx.doi.org/10.1016/j.rse.2014.02.015
0034-4257/

1. Introduction

Land change maps quantify a wide range of processes including wildfire (Schroeder, Wulder, Healey, & Moisen, 2011), forest harvest (Olofsson et al., 2011), forest disturbance (Huang et al., 2010), land use pressure (Drummond & Loveland, 2010) and urban expansion (Jeon, Olofsson, & Woodcock, 2013). Map users and producers are acutely interested in communicating and understanding the quality of these maps. Accordingly, guidance on how to assess accuracy of these maps in a consistent and transparent manner is a necessity. The use of remote sensing products depicting change for scientific, management, or policy support activities all require quantitative accuracy statements to buttress the confidence in the information generated and in any subsequent reporting or inferences made. Area estimation, whether of change in land cover/use or of status of land cover/use at a single date, is a natural value-added use of land change maps in many local, national and global land accounting applications. For example, the amount of land area allocated for a specific use is a key country reporting requirement to the United Nations (UN) Food and Agriculture Organization (FAO) statistics and the global forest resources' assessment (FAO, 2010) as well as for countries reporting under the Kyoto protocol and the evolving activities for the UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation — UN-REDD (Grassi, Monni, Federici, Achard, & Mollicone, 2008; UN-REDD, 2008). Estimates of forest extent or deforestation are often derived via remote sensing (cf. Achard et al., 2002; DeFries et al., 2002; Hansen, Stehman, & Potapov, 2010), and area estimation also plays a prominent role in ongoing efforts to establish scientifically valid protocols for forest change monitoring in the context of specific accounting applications to policy approaches for reducing greenhouse gas emissions from forests (DeFries et al., 2007; GOFC-GOLD, 2011).

A key strength of remote sensing is that it enables spatially exhaustive, wall-to-wall coverage of the area of interest. However, as might be expected with any mapping process, the results are rarely perfect. Placing spatially and categorically continuous conditions into discrete classes may result in confusion at the categorical transitions. Error can also result from the change mapping process, the data used, and analyst biases (Foody, 2010). Change detection and mapping approaches using remotely sensed data are increasingly robust, with improvements aimed at the mitigation of these sources of error. However, any map made from remotely sensed data can be assumed to contain some error, with the areas calculated from the map (e.g., pixel counting) also potentially subject to bias. An accuracy assessment identifies the errors of the classification, and the sample data can be used for estimating both accuracy and area along with the uncertainty of these estimates. While the notion of accuracy assessment is well-established within the remote sensing community (Foody, 2002; Strahler et al., 2006), studies of land change routinely fail to assess the accuracy of the final change maps and few published studies of land change make full use of the information obtained from accuracy assessments (Olofsson, Foody, Stehman, & Woodcock, 2013).

1.1. Good practice recommendations

In this article, we synthesize the current status of key steps and methods that are needed to complete an accuracy assessment of a land change map and to estimate area of land change. This article addresses the fundamental protocols required to produce scientifically rigorous and transparent estimates of accuracy and area. The set of good practice recommendations provides guidelines to assist both scientists and practitioners in the design and implementation of accuracy assessment and area estimation methods applied to land change assessments using remote sensing. The accuracy and area estimation objectives are linked via a map of change. A change map provides a spatially explicit depiction of change and this spatial information can be readily aggregated to calculate the total mapped area or the proportion of mapped area of change for the region of interest (ROI). Accuracy assessment addresses questions related to how well locations of mapped change correspond to actual areas of change. A fundamental premise of the recommended good practices methodology is that the change map will be subject to an accuracy assessment based on a sample of higher quality change information (i.e., the reference classification). The higher quality reference classification is compared to the map classification on a location-specific basis to quantify accuracy of the change map and to estimate area. Although it is possible to estimate area of change without producing a change map (Achard et al., 2002; FAO, 2010; Hansen et al., 2010), we will assume that a map of change exists (although there will not necessarily be a map for each date). The focus for this document is change between two dates.

Before any detailed planning of the response and sampling designs is undertaken, a basic visual assessment should be conducted to identify obvious errors and concerns in the remotely sensed product. This assessment provides an evaluation of the map's suitability for the intended application and should detect if a map is so unsuitable for