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Analysis

Valuing map validation: The need for rigorous land cover map accuracy assessment in economic valuations of ecosystem services

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ABSTRACT

Valuations of ecosystem services often use data on land cover class areal extent. Area estimates from land cover maps may be biased by misclassification error resulting in flawed assessments and inaccurate valuations. Adjustment for misclassification error is possible for maps subjected to a rigorous validation programme including an accuracy assessment. Unfortunately, validation is rare and/or poorly undertaken as often not regarded as a high priority. The benefit of map validation and hence its value is indicated with two maps. The International Geosphere Biosphere Programme's DISCover map was used to estimate wetland value globally. The latter changed from US$ 1.92 trillion yr^{-1} to US$ 2.79 trillion yr^{-1} when adjusted for misclassification bias. For the conterminous USA, ecosystem services value based on six land cover classes from the National Land Cover Database (2006) changed from US$ 1118 billion yr^{-1} to US$ 600 billion yr^{-1} after adjustment for misclassification bias. The effect of error-adjustment on the valuations indicates the value of map validation to rigorous evidence-based science and policy work in relation to aspects of natural capital. The benefit arising from validation was orders of magnitude larger than mapping costs and it is argued that validation should be a high priority in mapping programmes and inform valuations.

1. Introduction

It is now widely, but not universally, accepted that the benefits provided by ecosystems can be ascribed a monetary value (Costanza et al., 1998; Adams, 2014). These monetary estimates of the value of ecosystem goods and services should not be regarded as a price at which to trade but as a guide to the benefit that arises from aspects of natural capital that can aid activities such as policy formulation, decision-making and elements of natural accounting. A key role of the monetary estimates of ecosystem services obtained is in helping to communicate the value of the natural world and make informed decisions especially when competing uses require assessment (de Groot et al., 2012; Kubiszewski et al., 2013). To be useful in support of evidence-based decision making the estimates must, of course, be credible and accurate (Hauck et al., 2013; Schägner et al., 2013).

Determining the monetary value of ecosystem services is a challenging task (Costanza et al., 1997). However, one approach that has been widely used, especially in studies of very large regions, is to employ a simple benefit transfer method based on the areal extent of key land cover classes. In brief, the approach involves multiplying an estimate of the monetary value of the services provided by the land cover class per-unit area by the area of the land cover class in the region under consideration and summing values over all classes present (Costanza et al., 1997; Kreuter et al., 2001; Konarska et al., 2002; Kubiszewski et al., 2013). Although more sophisticated approaches that, for example, incorporate supply and value variables together have been developed recently (Ingraham and Foster, 2008; Maes et al., 2012; Schägner et al., 2013) it is still common for land cover to be used as a proxy variable in valuations of ecosystem services (Brown, 2013; Schägner et al., 2013). This type of approach can also be easily extended by incorporating spatially explicit information on relevant variables such as those that might lead to local fluctuations in the value of a site arising from its particular condition or of the beneficiaries of the ecosystem services (Troy and Wilson, 2006; Brander et al., 2012). Thus rather than apply a single value to all regions of a particular class a range of monetary values for key land cover classes may be used. The development of resources such as the Ecosystem Service Value Database may aid the selection of an appropriate monetary value per-unit area for a study (de Groot et al., 2012). None-the-less the basis of the approach is the simple benefit transfer method and this will be used throughout this article.

The land cover information required for valuations of ecosystem services may be obtained from maps produced via remote sensing. The latter is especially attractive as it offers the means to generate land cover data at a range of spatial and temporal scales. Remote sensing can, therefore, support the provision of land cover information to inform assessments for regions from the local through to the global scale that may, if desired, be updated in time. Although the approach is rather crude it provides a means to generate a first approximation for the value of ecosystem services (Costanza et al., 1997; Kubiszewski et al.,

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2013). Additionally, it is an approach that has been used to derive estimates for large areas, notably at the national and regional scale (Konarska et al., 2002; Kubiszewski et al., 2013) through to the global scale (Costanza et al., 1997) and to study changes in time (Kreuter et al., 2001; Costanza et al., 2014; Wang et al., 2014).

The quality of the estimates of the value of ecosystem services derived with the benefit transfer method is a function of the data used. A variety of issues have been highlighted with this approach to ecosystem services valuation, including issues connected with the land cover data and the monetary valuations associated with each class (e.g., Costanza et al., 1997; Kreuter et al., 2001; de Groot et al., 2012). This article focuses on the land cover data used as this can have a major impact on the valuation obtained. For example, Konarska et al. (2002) focus on a scale issue and report that for the same region, the conterminous USA, that the estimate of the value of ecosystem services differs by a factor of approximately three depending on the source of the land cover map used. Specifically, the use of a map with a 1 km spatial resolution yielded an estimate of ecosystem services value of US\$ 258 billion yr^{-1} and that this rose to US\$ 773 billion yr^{-1} if a more spatially detailed map with a 30 m spatial resolution was used. A key issue behind this result is that the accuracy of a land cover map, and hence estimates of class extent derived from it, will vary with the spatial resolution of the imagery used in its production. This is because the ability to detect and so to map a land cover patch is a function of its size relative to the spatial resolution of the sensor that acquired the imagery used for mapping; ideally patches should be larger than the pixel size of the imagery (Strahler et al., 1986; Woodcock and Strahler, 1987). The magnitude of the problem of mapping patches will vary as a function of the land cover mosaic on the ground and the spatial resolution of the imagery, being most severe for highly fragmented regions when using coarse spatial resolution imagery (Crapper, 1984; Foody et al., 1996). Since the areal extent of land cover classes can be greatly mis-estimated because of this problem (e.g., Skole and Tucker, 1993; Olofsson et al., 2013) methods to reveal sub-pixel scale land cover information via analyses such as soft classification and super-resolution mapping have become popular (Foody, 1996; Boucher et al., 2008; Muad and Foody, 2012; Su et al., 2012; Ling et al., 2013). However, the potential for error arising from other sources, notably thematic misclassification, remains.

The spatial resolution of the imagery used in mapping land cover is only one of a large number of issues that affect the accuracy of land cover maps and estimates of the areal extent of classes that can be derived from them. The spectral, temporal and radiometric resolutions of the sensor used to acquire the imagery, the classification algorithm used to produce the map, the ground reference data used to train and test the classification, and the thematic resolution of the map, for example, have a marked effect on mapping accuracy (Irons et al., 1985; Kenk et al., 1988; Gong and Howarth, 1990; Peddle et al., 1994; Arora and Foody, 1997; Foody, 2002; Lu and Weng, 2007; Kavzoglu, 2009). There should be little surprise, therefore, that maps of the same area produced from different datasets or by different methods vary in their representation and hence could yield dissimilar estimates of ecosystem services value. What may be less obvious is that very dissimilar estimates of ecosystem services value can be obtained from the same map.

A map is a generalisation and will, therefore, be expected to contain error. However, in the calculation of ecosystem services value by the simple benefit transfer method discussed above, land cover maps have been taken, essentially, at face value. That is, the map is used as a representation of the land cover and areal extent measured directly from it. For example, the areal extent of the land cover classes for ecosystem services valuations in studies such as Konarska et al. (2002) was derived by counting all the image pixels allocated to each class. Even if a map is highly accurate this approach can result in large mis-estimation of class area (Olofsson et al., 2013). This type of problem arises especially when misclassification errors are asymmetric, with, for example, imbalanced errors of omission and commission. If, however, the error is known and characterised its effects can be accounted for (Staquet et al., 1981; Foody, 2010). A variety of approaches to correct for the effects of mis-classification bias in order to derive accurate areal estimates have been discussed in the remote sensing literature (Card, 1982; Hay, 1988; Czaplewski, 1992; Gallego, 2004; McRoberts, 2010; Stehman, 2013). Critically, adjustment for misclassification error allows accurate estimates of class areal extent to be obtained even if the map is itself not highly accurate in its representation of the land cover. The information required to adjust estimates of class areal extent for misclassification error can be derived from a standard confusion matrix that is generated in a validation programme to assess the accuracy of the land cover map. Although the assessment and interpretation of map accuracy is itself far from a trivial activity (Foody, 2002, 2008) it can, if undertaken rigorously, yield information to aid accurate area estimation in addition to a description of map accuracy (Stehman, 2012; Olofsson et al., 2013, 2014). Unfortunately, validation is commonly not viewed as a high priority in mapping land cover from remote sensing and many maps are not, or only poorly, validated (Olofsson et al., 2013) which greatly compromises their utility.

Attitudes to map validation may change if a monetary value could be ascribed to the benefit that arises from undertaking it. This has been the case with studies of ecosystem goods and services with estimates of the benefits that arise from these components of natural capital helping to inform decision making and policy. Ecosystem services also provide a basis to indicate the monetary value of map validation as land cover extents are used in valuations. This paper aims to illustrate the value or importance of map validation to the estimation of the value of ecosystem services. It will illustrate the effects of mis-classification error on class areal estimates and hence the valuation of ecosystem services. The difference between the valuations obtained with the use of the original mapped areas and that from the error-adjusted areas will be used to give a guide to the benefit that arises from a rigorous validation programme that provides information on map accuracy. The derived values will be put in the context of the financial costs of other parts of a major mapping programme to illustrate the size of the benefit arising from a validation programme relative to the cost of its undertaking.

2. Materials and Methods

The approach discussed by Card (1982) to adjust class area estimates for misclassification error was adopted as it is easy to use and fits with recommended good practice for the assessment and use of land cover maps derived from remote sensing (Strahler et al., 2006; Olofsson et al., 2013, 2014). With this approach the misclassification error-adjusted estimates of area are derived from the confusion matrix that is often central to map validation programmes as it forms the basis for the estimation of map accuracy.

The confusion matrix is a cross-tabulation of the class label shown in the map against that in a reference dataset for a sample of units selected in a validation programme (Table 1). Ideally the sample of units (e.g., pixels) for the accuracy assessment will be independent from any used in the training of the classifier that was used to produce the map and be acquired in a carefully designed manner. The latter includes ideally the use of a probability sampling design such as random, systematic

Table 1
The confusion matrix used in accuracy assessment and additional information required to obtain a misclassification error adjusted estimate of class area using Eq. (1).

	Confusion matrix							
		Reference data (↓)						
	Class	1	2	⋯	q	Total	Area (ha)	W_i
Map (↓)	1	n_{11}	n_{12}	⋯	n_{1q}	$n_{1.}$	A_1	W_1
	2	n_{21}	n_{22}	⋯	n_{2q}	$n_{2.}$	A_2	W_2
	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮
	q	n_{q1}	n_{q2}	⋯	n_{qq}	$n_{q.}$	A_q	W_q
	Total	$n_{.1}$	$n_{.2}$	⋯	$n_{.q}$	n	A_{total}	