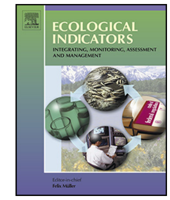
Ecological Indicators 71 (2016) 123–133

Contents lists available at ScienceDirect

Ecological Indicators

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



Seeing the forest for its multiple ecosystem services: Indicators for cultural services in heterogeneous forests

Ira J. Sutherland[a,*], Sarah E. Gergel[b], Elena M. Bennett[a]

[a] Department of Natural Resource Sciences, McGill University, Ste. Anne-de-Bellevue, QC, 21111 Lakeshore H9X3V9, Canada
[b] Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, BC, 2424 Main Mall V6 T 1Z4, Canada

ARTICLE INFO

Article history:
Received 8 March 2016
Received in revised form 9 June 2016
Accepted 18 June 2016

Keywords:
Ecosystem service
Heterogeneous forest
Forest structural attribute
Coastal temperate forest
British columbia
Traditional ecological knowledge

ABSTRACT

The ecosystem service (ES) framework is gaining traction in ecosystem management as a means to recognize the multiple benefits that ecosystems provide. In forested ecosystems, many structural attributes (trees, understory plants and woody debris) create heterogeneous ecosystems that provide numerous ecosystem services, including many that are culturally important. However, application of the ES framework to forest management is challenged by difficulties measuring and comparing multiple ES across diverse and heterogeneous forest conditions. Indicators can help bring the ES approach to forest management by providing a means for accurate ES inventory and mapping. We measured 10 forest ES in contrasting forest types to investigate the effects of past forest harvesting in coastal temperate rainforest of Vancouver Island, BC, Canada. Our objectives were to build a systematic set of ES indicators for coastal temperate forests based on forest structural features, including trees, coarse woody debris, and understory plants. To achieve this, we 1) analyzed field data to compare the effects of forest age (old-growth vs. second-growth) and ecological site conditions (riparian vs. upland forest) on the bundle of ES provided by different forest types; and 2) worked with a local indigenous wood carver to identify attributes of cedar trees (*Thuja plicata*) essential for traditional uses, including canoe carving. Forest age and forest type had significant and major effects on bundles of ES. Old-growth forests provided three times higher carbon storage, nine times higher wood volume, and eighteen times higher canopy habitat services than recovering forests. Within old-growth forests, the proportion of trees suitable for traditional indigenous wood carving was significantly higher in riparian stands. Yet of 456 trees measured, only 17 were cedar with potential traditional uses. Of those, trees for canoe carving were the least frequent (n = 3), which we identified as large (>110 cm DBH) trees of exceptional quality. In general, old-growth riparian forests were a hotspot of ES, providing for example nearly three times as much carbon storage as old-growth forests on upland sites and 12 times the amount of carbon storage as found in second-growth forests on upland sites. These results indicate that typical inventories of forest ES, which usually generalize across heterogeneity, may oversimplify dramatic variations in ES bundles in forested landscapes. Our novel set of stand-level ES indicators can improve the accuracy of ES assessments, incorporate important cultural ES, and help address the role of landscape heterogeneity in influencing ES.

1. Introduction

Ecosystem service (ES) frameworks are gaining traction in forest management as they help managers recognize and measure the multiple benefits provided by forested landscapes (De Groot and Van der Meer, 2010). A steady shift is occurring away from an industrial model of forestry towards managing for multiple values (Bunnell and Dunsworth, 2010; Oliver, 2014). Both sustainable forest management and ecosystem-based management paradigms seek to maintain ecosystem integrity while preserving opportunities for humans to derive benefits from forests (Higman et al., 1999; Price et al., 2009). Recent advances in ES mapping now form the basis of much landscape inventory of ES and analyses of tradeoffs (Grêt-Regamey et al., 2013; Qiu and Turner, 2013; Raudsepp-Hearne et al., 2010; Willemen et al., 2010). As a result, policy and management tools are rapidly being developed to implement ES management on broad spatial scales, through the US Forest Service, European Environmental Agency, and United Nations

* Corresponding author.
E-mail addresses: ira.sutherland@mail.mcgill.ca (I.J. Sutherland), sarah.gergel@ubc.ca (S.E. Gergel), Elena.bennett@mcgill.ca (E.M. Bennett).

http://dx.doi.org/10.1016/j.ecolind.2016.06.037
1470-160X/

programs, among others (Díaz et al., 2015; Patterson, 2014; Schaefer et al., 2015).

Despite this momentum, major data and methods gaps exist for how to measure, monitor and assess ES in heterogeneous forests (Syrbe and Walz, 2012; van Oudenhoven et al., 2012). In general, inventory and mapping studies of forest ecosystem services (ES) have relied on coarse scale, generalized land cover classes as spatial proxies for ecosystem services (Andrew et al., 2015). While efficient for large areas, applying generalized ES measures across large areas of forest can result in major errors and uncertainty (Eigenbrod et al., 2010; Mitchell et al., 2013; Plummer, 2009). ES can vary dramatically among forest stands for reasons not typically considered in such broad-scale land-cover-based ES assessment. For example, forest stands of differing ages, species composition, or tree density may provide different amounts of carbon storage, wildlife habitat, and wild edible foods (Alamgir et al., 2016; Clason et al., 2008; Pollock et al., 2012; Sutherland et al., 2016; Trofymow et al., 2003; Trofymow et al., 2008). Broad-scale land cover based methods may also entirely disregard key forest types (such as riparian corridors or sacred forests), which may be smaller than the resolution of the geodata used in assessment, yet contain locally important ES (Gergel et al., in revision). Thus, broad-scale ES assessment methods may be too imprecise to detect subtle nuances among forest stands that occur at fine resolution.

Indicators capable of distinguishing differences in the provision of ES within and among heterogeneous forest stands are needed to support effective planning and decision-making. To date, no ES study has examined how the nuanced architecture of forest stands influences forest stand capacity to provide ES (but see Alamgir et al., 2016). Forest stands are composed of numerous biophysical structures, which have unique roles in providing ES (Sutherland et al., 2016). For example, understory plants species provide wild edible foods (Clason et al., 2008), accumulations of woody debris (i.e. dead fallen trees) store carbon, and dead trees provide habitat for culturally important cavity-nesting bird species (Pollock and Beechie, 2014; Sutherland et al., 2016). Trees, depending on their shape, size and species, may be valuable as timber or fuelwood, provide critical habitat for rare species, or act as a cultural resource to Indigenous people who gather their fruits and nuts, carve them into canoes, or strip their bark for use in weaving (Blicharska and Mikusiński, 2014; Turner et al., 2009).

Biophysical indicators for cultural ES (the non-material benefits people obtain from ecosystems; MA, 2005) are generally lacking worldwide (Daniel et al., 2012; Hernández-Morcillo et al., 2013). However, many biophysical attributes of forests fundamentally support cultural practices, such as the harvesting and processing of tree and plant materials by indigenous people (Blicharska and Mikusiński, 2014; Emery et al., 2014; Turner et al., 2009). Identifying the cultural role of particular plants and their specific traits, with help of traditional ecological knowledge, can assist efforts now underway to create indicators for tracking sustainability of cultural ES (e.g., through the Intergovernmental Panel on Biodiversity and Ecosystem Services; Hernández-Morcillo et al., 2013).

On the coast of British Columbia (BC), Canada, there is an ongoing shift towards management for multiple forest values motivated, in part, by concern over the impacts of forest harvesting on cultural ES (Turner and Bitonti, 2011). First Nations (the common term used in Canada to describe people of indigenous ancestry) are now key actors in BC forest policy (Hoberg and Morawski, 1997). First Nations have mandated sustenance of their traditional cultural forest resources including large cedar used for building canoes, carving ceremonial poles, and stripping cedar bark for use in weaving (Haida Gwaii Strategic Landuse Agreement, 2007). However, the indicators needed to identify and responsibly steward these cultural resources are lacking.

To improve our ability to measure and predict ES across heterogeneous landscapes, we examined ES in Clayoquot Sound, Vancouver Island, BC, Canada. Using fieldwork, we contrasted the sets (or bundles) of ES provided between old-growth and second-growth forests within two distinct forest types—productive riparian and upland forests. Our primary research objective was to build a systematic set of ES indicators based on forest stand structural features, including trees, coarse woody debris and understory plants, and to explore the use of existing geodata as spatial indicators to inventory forest ES. To incorporate traditional knowledge, we worked with a First Nations carver to develop indicators for cedar trees with potential traditional uses. Thus, we asked the following: 1) How do ES bundles differ by forest age (old-growth vs. second-growth) and ecological site conditions (riparian vs. upland forest)? and 2) What indicators are useful in identifying cedar trees suitable for First Nations traditional uses?

Based on archaeological records of aboriginal forestry, we hypothesized that size (tree height and diameter) would partially determine the suitability of cedar trees for different traditional uses (e.g., Branch BCA and Committee RI, 2001), but that nuances in tree quality would be important as well. Because more productive sites produce larger trees quicker, we expected provision of most ES (including culturally important cedar) to be higher in riparian forests, both in old-growth and in recovering stands. Also, riparian forests help regulate environmental quality for spawning salmon and provide habitat for an iconic rare bird species the marbled murrelet (*Brachyramphus marmoratus*), so we expect these areas to be ES hotspots, providing the highest levels of many ES (Green, 2007; Burger et al., 2010). However, we expected upland sites to have higher wild edible berries and other botanical forest products due to the thick shrub layer at upland sites (Meidinger and Pojar, 1991). Because many forest structural attributes recover slowly following harvest, we expect some ES to be absent in recovering forests.

2. Methods

We collected field data from 12 forest stands at Clayoquot Sound, Vancouver Island, BC, Canada, (Aug 2014) to contrast ES among different forest types (riparian vs. upland) as well as between older, late seral forests >250 years age (herein referred to as *old-growth*) and second-growth forest ~35 years age. We measured elements of forest stand structure (e.g., trees, understory plants, and coarse woody debris) for use as biophysical indicators of ES then compared differences in ES provision among forest stands using mixed effect models. To develop indicators for lesser-studied cultural ES, we worked with a First Nations carver to identify key attributes of cedar trees that determine the utility of a tree for several traditional uses.

2.1. *Study system*

In Clayoquot Sound on Vancouver Island, BC, Canada (Fig. 1), the social and ecological effects of forest harvest have received considerable research and management attention (Clayoquot Sound Scientific Panel, 1995). The diverse forest-dependent livelihoods of multiple stakeholders, including forestry licensees, national park operators, local communities, as well as three First Nations (*Tla-o-qui-aht*, *Ucluelet* and *Ahousaht* First Nations), make it an important region in which to evaluate multiple ES and their recovery following forest harvest. Forest harvesting, primarily using the clear-cut method of harvest, was widespread in the 1960's through the 1980's. In the early 1990's, protests and intense debates resulted in new provincial forest management guidelines, which slowed the rate of old-growth harvesting (Clayoquot Sound Scientific Panel, 1995). A new era began, emphasizing broader social, ecological and