Ecological Indicators 66 (2016) 10–19

Contents lists available at ScienceDirect

Ecological Indicators

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

Decreasing Net Primary Production in forest and shrub vegetation across southwest Australia

Niels Christiaan Brouwers[a,*], Nicholas C. Coops[a,b]

[a] Centre of Excellence for Climate Change, Woodland and Forest Health, School of Veterinary and Life Sciences, Murdoch University, Building 335, 90 South Street, Murdoch 6150, Western Australia, Australia
[b] Faculty of Forest Resources Management, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada

ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form
14 December 2015
Accepted 8 January 2016
Available online 30 January 2016

Keywords:
Western Australia
Tree decline
MODIS
Climate change
Mediterranean
Fire
NPP
GPP
Biodiversity hot spot
Woodland
Rate of change
Ecological change indicator
Time series analysis
Theil Sen
Dynamic Land Cover Dataset

ABSTRACT

Monitoring changes in the terrestrial carbon cycle and vegetation health can only be undertaken over large areas and on a regular basis using ecological indicators derived from satellite-based sensors. Climate conditions in Mediterranean ecosystems have undergone, and are projected to undergo, significant change in the future with marked impacts on forest and shrubland vegetation. In the southwest of Australia (SWAU), endemic tree species have experienced significant declines in health and mortality since the early 1990s primarily due to these climatic changes. In this paper we examine trends in Net Primary Production (NPP) from 2000 to 2011 as an indicator of productivity and health condition of the woody vegetation across the SWAU region. To do so, we examine NPP estimates derived from satellite imagery and climate data to answer the questions: (1) what is the extent and rate of change in NPP for the SWAU region over the study period, and (2) how important is fire as a contributing factor in the observed trends? Our results suggest that, similar to the global trend in Mediterranean ecosystems, between 2000 and 2011, overall NPP declined across the study region, with the majority of declines occurring in the ecological transition zone between trees and shrubs. Twenty-six percent of the 37,042 square kilometre of woody vegetation that showed a declining NPP trend, was affected by fire. The overall rate of NPP decline for the region was estimated to be −0.38 megaton C per year since 2000, indicating a reduction in the capacity of the region to act as a carbon sink. Under climate change projections, the observed decline trends are likely to continue and our results suggest that the carbon storage potential in this region is gradually decreasing following an ecological shift from tall tree-dominated to lower shrub-dominated vegetation.

1. Introduction

Globally, over recent decades, forested ecosystems have been undergoing substantial changes in cover (Hansen et al., 2013) and have increasingly shown declines in health (Allen et al., 2010; Peng et al., 2011; Phillips et al., 2009). These changes have been attributed to a variety of direct anthropogenic activities such as land clearing and conversion as well as disturbances such as fire (e.g., Hansen et al., 2013) and pest outbreaks (e.g., Allen et al., 2010). A further major contributor of the observed changes and health declines in forested regions has been the ongoing changes in global and regional climate (e.g., Allen et al., 2010; Brouwers et al., 2012; Peng et al., 2011; Phillips et al., 2009).

Monitoring of vegetation dynamics and health has been undertaken at global and regional scales using a range of approaches, from observational (e.g., Allen et al., 2010; Brouwers et al., 2012; Matusick et al., 2013), to a suite of remote sensing (RS) based methods using various ecological indicators (e.g., Brouwers et al., 2015; Hansen et al., 2013; Reeves and Baggett, 2014; Zhao and Running, 2010). The National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on-board the TERRA and AQUA satellites has been providing information on land surface and vegetation dynamics since 2000. At the global and regional scale, remote sensing based estimates of Gross and Net Primary Production (GPP and NPP, respectively) derived from MODIS have increasingly proven useful as indicators for monitoring changes in vegetation productivity and health (e.g., Coops and Wulder, 2010; Running et al., 2004; Zhao and Running, 2010). For example, MODIS derived estimates for GPP have been used as an indicator to monitor losses in carbon sequestration of forests after large regional-scale insect infestations by the mountain pine

* Corresponding author. Tel.: +61 893602737.
E-mail addresses: n.brouwers@murdoch.edu.au (N.C. Brouwers), nicholas.coops@ubc.ca (N.C. Coops).

http://dx.doi.org/10.1016/j.ecolind.2016.01.010
1470-160X/

beetle (Coops and Wulder, 2010). At a global scale, trend analysis from 2000 to 2009 of annual MODIS NPP estimates indicated that despite general warming trends globally, NPP demonstrated an overall reduction primarily due to large scale droughts and a general drying trend in the Southern Hemisphere, including large parts of Australia (Zhao and Running, 2010).

Studies focusing on forested regions around the world (e.g., Allen et al., 2010) as well as more recently in the Mediterranean climate of southwest Australia (SWAU) (Brouwers et al., 2013, 2012, 2015; Matusick et al., 2013, 2012), have increasingly showed declines in forest health in relation to gradual drying and warming as well as extreme drought and heating events. The observed health declines within the forests in the SWAU have primarily manifested themselves in dieback of tree crowns (i.e., death of foliage and branches) (Brouwers et al., 2012; Matusick et al., 2013, 2012) as well as tree mortality triggered by extreme drought and heat (Matusick et al., 2013; Ruthrof et al., 2015b). These climate related decline processes were further found to increase fuel loads and the potential for more severe and intense fires to occur (Ruthrof et al., 2015a)

Fires are a common disturbance in forested regions with a distinct dry season (e.g., Bradstock et al., 2002; Hurteau and Brooks, 2011), affecting the carbon cycle through direct emissions and (temporary) reducing the capacity of vegetation to sequester carbon (Beringer et al., 2007; Hurteau and Brooks, 2011; Williams et al., 2004). Changes in climate, specifically drying and warming, have the potential to increase the impacts of fire on forested regions (Hurteau and Brooks, 2011; Williams et al., 2009). The frequency and intensity of fires under drying and warming conditions are likely to increase, and because of lesser water availability, might result in permanent changes in vegetation structure and composition (Hurteau and Brooks, 2011; Williams et al., 2009), shifting from tree dominated to shorter shrub dominated vegetation (Acácio et al., 2009). Consequently, the amount of carbon stored in these systems will be reduced as well as the amount of carbon that can be sequestered by the vegetation (Hurteau and Brooks, 2011).

Together, the climate-related dieback and fire-climate interactions in forested areas have clear ramifications for the carbon cycle (Hurteau and Brooks, 2011; Reichstein et al., 2013) as well as the potential to impact on regional and global climate change through forest-atmosphere feedbacks (Bonan, 2008; Lee et al., 2011; Li et al., 2015). Consequently, ecosystem functioning will be impacted with a high likelihood of negative flow-on effects on biodiversity and the potential of forests to act as efficient permanent carbon sinks in the future (Hurteau and Brooks, 2011; Williams et al., 2009).

In this research we focus on the SWAU ecoregion (Fig. 1) due to its global recognition as an area of biodiversity conservation importance (Brooks et al., 2006; Klausmeyer and Shaw, 2009; Mittermeier et al., 2011). Persistent drying and warming trends have been shown and are projected for SWAU (Bates et al., 2008; CSIRO & Bureau of Meteorology, 2015) as well as for the other sensitive Mediterranean ecoregions globally (IPCC, 2013). These climate change projections indicate the large potential of Mediterranean areas to lose biodiversity (Klausmeyer and Shaw, 2009) as well as carbon uptake potential. Measuring NPP over time allows us to quantify the amount of atmospheric CO_2 fixed by vegetation and stored as carbon within woody tissue (Zhao and Running, 2010), and more importantly look at carbon sequestration trends. Trend analysis of spatially explicit NPP estimates are highly useful as ecological indicators of where, and what types of vegetation across the landscape are likely undergoing changes now and into the future. These trend indicators can provide insights into, for instance, where and to what extent the vegetation is changing as well as if carbon sequestration potential is decreasing, allowing more accurate carbon accounting as well as assist sustainable management practices in the global push to mitigate climate changes (Hurteau et al., 2008).

In the decadal global analysis of NPP trends by Zhao and Running (2010), the SWAU region largely indicated a positive trend in NPP, primarily across the large areas of agricultural land. The NPP trends in the more important (in terms of long-term carbon sequestration potential and biodiversity values) woody vegetation types in this region, however, was less clear due to the global focus of their research (Zhao and Running, 2010). The fact that the region is a global biodiversity hotspot (Mittermeier et al., 2011) necessitates a closer view. To investigate trends in NPP in more detail for this internationally important region, this study focussed on eight specific woody vegetation classes across the SWAU. Specifically we ask: (1) what is the extent and rate of change in NPP for the SWAU region over the study period and does it vary across different woody

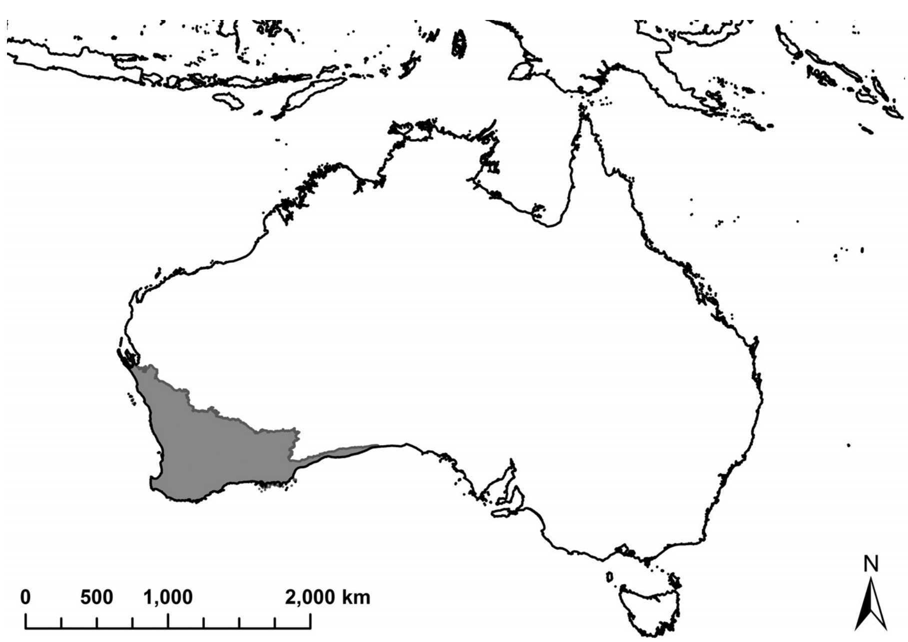

Fig. 1. The southwest Australia (SWAU) ecoregion.