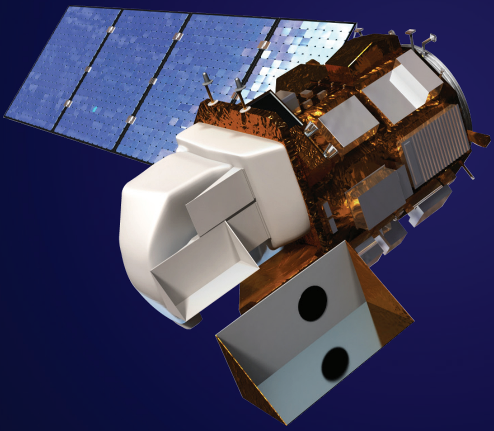
EARTH OBSERVATION OF ECOSYSTEM SERVICES



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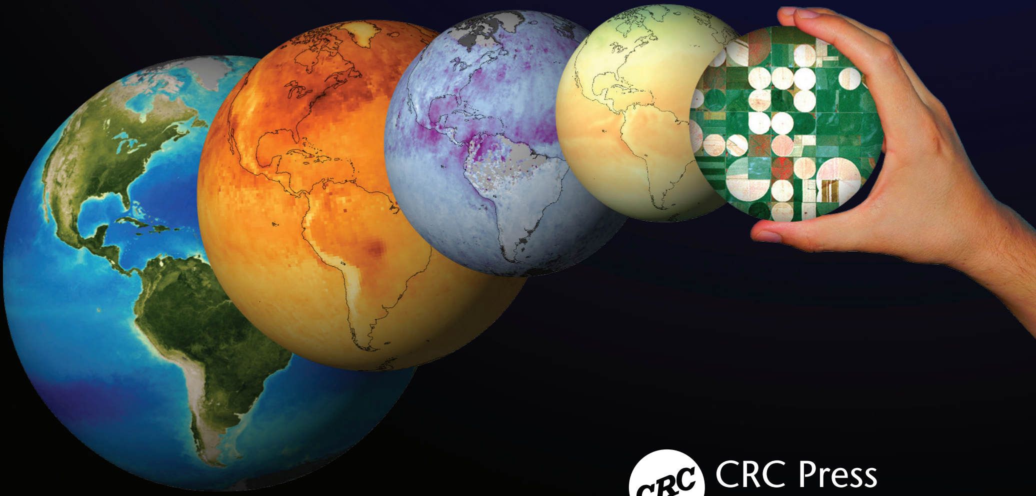

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EARTH OBSERVATION OF ECOSYSTEM SERVICES

Earth Observation of Global Changes

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Earth Observation of Ecosystem Services
edited by Domingo Alcaraz-Segura, Carlos Marcelo Di Bella, and Julieta Veronica Straschnoy

Global Forest Monitoring from Earth Observation
edited by Frédéric Achard and Matthew C. Hansen

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Foreword

Trend monitoring is considered increasingly critical for a better understanding of environmental changes. Our planet is a living system with multiple interactions between physical and biological processes that are continually modifying the Earth's landscapes. In addition to these natural processes, human activities play a very relevant role in explaining the environmental processes, as humans interact with a wide variety of atmospheric, ocean, and land flows. This interaction has two complementary heads—how humans affect and are affected by ecological processes. Planet Earth primarily serves as our home. We rely on natural resources to find food and shelter and even to find our spiritual guidance. For millennia, we have used those resources in diverse ways, perceiving them as infinite. This planet was considered vast and diverse enough to serve human needs unconditionally. However, we now realize that the human footprint is almost everywhere, and we have gradually begun to consider natural resources as precious and limited goods. Our house is becoming too small, or at least this is how we perceive it. We can react to this perception by ignoring the potential collapse to which our current way of living may bring us or we can limit our growth. But the first effort should be to better understand the problem: whether this perception is true and what are the trends to estimate near-term scenarios.

Earth observation by satellite has become an indispensable tool for obtaining a global view of many natural processes as well as for monitoring their trends. Even though the historical archives of satellite images are small (the first reliable satellites were launched only 25 to 30 years ago), they provide critical information on tropical deforestation, land use trends, water quality, crop yields, snow and ice extents, coastal processes, oceans, cloud and aerosol distribution, and many other variables that are essential to describe the global system.

Ecosystem services refer to all natural processes that have a significant impact on human societies. In recent decades, these services have been as inputs to be accounted for in any economical evaluation. Nature provides a wide range of services to humanity, from water quality to wood or pasture, from hunting to fishing, from biodiversity conservation to snow cover, from carbon stocks to soil erosion protection, from cork to nuts to mushrooms. Many of these aspects are covered in this book, which serves as a very relevant method of facilitating updated material for better appreciating how satellite images can be used operationally in monitoring ecosystem services. This is probably the first book to cover most of those topics, providing a comprehensive analysis of a very innovative field of research that should be promoted in the near future. The editors' efforts to cover such a wide range of topics with such a diverse list of authors should be greatly acknowledged. The resulting text will facilitate extensive material for ecologists, hydrologists, biologists, geographers, and many other environmental scientists, who can further rely on the growing availability of satellite images for better understanding and monitoring our fragile environment.

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Domingo Alcaraz-Segura was born in Alhama de Almería, Spain, in 1978. He received his bachelor degree in environmental sciences in 2000 and his PhD degree in 2005, both at the University of Almería. He has enjoyed post-doctoral positions at the University of Virginia, University of Buenos Aires, University of Texas at Austin, University of Maryland, and Spanish Council for Research (Doñana Biological Station). Currently, he is a professor at the University of Granada (Spain) and an associate researcher of the Andalusian Center for the Assessment and Monitoring of Global Change. He teaches courses in botany, geobotany, global change, biodiversity conservation and human well-being, and time series analysis of satellite images. His current research interests are the environmental controls of biodiversity, the impact of land cover and land use changes on ecosystem functioning and services and on hydroclimate, and the development of monitoring and alert systems of global change effects on protected areas. His research is based on fieldwork, remote sensing techniques, time series analysis, and geographical information systems.

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Section I

Introduction

1

A Global Vision for Monitoring Ecosystem Services with Satellite Sensors

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CONTENTS

1.1 General Overview of Remote Sensing of Ecosystem Services

Ecosystem services can be defined as "an activity or function of an ecosystem that provides benefit (or occasionally detriment) to humans" (Mace et al. 2012; see also Burkhard et al. 2012; Crossman et al. 2012). Repeated efforts have been made to quantify, value, map, monitor, and analyze the various ecosystem service components that sustain human well-being: from the early attempts of Costanza et al. (1997) and the Millennium Ecosystem Assessment (MA 2005) to the more recent integrative initiatives of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2013) and the Global System for Monitoring

Section II

Ecosystem Services Related to the Carbon Cycle

2

Ecosystem Services Related to Carbon Dynamics: Its Evaluation Using Remote Sensing Techniques

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CONTENTS

2.1 Introduction

Policies aimed at integrating social, economic, and environmental dimensions of sustainability have to explicitly consider evaluating the influence of human activities on the provision of ecosystem services (ESs). The decision-making process for land use planning requires ES inventory along with an estimation of the ES provision rates and the effects of related human activities. ESs are commonly evaluated on the basis of indicators that do not provide a proper representation of the whole territory and/or do not capture

3

Recent Advances in the Estimation of Photosynthetic Stress for Terrestrial Ecosystem Services Related to Carbon Uptake

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CONTENTS

4

Earth Observation of Carbon Cycling Pools and Processes in Northern High-Latitude Systems

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CONTENTS

4.1 Introduction to Remote Sensing of Carbon Cycling Processes at Northern High Latitudes

Ecosystem services of northern terrestrial systems encompass all three main categories of service: provisioning, regulating, and cultural (Haynes-Young and Potschin 2010). The ecosystem services focused on within this chapter are largely provisioning (e.g., biomass production) and regulating (e.g., carbon sequestration and storage). One key service of the northern high latitudes has been their ability to store carbon. Arctic and subarctic ecosystems have

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Monitoring the Ecosystem Service of Forage Production

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5.1 Introduction

Worldwide, 80% of the energy required by cattle to reach market weight is derived from rangelands and pastures (Wheeler et al. 1981; Oltjen and Beckett 1996). Managing these forage resources requires knowing

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Missing Gaps in the Estimation of the Carbon Gains Service from Light Use Efficiency Models

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6.1 Introduction

The scientific community is being urged to invest more time and economic resources to improve current estimates of global and regional carbon budgets (Scurlock et al. 1999). Carbon gains are considered either as an intermediate service (Fisher et al. 2009) or as supports of provision and regulating services (MA 2005). In addition, net primary production (NPP), an estimate of ecosystem carbon gains, is often considered the most integrative descriptor of ecosystem function (McNaughton et al. 1989). NPP estimates are derived from biomass harvesting, flux tower measurements, remote sensing, and model simulation (Ruimy et al. 1995; Sala et al. 2000; Still et al. 2004). Biomass harvesting is expensive and not exempt from errors and methodological problems. These methods are limited in their spatial and temporal coverage. Given the linear relationship between the fraction of solar radiation absorbed by vegetation and spectral vegetation indices (Sellers et al. 1992), Monteith's model (Monteith 1972) offers the possibility of estimating seasonal variation in carbon gains from remote sensing data (Potter 1993). Monteith's model states that carbon gains (Equation 6.1) of vegetation cover are a function of the quantity of incoming photosynthetically active radiation (PAR), the fraction of this radiation intercepted by vegetation (fPAR), and the light use efficiency (LUE; Still et al. 2004). The flux estimated using the Monteith's model included net and gross primary production and net ecosystem exchange (NEE) (Ruimy et al. 1999; see Equations 6.2 and 6.3).

$$\mathrm{NPP} = \mathrm{PAR}*\mathrm{fPAR}*\mathrm{LUE} \tag{6.1}$$

$$\mathrm{GPP} = \mathrm{PAR}*\mathrm{fPAR}*\mathrm{LUE} \tag{6.2}$$

$$\mathrm{NEE} = \mathrm{PAR}*\mathrm{fPAR}*\mathrm{LUE} \tag{6.3}$$

PAR can be directly measured using radiometers; fPAR can be estimated from spectral indices such as the Normalized Difference Vegetation Index (NDVI; Asrar et al. 1984) or the Enhanced Vegetation Index (EVI). The relationship of fPAR-spectral indices may vary between land cover types, but several authors have proposed different empirical relationships: (a) linear (Choudhury 1987); (b) nonlinear (Potter 1993; Sellers et al. 1994); and

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Biomass Burning Emission Estimation in Amazon Tropical Forest

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Section III

Ecosystem Services Related to Biodiversity

8

Earth Observation for Species Diversity Assessment and Monitoring

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CONTENTS

8.1 Introduction

Species loss and the decline of populations are among the most important threats to the preservation of ecosystem processes and their services to humans (Chapin et al. 2000). These threats will increase in the near future: even the most conservative estimates indicate that current extinction rates have no precedent since the Cretaceous event (Barnosky et al. 2011), thus supporting the idea that anthropogenic activity is triggering the sixth mass extinction on Earth. As an example, recent assessments of the status of animal species showed that, among all species included in the catalog of the International Union for Conservation of Nature (IUCN), 19% of vertebrates and 26% of invertebrates were threatened, and a large number of these move to a higher risk category every year (Hoffmann et al. 2010; Collen et al. 2012). Overall, diversity is suffering an additional reduction through the loss of

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Ecosystem Services Assessment of National Parks Networks for Functional Diversity and Carbon Conservation Strategies Using Remote Sensing

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Catchment Scale Analysis of the Influence of Riparian Vegetation on River Ecological Integrity Using Earth Observation Data

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10.1 Introduction

During the past decade, river ecosystems have been identified as delivering ecosystem services that are fundamental to human well-being (Postel and Carpenter 1997; Aylward et al. 2005). River ecosystems provide cultural (e.g., recreation, tourism, existence values), regulating (e.g., maintenance of water quality, buffering of flood flows, erosion control), and supporting (e.g., role in nutrient cycling, predator–prey relationships, ecosystem resilience, and maintenance of biodiversity) services that contribute greatly, directly and indirectly, to human well-being (Aylward et al. 2005). Although the links between biodiversity, ecological functions, and the provision of ecosystem services are often poorly understood (Mertz et al. 2007), it has become evident that maintaining the river ecosystem integrity can support the protection of river ecosystem services.

The riparian zone, as an interface between the terrestrial and aquatic ecosystems, encompasses the strip of land containing distinctive vegetation along the margin of a stream. The vegetation may include trees, woody shrubs, herbs/forbs, grasses, and sedges. The ecological importance of riparian zones to ecosystem functions has been well recognized (e.g., Naiman and Décamps 1997; Naiman et al. 2005; Shearer and Xiang 2007). On the one hand, riparian vegetation contributes to the regulation of trophic status and food chains (organic debris), temperature (providing shade and cover for the aquatic communities), and habitat (stabilizes the banks, provides woody debris), which are key parameters of river ecosystems. On the other hand, it plays a buffer role against agricultural and urban diffuse pollution (e.g., nutrients, sediments, pesticides). Maintaining and restoring

Section IV

Ecosystem Services Related to the Water Cycle

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Evaluation of Hydrological Ecosystem Services through Remote Sensing

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11.1 Society and Hydrological Services

Water plays an essential role in the functioning of ecosystems, underpinning biochemical cycles, supporting living organisms and their growth, and creating aquatic habitats on Earth (Chapin et al. 2002). In addition, humans and society rely on ecosystems to provide hydrological services and the resulting benefits (MA 2003). Two major types of hydrological services (Figure 11.1) can be identified according to the benefits they generate: (1) water supply, which includes water for household, irrigation, and industry; hydropower generation; freshwater products; transportation; and recreational and spiritual benefits and (2) water damage mitigation, which includes the reduction in the number and severity of floods, the decrease in soil erosion and sediment deposition, and the mitigation of landslides (Brauman et al. 2007). Both types of services may be evaluated according to three dimensions: (1) quantity (i.e., total amount of water), (2) timing (i.e., seasonal distribution of the water), and (3) quality (related to removal and breakdown of pollutants and trapping of sediments) (Brauman et al. 2007; Elmqvist et al. 2009).

The provision of hydrological services depends on the biophysical structures and processes involving water in ecosystems (Figure 11.1). The rate of ecosystem functioning determines the capacity to deliver a potential service for people (Haines-Young and Potschin 2010). The intrinsic capacity to provide services exists in nature independently of human options in the form of ecosystem functions, and services are only materialized when people use or feel the benefits of those functions (Fisher et al. 2009). From one service, multiple benefits can be generated that translate into a welfare gain—the subject of economic, ecological, and social valuation (Ansink et al. 2008; de Groot et al. 2010). For instance, the amount of water infiltrated will recharge groundwater reservoirs, increasing water storage capacity (properties and functions; Figure 11.1). Once people use this water, the water supply service is translated into economic benefits, such as water being available for household consumption.

Concerns over water problems have been increasing in the last decades, with special emphasis on water scarcity in arid and semiarid regions (van Beek et al. 2011). Water availability is a function of the biophysical

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Assimilation of Remotely Sensed Data into Hydrologic Modeling for Ecosystem Services Assessment

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12.1 Introduction

The so-called water cycle was already observed, studied, and described by the ancient civilizations (Biswas 1970). But it was during the nineteenth century that hydrology was consolidated as an individual science, when the

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Detecting Ecosystem Reliance on Groundwater Based on Satellite-Derived Greenness Anomalies and Temporal Dynamics

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13.1 Introduction

Groundwater-dependent ecosystems (GDEs) play a key role in human development, and are especially relevant in regions with low rates of rainfall, by providing a broad range of ecosystem services such as physical support for wildlife habitats and biodiversity hotspots, control of floods and erosion, regulation of nutrient cycling, or provision of landscape refuges for cognitive development (de Groot et al. 2002; Chen et al. 2004; Eamus et al. 2005; Bergkamp and Katharine 2006; Ridolfi et al. 2007). During the past decade, research on ecology and functioning of GDEs has received a growing interest from the scientific community and from landscape managers. However, in spite of their high intrinsic values, many of these ecosystems have been strongly impacted as a consequence of disruption of hydrological linkages with groundwater resources. This disruption has been generally promoted by excessive rates of groundwater extraction and depletion, for example, Las Tablas de Daimiel and Doñana National Reserves in Spain (Llamas 1988; Muñoz-Reinoso and García-Novo 2005); Swan Coastal Plain in southwest Australia (Groom et al. 2000); desert springs in the Mojave and Great Basin deserts in the United States (Patten et al. 2008); San Pedro River in the United States (Stromberg et al. 1996). It has also been caused by modification of morphology of stream channels or wetlands through dredging or artificial diversions (Ellery and McCarthy 1998) or as a consequence of changes in their water balance due to climatic factors (Murray-Hudson et al. 2006). A better understanding of the functioning and water consumption of GDEs is then critically required to evaluate the ecological services provided by them (Murray et al. 2006; Brauman et al. 2007) and, for developing adaptive management frameworks that reconcile compatible human activities, ecosystem conservation, and their underlying hydrological tradeoffs under future scenarios of land use and climate change (MacKay 2006; Barron et al. 2012b).

GDEs are ecosystems that require groundwater inflows to maintain their current structure and functioning and the subsequent delivery of ecosystem services (Hatton and Evans 1997; Murray et al. 2003; Eamus et al. 2006). GDEs may display an obligate reliance requiring a constant groundwater presence, or a facultative one where they adapt their functioning to fluctuating groundwater availability (Murray et al. 2003; Bertrand

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Surface Soil Moisture Monitoring by Remote Sensing: Applications to Ecosystem Processes and Scale Effects

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Snowpack as a Key Element in Mountain Ecosystem Services: Some Clues for Designing Useful Monitoring Programs

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Section V

Ecosystem Services Related to the Land-Surface Energy Balance

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Characterizing and Monitoring Climate Regulation Services

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16.1 Introduction

16.1.1 The Ecosystem Service of Climate Regulation

Ecosystem services related to the atmospheric composition and climate regulation group (Haines-Young and Potschin 2013) are associated with the maintenance of both global and local climate conditions that are favorable for health, crop production, and other human activities. At the global scale, ecosystem biogeochemical processes influence the climate by emitting/absorbing greenhouse gases and aerosols to/from the atmosphere. Forests capture and store carbon dioxide, while marshlands, lakes, rice paddies, and cattle-raising rangelands emit methane. Ecosystems' biophysical properties, such as albedo, latent heat, and sensible heat, affect the local or regional temperature, precipitation, and other climatic factors (Pielke et al. 2002; Bonan 2008; Oki et al. 2013). For instance (see Bonan, 2008), part of the incoming solar radiation in a tropical forest is used for water evapotranspiration (latent heat flux), which decreases surface temperature. Furthermore, the forest's evapotranspiration may favor cloud formation as part of the local climate but also help maintain air quality. In a tropical desert, radiation heats up the soil, which then heats the air (sensible heat flux).

Despite ecosystems regulate climate through biogeochemistry (e.g., greenhouse gas exchanges) and biophysics (e.g., water and energy balance), current policies only focus on biogeochemical influences (i.e., CO_2 emissions). Recently, Anderson-Teixeira et al. (2012) proposed a climate regulation value (CRV) index that accounts for the biogeochemical and biogeophysical ecosystem properties that affect the value of ecosystem–climate services. The CRV converts the biophysical effects into biogeochemical units. Hence, the CRV offers the possibility of expanding the suite of climate regulation services considered in the current global policies and carbon markets. The biophysical part of the CRV is estimated from ecosystem's surface net radiation and latent heat flux, which are simulated using land surface models such as Integrated Biosphere Simulator (IBIS) (Foley et al. 1996; Kucharik et al. 2000) or Noah Land Surface Model (LSM) (Chen et al. 1996; Chen and Dudhia 2001; Ek et al. 2003). In general, these simulations involve the use of variables related to vegetation such as leaf area index, stomatal resistance, rooting depth, albedo and transmittance

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Ecosystem Services Related to Energy Balance: A Case Study of Wetlands Reflected Energy

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17.1 Introduction

Ecosystems play an essential role providing goods and services to humans. Directly or indirectly, their benefits to humans include provisioning (e.g., food, water, fuel, fiber, and genetic resources), supporting (e.g., ecosystems primary production, soil formation, oxygen production), cultural developments (e.g., recreation, cognitive development, reflection, and spiritual enrichment), and regulating services (e.g., air maintenance, water purification, regulation of human diseases, erosion control, and climate regulation) (MA 2005). Studying, quantification, and mapping of ecosystem services have gained increasing interest in the scientific community in recent years.

At the ecosystem level, several processes regulate water, mass, and energy fluxes toward the atmosphere (e.g., Baldocchi and Wilson 2001; Noe et al. 2011): photosynthesis—affecting the level of carbon dioxide in the atmosphere; evapotranspiration—controlling latent heat and water

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Energy Balance and Evapotranspiration: A Remote Sensing Approach to Assess Ecosystem Services

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Urban Heat Island Effect

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19.1 Introduction

In 2011, the percentage of the total world population living in urban areas was 51%, according to the Population Reference Bureau's world population data sheet (PRB 2011). Even though countries define urban in many different ways, from population centers of 100 or more dwellings to only the population living in national and provincial capitals, one thing is clear: the world is being urbanized. Ecosystems regulate the climate through biophysical processes that mediate energy and water balances at the land surface (West et al. 2011) (see Chapter 16). Consequently, the replacement of natural surfaces by

Section VI

Other Dimensions of Ecosystem Services

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Multidimensional Approaches in Ecosystem Services Assessment

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REMOTE SENSING

EARTH OBSERVATION OF ECOSYSTEM SERVICES

“Monitoring and mapping ecosystem services is critical to their effective management. This book covers the latest remote sensing techniques for doing that. A must read for anyone concerned with ecosystem services.”

—**Robert Costanza**, The Australian National University

“… a broad and valuable introduction to the use of remotely sensed data sets in assessing and monitoring key ecosystem services. … relevant to students and researchers interested in using earth observations in advancing their methods of inquiry. The subject matter is impressive, ranging from the carbon cycle to urban heat island effects. As humankind brings increasingly greater pressure to bear on natural systems, an improved understanding of their function in the context of change is critical. … an important contribution in explaining the utility of remotely sensed data in meeting this challenge.”

—**Matthew C. Hansen**, University of Maryland

“… synthesizes the state of the art of how remote sensing can contribute to get the pulse of the planet, specifically on how our ecosystems are changing and what key benefits they provide to societies. … New conceptual approaches and techniques are synthesized. Timely, systematic, reliable, and easily accessible information on the flow of services to society from ecosystems is urgently needed: this book contributes one great leap forward. A massive effort from all nations will be needed to achieve full implementation of the suggested approach.”

—**Patricia Balvanera**, Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México

“…for biodiversity and ecosystem services in situ observation cannot function without remote sensing. However, there are many earth observation systems and not every approach fits every problem. To build the global community of practice on biodiversity and ecosystem services three things are important: sharing knowledge, harmonisation of approaches and improving the observation tools. … offers a great overview of how earth observation systems are being used, can be used in the near future and what the caveats and pitfalls are at present. … It is one of the objectives of GEO BON to provide this overview and develop capacity building programmes for the whole community. This book is a good step into that direction.”

—**Rob H.G. Jongman, Alterra**, Wageningen UR, Steering Committee GEO BON

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