Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space

atmospheric CO_2, indicating that marine ecosystems have significant impacts on the global carbon cycle. We currently do not know if there are thresholds to changes in the carbon biological pump and cascading effects on the food web. Remote sensing of ocean biomass and composition together with in situ data and ecosystem models are the path to accurately quantify changes in the carbon biological pump over time. Measurements of GPP, NPP, and ocean carbon fluxes are described in the previous sections.

There are a myriad of ecological feedbacks that influence long-term carbon storage in marine and terrestrial ecosystems. Changes in temperature and moisture, land use, plant and plankton community structure, ocean circulation and sea-level patterns, ocean acidification, and other environmental changes can affect the storage of carbon in Earth's ecosystems. Many of these influences will have a threshold response below which responses to environmental changes to long-term carbon storage are undetectable but above which large changes are likely. Examples of threshold effects include melting permafrost and tundra carbon storage, rising sea level on mangrove ecosystems, and changes in the ocean's meridional overturning circulation on the ocean's sequestration of anthropogenic carbon dioxide. Other ecosystems influences have cascading effects (discussed in the next section), such as the role of bark beetle invasions on forest stand mortality, increasing the probability of aboveground carbon storage loss in trees (Meigs et al., 2011). Similar cascading effects occur in marine environments, where the demise of large phytoplankton blooms can lead to hypoxia (critically low dissolved oxygen concentrations) in subsurface waters, which in turn alters zooplankton grazer communities that influence rates of vertical carbon export and storage.

Measurement Objectives

Understanding the coupled processes linking changes of ecosystems to long-term carbon storage is clearly a high priority for the Earth sciences and for return of the nation's investment in satellite observations. However, their interdisciplinary nature makes the detailed description of required measurements complicated. Clearly, as many aspects of the coupled system need to be measured as possible so that thresholds and cascading processes can be quantified and hypotheses about their roles on carbon storage tested.

An example of how ecological threshold effects can be estimated from satellite observation is shown in Figure 8.6. Here, time series of giant kelp forest canopy biomass from a 28-year time series of Landsat-5

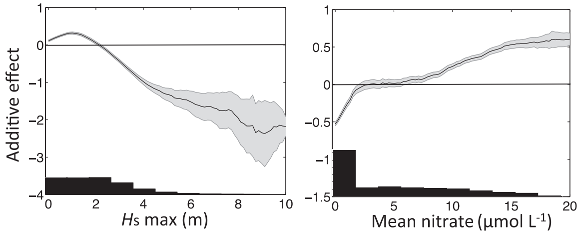

FIGURE 8.6 *Left panel:* Additive effects of surface wave significant wave height (from swell propagation wave model) on coincident giant kelp forest canopy biomass observations from Landsat-5. *Right panel:* Additive effects of surface nitrate concentration (from MODIS SST and known nitrate/SST relationships) on coincident giant kelp forest canopy biomass. Gray regions denote 95 percent confidence intervals in the calculated additive effects. SOURCE: Adapted from Bell et al. (2015).

imagery from the California coast are used to assess the controls on their population density (Bell et al., 2015a). Giant kelp populations are controlled by many processes, including nitrate availability and disturbance from surface waves forcings. Figure 8.6 shows the additive effects for changes in significant wave height (left) and nitrate concentrations (right). This demonstrates detrimental threshold effects on California giant kelp forests for significant wave heights above 3 meters and nitrate concentration below 2 μM. Positive effects are also found for smaller significant wave heights ($H_S \leq 2$ m) and nitrate concentrations above 7 μM. Similar threshold detection analyses can be conducted for other ecosystems.

Better estimation of carbon emissions of terrestrial ecosystems from disturbance, particularly fire severity related to thresholds of warming and drying, have the potential to dramatically increase our ability to model combustion of forest biomass as well as soil organic matter, particularly in high-latitude ecosystems. Threshold changes in terrestrial ecosystems are particularly relevant to rapid thawing and degradation of permafrost carbon as the freezing temperature threshold of melting ice is crossed at greater depths (Schuur et al., 2015; Schädel et al., 2016). This issue is exacerbated when fire disturbance combusts insulating soil layers and accelerates the rate of permafrost thaw (Grosse et al., 2011). These issues are addressed in greater detail in a recent National Academy workshop report (NRC, 2014).

Measurement Approaches

The measurement approach for elucidating ecological threshold and cascading effects on carbon storage will require the satellite observation of the stocks and fluxes for the ecosystem of interest as well as indices for processes known to affect the ecosystem. For the kelp forest ecological thresholding example earlier (see Figure 8.6), kelp biomass variations in time and space from Landsat imagery are compared with significant wave height and nitrate concentration estimates based on remote sensing, field observations, and models (see Bell et al., 2015a, for details). In this example, generalized additive models (GAMs; Hastie and Tibshirani, 1990; Wood, 2006) were used to quantify the nonlinear responses of the population density (kelp canopy biomass) to known forcing time series (see Figure 8.6). Many other statistical techniques can be used to assess ecological thresholds. The extension of this approach to other ecosystems is clearly dependent upon the ecosystem to be explored and known processes driving its variability in its components. Key for the elucidation of ecological thresholds from remote sensing observations are extensive data on ecosystem stocks and potentially rates and concurrent forcings on the appropriate time and space scales. The previous sections of this report provided approaches for assessing ecosystem stocks and rates that would useful for this general approach for quantifying ecological thresholds from satellite observations.

Objective E-5b

Objective E-5b. Discover cascading perturbations in ecosystems related to carbon storage.

Motivation

The panel identified discovering cascading perturbations in ecosystems related to carbon storage as an Important priority.

Alterations or perturbations in one component of an ecosystem may have cascading impacts for the entire ecosystem via altering rates of disturbance, trophic interactions, or other ecological processes. Improved understanding of the extent and direction of these relationships is critical for understanding ecosystem changes in a changing climate. This panel focused on the role of cascading perturbations in

Copyright National Academy of Sciences. All rights reserved.