Appendix B. Land-Use and Land-Cover Modeling

This appendix describes details of the spatially explicit land-use and land-cover (LULC) modeling component of this methodology. The simulation model FORE–SCE (forecasting scenarios of land cover change) will be used, which is a spatially explicit modeling framework that produces scenario-based, thematic LULC maps at annual time steps. The model begins with a LULC map representing conditions at the beginning of the simulation period and places realistic patches of LULC "change" for each subsequent yearly iteration. The proportion and type of LULC change are determined by the scenario being simulated, whereas the location of change is driven by site-specific biophysical characteristics. The modeling framework is capable of producing scenario-based simulations of future LULC change at a variety of spatial and thematic resolutions.

FORE–SCE originally was developed in support of a sensitivity analysis of the effects of LULC change on climate variability (Sohl and others, 2007; Sohl and Sayler, 2008). Although the initial application had specific requirements that helped define the initial model structure, the U.S. Geological Survey (USGS) modeling team designing FORE–SCE wanted to develop a flexible modeling system that could be adapted for future applications covering a range of research interests. FORE–SCE development began by adopting some of the key characteristics of the Conversion of Land Use and its Effects (CLUE) series of models (Veldkamp and Fresco, 1996; Verburg and others, 2006, 2008). One of the primary components adopted from CLUE is the modular framework, with distinct but linked "Demand" and "Spatial Allocation" modules. This structure allows for both linkages with exogenous models, but also for direct or indirect incorporation of driving force factors operating at multiple scales. The flexibility offered by this framework greatly increases model utility for a variety of applications. What follows is an explanation of model design, potential data gaps, and primary outputs.

B.1. FORE–SCE Structure

B.1.1. Demand Component

The "Demand" component of FORE–SCE provides overall, regional proportions of LULC annual change (an annual regional "prescription" of LULC change). A wide variety of methodologies potentially can be used to construct demand, as long as the final products are simple tables of annual LULC change for each LULC class being mapped. Approaches used for construction of demand for past FORE–SCE applications consisted of extrapolations of historical trends (Sohl and others, 2007; Sohl and Sayler, 2008) and exploratory scenarios constructed through the use of expert knowledge (Sohl and others, 2007). CLUE modeling applications also have used trends extrapolations for demand (Verburg and others, 1999, 2006), scenarios constructed through the use of empirical data and expert knowledge (Kok and Winograd, 2002), and complex modeling of demand through the use of a global economic model and an integrated assessment model (Verburg and others, 2008).

Demand for this application is directly linked to the use of storylines from the Intergovernmental Panel on Climate Change (IPCC) "Special Report on Emission Scenarios" (SRES) (Nakicenovic and others, 2000). Reference scenario demand will be provided by the scenario downscaling processes discussed in section 3.2 of this report ("Methodology Framework") and appendix A of this report ("Reference and Alternative Mitigation Scenarios"). Demand for alternative management scenarios associated with policy and mitigation actions will be provided by the methodologies discussed in section 3.2 of this report. Scenario-specific demand for reference and alternative scenarios will be provided as regionally specific prescriptions for annual LULC change from 2001 to 2050, with annual net change in individual LULC types. This information will be passed to the spatial allocation component of FORE–SCE, which will spatially distribute annual demand for change.

B.1.2. Spatial Allocation Component

The spatial allocation component of FORE–SCE ingests "demand" for a given region and spatially allocates prescribed LULC change on the landscape. The core drivers for identifying locations of LULC change are probability surfaces, constructed through the analysis of empirical relations between existing LULC patterns and a wide array of spatially explicit biophysical and socioeconomic data. Although the use of probability surfaces follows the primary methodology used by the CLUE series of models, the actual allocation of change is markedly different, with FORE–SCE utilizing a patch-based allocation methodology. The following provides a summary of the primary elements of the spatial allocation methodology.

B.1.2.1. Construction of Probability Surfaces

The spatial allocation component requires probability surfaces for each LULC class being modeled. Empirical analyses of the relation between spatial datasets representing drivers of LULC change and existing LULC patterns are used to construct the probability surfaces, using a stepwise logistic regression. The most stable and robust explanation for regional LULC patterns is obtained by analysis of endpoint (the most current) LULC (de Koning and others, 1998); therefore, the dependent variable for use in the logistic regression analysis is the presence or absence of a given LULC type as mapped by the 2001 starting land-cover product (section 3.2 of this report). Independent variables used in the logistic regression include any spatially explicit datasets representing LULC driving forces.

Drivers of LULC change are unique and are based on geographic setting (Sohl and others, 2007). Given the unique characteristics of each region, probability surfaces will be independently modeled and constructed for each U.S. Environmental Protection Agency (EPA) Level II ecoregion (modified from Omernik, 1987). For each ecoregion, driving-force variables linked to LULC change for that region will be identified, acquired, and formatted. Spatially and thematically stratified sample points are drawn from within an ecoregion, and values for land cover (dependent variable) and all ancillary datasets (independent variables) are extracted. Probability surfaces are then constructed for every thematic LULC class being modeled. For each LULC class, driving-force variables linked with the LULC class are identified, and an initial logistic regression run is performed. Initial results are examined for the presence of correlated independent variables. In cases where two highly correlated variables are selected by the stepwise regression, one of the two paired variables is discarded to mitigate the effects of multicollinearity. The regression is run again with the remaining variables. Output from the stepwise logistic regression is then used in the construction of probability-of-occurrence surfaces for that LULC class, as:

$$\theta_h = \left\{ 1 + \exp\left[-a - \sum_{k=1}^{i} b_k x_{hk} \right] \right\}^{-1}, \tag{B1}$$

where θ_h is the probability for pixel h being a member of the class (values range from 0 to 1);
α is the intercept parameter;
b is the regression coefficient for LULC class k; and
x is an explanatory variable.

The probability surfaces constructed from the logistic regression process are referred to as “baseline probability” and are a primary component of the remaining spatial allocation procedure as described below.

B.1.2.2. Model Parameterization

The FORE–SCE model relies on historical LULC data for parameterization of the spatial allocation component. Several key parameters governing FORE–SCE’s patch-placement procedure use information from the USGS Land Cover Trends project (Loveland and others, 2002). As with the probability surface construction, model parameterization is done on an ecoregion-by-ecoregion basis. Before running the spatial allocation module, the following parameters are populated as follows: patch size, “clumpiness,” probability modifier, and patch library.

Patch size.—Typical patches of LULC change differ in size and configuration, depending upon LULC type and region. For the patch-based spatial allocation procedure, patch-size distribution for every LULC type is required. Empirically measured patch sizes from the USGS Land Cover Trends project are analyzed for each LULC type. Mean patch size and standard deviation for every LULC type is used to populate tables for each ecoregion in the analysis area.

“Clumpiness.”—Some forms of LULC change tend to occur as tightly collocated clumps, whereas other forms of LULC change tend to be more dispersed. A “clumpiness” parameter is used to control dispersion of LULC-change patches in the spatial allocation procedure. “Clumpiness” refers to the parts of the probability surface where change patches are allowed to be placed, and is expressed as a threshold value on the probability-surface histogram. For typically “clumped” LULC types such as urban and developed lands, the greatest probability values get preference for selection and placement of a change patch. For more dispersed LULC types, restrictions on the part of the probability histogram that can be used are more relaxed, resulting in more dispersed change patches. The “clumpiness” parameter for each LULC type is established through examining LULC change characteristics as mapped by the USGS Land Cover Trends project.

Probability modifier.—A probability modifier for a given LULC transition is based on scenario specifications and the likelihood of a given transition based on empirical historical data. Contingency tables from the USGS Land Cover Trends project provide a complete descriptive matrix of historical land-cover change for a given Level II ecoregion, and thus provide historical context for the likelihood of a given LULC transition in that region. Scenario specifications also may have a strong effect on the potential likelihood of a given LULC transition. The USGS Land Cover Trends contingency tables and a scenario’s unique specifications are used to construct probability-modifier tables for each ecoregion. Probability-modifier values range from 0 to 1 at 0.1 increments and simply are multipliers affecting the baseline probability surfaces (those constructed through the logistic regression procedure). For example, a probability modifier of “0” typically is assigned to all possible transitions of urban or developed land to another LULC type because these transitions are extremely unlikely given the relative permanence of development on the landscape once it has occurred. As a multiplier to baseline probability, existing urban lands are thus excluded from potential change to another LULC type. A similar application of probability-modifier values can be used to alter baseline probability surfaces, reducing probabilities for specific forms of transition. Using the probability modifier is a powerful methodology for controlling specific scenario-defined storylines.

Patch library.—Patch size and distribution (through patch size and “clumpiness” parameters) are only two components affecting aggregate landscape pattern. Patch configuration and shape are another component. FORE–SCE mimics actual historical patches of landscape change to better represent landscape pattern. For each ecoregion, patch “libraries” are populated for every LULC type by copying actual patch configurations (patches of a specific size, shape, and orientation) from the USGS Land Cover Trends database. The populated patch libraries are sorted by size, with multiple configurations for each patch size. The patch libraries are then used for the patch-by-patch spatial allocation procedure as discussed below.

B.1.2.3. Establishing Protected Areas

Although the probability surfaces define the suitability of a location to support a given LULC type, they do not account for the protected status of each parcel of land. The Protected Areas Database of the United States (PAD-US Partnership, 2009; for this methodology, the version of the database maintained by the Conservation Biology Institute of Oregon is used (PAD-US (CBI)) provides attributed polygons of protected lands in the United States. The PAD-US Partnership is a public and private collaboration to provide a database of public and private protected lands and includes Federal, State, and local protected lands, as well as information from national nonprofit organizations, such as The Nature Conservancy and Ducks Unlimited. Although it does not cover some protected lands, such as private conservation easements, the database does cover most of the protected lands in the United States. These data are used to better represent LULC change that may occur on these lands, with decision rules used to either alter or eliminate probabilities of LULC change occurring, dependent on the type of protection identified with each polygon.

B.1.2.4. Tracking Forest-Stand Age

FORE–SCE utilizes a forest-stand-age layer to establish and track the age of a stand of forest. This layer is used to mimic actual forest-cutting cycles and to inform the biogeochemical modeling on not only LULC type, but also the age structure of forested lands. Two sources of information are being used to construct an initial forest-stand-age layer. The vegetation change tracker (VCT) product (Huang and others, 2010) tracks disturbance using stacks of Landsat Thematic Mapper (TM) data. These data are being used to populate a database that identifies forest pixels disturbed between 1984 and 2001 and the date of last disturbance. In areas that have not been disturbed since 1984, an interpolated stand age surface is constructed from Forest Inventory and Analysis (FIA) sampling points. The "composite stand age" image constructed from these two sources will be used to track forest age as the model iterates through 2050.

B.1.2.5. Running the Spatial Allocation Component

The core of the spatial allocation module consists of the placement of individual patches of LULC change, guided by the aforementioned model parameterization and the regional probability surfaces. The process begins with the baseline probability surface for one of the LULC types being modeled. Patch placement is dependent on the combined characteristics of baseline probability, LULC type in the current iteration, the probability modifier parameter, decision rules on protected areas, and in the case of forest pixels, a function of current stand age. A "total probability" value is calculated for each pixel in the study area:

$$TPROB_{ij} = PROB_{ij} \times PROBABILITYMODIFIER_{ij} \times \text{Function}(PROTECTED) \times \text{Function}(HISTORY) \quad \text{(B2)}$$

where
$TPROB_{ij}$ is the total probability for LULC type *i* in ecoregion *j*;
$PROB_{ij}$ is the baseline probability for LULC type *i* in ecoregion *j* from the regression results;
$PROBABILITYMODIFIER_{ij}$ is the scenario-prescribed probability modifier for LULC type *i* in ecoregion *j*;
PROTECTED are decision rules specific to the type of protected land; and
HISTORY is the age since the last change in thematic LULC type.

The probability modifier is applied independently for every possible transition type in a given ecoregion. Probabilities within protected lands are altered according to decision rules specific for each form of protection. The HISTORY component is used to alter baseline probability for forest pixels, depending on when a pixel was last harvested.

Once total probability is calculated for a given LULC type, the "clumpiness" parameter is used to segment the probability-surface histogram into an "allowable" part for patch placement. To begin the patch-placement procedure, a stochastic methodology is used to place a "seed" pixel on the probability surface. A patch size then is assigned to the seed pixel. In past applications, patch size distributions are represented as Gaussian, an assumption that greatly simplifies the patch development process. A number generator capable of producing a random value within the desired Gaussian distribution is used to select a patch size based on the mean and standard deviation of patch sizes measured by the USGS Land Cover Trends project for that LULC type. The patch library for that LULC type is then consulted, and a random patch configuration for the assigned patch size is selected. The patch then is placed on the landscape.

The process is repeated for each LULC type, with the requisite number of patches placed on the landscape to meet areal "demand" for each LULC type. When demand is met, an LULC map is produced for that yearly iteration. Forest-stand-age maps are updated, with all undisturbed pixels iterated upwards by "1," and all disturbed (cut) forest pixels assigned a stand age of "0." The process then iterates forward to the next yearly iteration. At the start of each iteration, new probability surfaces are recalculated from updated, dynamic independent variables. For example, precipitation and temperature data will be used as independent variables in the logistic regressions, and if selected as predictor variables for a given LULC type, coefficients for the regression equation will be established. For future years, downscaled General Circulation Model (GCM) projections of precipitation and temperature will be used to update LULC probabilities, based on those changes in climate variables. Whereas some variables will remain static throughout the simulation period (for example, topographic variables), other variables associated with the changing landscape (for example, changes in urban development density) will be dynamic and will affect future probability surfaces.

Upon the completion of a modeling run, annual, thematic LULC maps from 2001 to 2050 will have been produced, consistent with the scenario-defined assumptions and resultant "demand" for each LULC type. Past applications of FORE–SCE have produced one set of maps for a scenario. For the national assessment, many model runs for each scenario will be produced. Given the stochastic components related to patch placement and configuration, using Monte Carlo simulations will allow for the examination of uncertainties associated with location of LULC change.

B.2. Land-Use and Land-Cover Modeling Components External to FORE–SCE

B.2.1. Coastal Modeling

The existing version of FORE–SCE is not equipped to deal with processes affecting coastal LULC change, especially coastal-wetland change in response to natural processes such as sea-level rise or erosion and deposition. Given the difficulties in specifically modeling all processes affecting LULC change, it is important that regional LULC models be able to use existing research and modeling activities where possible (Sohl and others, 2010). Rather than utilize FORE–SCE to loosely mimic coastal-change processes, an exogenous coastal-process model will be used with modeling results separately integrated with FORE–SCE results.

Assumptions of static landscapes inspire predictions that about one-half of the world's coastal wetlands will disappear in response to acceleration in the rate of sea-level rise during this century. These estimates, however, incorrectly rely on models where bed surfaces accrete at historical rates, where inundation occurs across static landscapes, or on comparisons between historical accretion and future sea-level rise (Kirwan and Guntenspergen, 2009).

Coastal ecosystems are dynamic environments that have significant capacity to adjust to changes in rates of sea-level rise through nonlinear feedback mechanisms. These types of ecogeomorphic feedbacks likely explain the persistence of wetlands within the intertidal zone for thousands of years, as indicated by the stratigraphic record, and observations of accretion rates that are highest in regions with historically high rates of sea-level rise.

An ecogeomorphic model that incorporates nonlinear feedbacks among inundation, plant growth, and substrate accretion (Kirwan and Guntenspergen, 2010) will be used to project coastal-wetland change for the United States under different sea-level-rise scenarios. In this model, the marsh surface accretes at a rate determined by its elevation relative to sea level. Increasing inundation leads to higher rates of sediment deposition, which helps coastal wetlands keep pace with sea-level rise. Vegetation also responds to increasing inundation and vegetation growth increases at low elevations, enhancing sediment trapping and organic matter accretion and limiting erosion; however, the model also recognizes that there are limits to the conditions under which feedbacks between inundation and sediment accretion can maintain a stable intertidal system.

This model has been used in the first comprehensive attempt to model coastal-wetland resilience to accelerating sea-level rise. Our experiments indicate that a threshold rate of sea-level rise exists above which inundation leads to rapid and irreversible conversion of intertidal marshland into unvegetated subtidal surfaces. The specific site conditions (tidal range and suspended-sediment concentration) that respond to maximum rates of sea-level rise also were identified. The results indicate that the amount of sediment available for accretion strongly affects the maximum rate of sea-level rise that coastal wetlands can survive, a positive relation exists between the threshold rate of sea-level rise and tidal range, and interactions occur between tidal range and suspended sediment in the water column.

The predictions of threshold sea-level-rise rates for a large range of sediment concentrations and tidal ranges agree with observations from estuaries worldwide that were not used to design or parameterize the model. The results indicate that regions with low tide ranges or suspended-sediment concentrations will submerge in the near future, even for conservative projections of sea-level rise, and that marshes in high-tide-range environments with abundant sediment are likely to remain stable under more rapid projections of sea-level rise.

B.2.2. Integration With Disturbance Modeling

To better represent processes related to fire disturbance, insect damage, and other natural disturbances, an exogenous disturbance modeling effort will be used (section 3.3.3 in this report). Given the "competition" for land between the primarily anthropogenic change modeled by FORE–SCE and the primarily natural change modeled by the disturbance modeling, annual communication between the models is essential for the national assessment. At the start of a yearly iteration, the disturbance model will produce polygons of disturbance and pass those data to the FORE–SCE modeling environment. Those natural disturbance polygons will be directly used in that year's final LULC map and will be excluded for consideration for LULC change within the FORE–SCE modeling environment. The relation between natural disturbance and potential effects on probabilities for the anthropogenic LULC change tracked by the FORE–SCE model also will be examined.

B.3. Potential Data Gaps

LULC modelers must try to establish causality between LULC change and the biophysical and socioeconomic drivers of change; however, a primary difficulty in establishing those linkages is the availability of representative spatial data for those driving-force variables (Parker and others, 2002). Spatially explicit statistical models have been criticized for overreliance on datasets that happen to be available and underrepresentation of significant drivers of LULC change without easily obtained spatial data (Briassoulis, 2000). This uneven availability of the data remains an issue for spatial models that rely on logistic regression and the use of probability surfaces. Simply put, adequate data to represent all pertinent driving forces of LULC change often are not available. Although the outlined methodology and available data should successfully meet the goals of the assessment, LULC modeling potentially could be improved if land-ownership information, water-availability information, updated wetlands information, FIA access, national VCT data, local zoning and regultory data, and data about dynamic independent variables were available. These data needs are summarized below.

Land ownership.—Individual land owners and resource managers make land-use decisions based on the constraints or opportunities afforded to them within their unique geographic and ecological setting (Sohl and others, 2010). Detailed land-ownership information at the national level would undoubtedly improve the ability to represent differences in land-use decisions between primary ownership groups. For example, shifts in ownership patterns in the southeastern United States have the potential to dramatically alter forest structure in the region (Sohl and others, 2010). Both private industrial forestry and private nonindustrial forestry are altering the landscape significantly in the southeastern United States, but there are major differences between the groups in land use and management. The capability is lacking to explicitly map and track land-management changes, as spatially explicit data on ownership at that level of thematic detail also are lacking. Because of the lack of ownership data, regional assumptions regarding land management across all ownership types are made.

Water availability.—Availability of groundwater or surface water has a tremendous affect on agricultural land use. Downscaled, projected climate data consistent with IPCC SRES storylines will be available for use by the land-cover modeling team, and projected precipitation changes will affect characteristics of probability surfaces used in the spatial allocation module; however, projected changes in surface water or groundwater that can be used as irrigation sources are not obtained. Ideally, FORE–SCE would link with a comprehensive hydrologic model that is tied to water use and projected climate change for each IPCC scenario; however, the complexity and site-specific nature of hydrologic models that potentially could provide information on groundwater or surface-water changes prohibits their utilization at the national scale. There is no mechanism, therefore, by which to model changes in irrigated agriculture as a direct response to changes in water availability. The primary option in lieu of this information is to make informed estimates of projected future affects of future water availability at the regional scale, and to handle changes in irrigated agriculture through the top-down, "demand" component of the LULC modeling (define future proportions of irrigated agriculture through the scenario construction process).

Updated wetlands information.—Wetland land covers are difficult to map through standard mapping methodologies relying on remote-sensing data. Dedicated, intensive interpretation efforts such as the National Wetlands Inventory (NWI) program are extremely valuable for providing consistent, accurate, and thematically detailed wetlands mapping. Two issues that potentially affect the ability to represent wetland extent are digital availability of products such as NWI for the entire Nation, and the date of wetland information and the lack of updating. A national wetlands layer for the National Spatial Data Infrastructure (NSDI) is being constructed, but as of late 2007, coverage was limited to 60 percent of the conterminous United States (U.S. Fish and Wildlife Service, 2007). The U.S. Fish and Wildlife stated two primary goals for the NSDI: (1) complete wetlands mapping for the Nation, and (2) explore ways to keep the national wetlands database populated with updated (current) information, while simultaneously acknowledging the practical considerations with regard to funding. A consistently updated wetlands layer for the NSDI likely would satisfy current and future needs of the national assessment.

Forest Inventory and Analysis (FIA) data access.—As discussed above, FIA data currently are used in conjunction with VCT data to produce a starting "forest-stand-age" surface. FIA data are used much more extensively by the biogeochemical modeling team. Given the privacy and dissemination issues associated with FIA data, data access remains a primary challenge.

National vegetation change tracker (VCT) data.—VCT data are used to populate an initial "forest cutting" class in the

2001 baseline land cover (section 3.2.1 of this report), as well as to produce an initial forest-stand-age surface. As of 2010, VCT data are not available at a national scale, as past VCT research has focused on prototype development, but plans are underway to produce these data at that scale. If timeline or other issues delay availability of VCT data for the national assessment, other data and methodologies will have to be used for mapping the initial forest-cutting class and the forest-stand-age surface.

Local zoning and regulatory data.—Urban development is a relatively small land use at the national scale, but LULC transitions to urban development typically are "one-way" transitions, with the land permanently removed from the pool of pixels available for LULC change (and also subsequently limited in the potential options for carbon sequestration and mitigation). The basic FORE–SCE design should provide realistic regional patterns of urban change, but because local zoning or regulatory information that may restrict or encourage urban development is not being used (apart from the PAD-US data discussed in the previous section), local accuracy may suffer. Availability and incorporation of nationally consistent zoning and regulatory information at the local scale would improve local accuracy of urban development; however, this is a minor issue at the national scale in terms of carbon-sequestration potential. It could potentially affect the ability to accurately portray local effects of LULC change on carbon and other ecosystem services.

Dynamic independent variables.—As mentioned previously, future climate projections are consistent with IPCC reference scenarios, and as the model iterates, neighborhood variables (for example, urban density) also will be updated to be used as independent variables for the logistic regressions. Future projected changes in many independent variables cannot be tracked or modeled. Some independent variables are relatively static and likely would not require updating (for example, topographic variables), but there are independent variables that are inherently dynamic and for which projected values through 2050 are not readily available. This limited availability limits the ability to examine LULC response to changes in these driving-force variables; however, trying to model processes governing all input independent variables is difficult.

B.4. FORE–SCE and Modeling Deliverables

LULC modeling deliverables include information and data related to scenario-based LULC forecasts and the scenario framework and assumptions themselves. In summary, primary deliverables provided by the LULC modeling team will include the following:

- Initial (2001) land cover
- Initial (2001) land-use and land-management characteristics
- Narrative storylines for each of the "baseline" IPCC scenarios. Constructing national and regionally specific scenarios will include techniques for incorporating exogenous modeling results, historical LULC data, and the primary assumptions associated with each IPCC scenario. These data will be used to construct regionally specific scenarios consistent with IPCC assumptions. Narrative storylines will illustrate general expected effects of IPCC storylines on regional LULC change and can be used to communicate regionally specific driving forces of change
- Quantified scenarios ("Demand"), including LULC trends with time, land-management characteristics, and land-use histories
- Annual LULC for each "baseline" IPCC scenario through 2050, including maps of LULC and spatially explicit probability distributions resulting from Monte Carlo runs of the spatial allocation module
- Annual LULC for each "alternative" policy or mitigation scenario, including maps of LULC and spatially explicit probability distributions
- Land-use history information, including annual forest-stand age, for each "baseline" and "alternative" scenario.

B.5. References Cited

[Reports that are only available online may require a subscription for access.]

Briassoulis, Helen, 2000, Analysis of land use change—Theoretical and modeling approaches, *in* Loveridge, Scott, ed., The Web book of regional science: Morgantown, W. Va., West Virginia University, Regional Research Institute, accessed March 31, 2010, at http://www.rri.wvu.edu/regscweb.htm.

de Koning, G.H.J., Veldkamp, A., and Fresco, L.O., 1998, Land use in Ecuador—A statistical analysis at different aggregation levels: Agriculture, Ecosystems, and Environment, v. 70, p. 231–247.

Huang, Chengquan, Goward, S.N., Masek, J.G., Thomas, Nancy, Zhu, Zhiliang, and Vogelmann, J.E., 2010, An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks: Remote Sensing of Environment, v. 114, p. 183–198.

Kirwan, M.L., and Guntenspergen, G.R., 2009, Accelerated sea-level rise—A response to Craft et al.: Frontiers in Ecology and the Environment, v. 7, no. 3, p. 126–127, doi:10.1890/09.WB.005.

Kirwan, M.L., and Guntenspergen, G.R., 2010, The influence of tidal range on the stability of coastal marshland: Journal of Geophysical Research, v. 115, F02009, doi:10.1029/2009JF001400.

Kok, K., and Winograd, M., 2002, Modeling land-use change for Central America, with reference to the impact of Hurricane Mitch: Ecological Modelling, v. 149, p. 53–69.

Loveland, T.R., Sohl, T.L., Stehman, S.V., Gallant, A.L., Sayler, K.L., and Napton, D.E., 2002, A strategy for estimating the rates of recent United States land-cover changes: Photogrammetric Engineering and Remote Sensing, v. 68, p. 1091–1099.

Nakicenovic, Nebojsa, Alcamo, Joseph, Davis, Gerald, de Vries, Bert, Fenhann, Joergen, Gaffin, Stuart, Gregory, Kenneth, Grübler, Arnulf, Jung, T.Y., Kram, Tom, La Rovere, E.L., Michaelis, Laurie, Mori, Shunsuke, Morita, Tsuneyuki, Pepper, William, Pitcher, Hugh, Price, Lynn, Riahi, Keywan, Roehrl, Alexander, Rogner, H.-H., Sankovski, Alexei, Schlesinger, Michael, Shukla, Priyararshi, Smith, Steven, Swart, Robert, van Rooijen, Sascha, Victor, Nadejda, and Dadi, Zhou, 2000, Special report on emissions scenarios; A special report of Working Group III of the Intergovernmental Panel on Climate Change [IPCC]: Cambridge, UK, Cambridge University Press, 599 p., accessed June 14, 2010, at http://www.grida.no/publications/other/ipcc%5Fsr/?src=/climate/ipcc/emission/index.htm.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118–125.

Protected Areas Database of the United States (PAD-US) Partnership, 2009, A map for the future—Creating the next generation of protected area inventories in the United States: Protected Areas Database of the United States Partnership, 20 p., accessed June 18, 2010, at http://www.protectedlands.net/images/PADUS_FinalJuly2009LowRes.pdf.

Parker, D.C., Berger, Thomas, and Manson, S.M., eds., 2002, Agent-based models of land-use/land-cover change—Report and review of an International Workshop, October 4–7, 2001, Irvine, Calif.: Indiana University, LUCC Focus 1 Publication 6.

Sohl, T.L., Loveland, T.R., Sleeter, B.M., Sayler, K.L., and Barnes, C.A., 2010, Addressing foundational elements of regional land-use change forecasting: Landscape Ecology, v. 25, no. 2, p. 233–247, doi:10.1007/s10980-009-9391-3.

Sohl, T.L., and Sayler, K.L., 2008, Using the FORE–SCE model to project land-cover change in the southeastern United States: Ecological Modelling, v. 219, p. 49–65.

Sohl, T.L., Sayler, K.L., Drummond, M.A., and Loveland, T.R., 2007, The FORE–SCE model—A practical approach for projecting land-use change using scenario-based modeling: Journal of Land Use Science, v. 2, no. 2, p. 103–126.

U.S. Fish and Wildlife Service, 2007, Wetlands layer—National spatial data infrastructure—A phased approach to completion and modernization: U.S. Fish and Wildlife Service, 9 p., accessed June 18, 2010, at http://www.fws.gov/wetlands/_documents/gNSDI/WetlandsLayerNSDI-PhasedApproachtoCompletionModernization.pdf.

Veldkamp, A., and Fresco, L.O., 1996, CLUE–CR—An integrated multi-scale model to simulate land use change scenarios in Costa Rica: Ecological Modelling, v. 91, no. 1, p. 231–248, doi:10.1016/0304-3800(95)00158-1.

Verburg, P.H., Eickhout, Bas, and van Meijl, Hans, 2008, A multi-scale, multi-model approach for analyzing the future dynamics of European land use: Annals of Regional Science, v. 42, no. 1, p. 57–77, doi:10.1007/s00168-007-0136-4.

Verburg, P.H., Overmars, K.P., Huigen, M.G.A., de Groot, W.T., and Veldkamp, A., 2006, Analysis of the effects of land-use change on protected areas in the Philippines: Applied Geography, v. 26, no. 2, p. 153–173.

Verburg, P.H., Rounsevell, M.D.A., and Veldkamp, A., 2006, Scenario-based studies of future land use in Europe: Agriculture, Ecosystems and Environment, v. 114, no. 1, p. 1–6.

Verburg, P.H., Veldkamp, A., and Fresco, L.O., 1999, Simulation of changes in the spatial pattern of land use in China: Applied Geography, v. 19, p. 211–233

This page intentionally left blank.