Executive Summary—Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of Alaska

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Alaska is approximately one-fifth the area of the conterminous United States and spans a broad range in climate from the maritime coastal regions of south-central and southeast Alaska to the boreal forest region in interior Alaska to arctic and maritime tundra regions of northern and western Alaska. The cold temperatures of Alaska have led to the storage of vast quantities of soil and vegetation carbon. Although forest ecosystems of southeast Alaska have been regularly included in national resource or greenhouse-gas inventory programs, other regions of Alaska have not been included in national-level resource or greenhouse-gas inventory programs because of the large size of Alaska, the lack of extensive transportation infrastructure, and the low density of field data to support such programs. Yet, high-latitude ecosystems are potentially more vulnerable to climate change than ecosystems in the temperate zone during the remainder of the 21st century because temperature is projected to increase more in boreal and arctic regions. In particular, these increases in temperature may expose the substantial stores of carbon in the region to loss from more wildfire and permafrost thaw, which could turn the ecosystems of Alaska into a net carbon source. Therefore, the assessment of Alaska ecosystem carbon stocks and fluxes as well as methane fluxes, as reported here, was conducted to better understand the baseline and projected carbon distributions and potential responses to a rapidly changing environment. The results of this assessment will inform national climate and carbon management policies.

Major components of the assessment included carbon and methane fluxes in upland and lowland (wetland) ecosystems, carbon fluxes of inland aquatic ecosystems, synthesis of soil carbon stocks and permafrost distribution, effects of forest management, and effects of climate change and associated shifts in vegetation and wildfire regime over space and time. Methods varied depending on the components, as described in respective chapters of this report. For uplands and wetlands, the boundaries of four Landscape Conservation Cooperatives (LCCs) in Alaska were used to stratify and report the assessment. For inland aquatic ecosystems, the boundaries of six hydrologic regions were used for stratification and reporting. Major findings from the assessment are:

- Estimates of total soil organic carbon (SOC) storage in boreal and arctic regions in Alaska, derived from both field observations and model simulations, ranged from 31 to 72 petagrams of carbon (PgC) from 1950 through 2009. In ecosystems with permafrost, the mean active-layer thickness (ALT; the maximum annual thaw depth) ranged between 76 and 84 centimeters (cm) from surface-derived field data; model simulations indicated that mean ALT was 86 cm.
- A conceptual model of soil susceptibility to climate change indicated that the Arctic LCC and Western Alaska LCC lowland shrub tundra ecotypes are highly susceptible to climate change because of large frozen and unfrozen SOC stocks potentially available for loss by decomposition.

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- Although there is a high variability in fire regime across interior Alaska, fire frequency, severity, and area burned have increased in recent years, and the trend was projected to continue for the rest of the century across most of the regions and most of the climate scenarios, with the boreal region projected to see the highest increase in fire activities. Correspondingly, in the boreal region late successional vegetation, such as spruce forest, was projected to decline, whereas early- to mid-successional vegetation, such as deciduous forest, was projected to increase. In tundra regions, shrub tundra was generally projected to increase and graminoid tundra to decrease.

- During the historical period of this assessment (1950–2009), upland ecosystems in Alaska were, on average, an overall carbon sink across the State of 5.0 teragrams of carbon per year (TgC/yr). However, the boreal region of the State has been a carbon source, losing 5.1 TgC/yr as the result of increased fire activity in recent decades. The overall carbon sink was projected to increase to 14.7 to 34.6 TgC/yr during the projection period (2010–2099).

- Perhumid coastal rainforest watersheds in southeast Alaska were net carbon sinks of an average 142 grams of carbon per square meter per year ($gC/m^2/yr$) from 2006 through 2009. The non-fire-prone, cool, forested region is expected to remain a stable carbon sink, and potentially increase this sink strength in the future.

- During the historical period (1950–2009), wetland ecosystems in Alaska were, on average, an overall carbon source at 1.3 TgC/yr across the State. Net biogenic methane emissions increased from 27.93 teragrams of carbon dioxide equivalent per year ($TgCO_2$-eq/yr) in the first decade (1950–1959) to 30.93 $TgCO_2$-eq/yr in the last decade (2000–2009). The combined global warming potential (GWP) of both carbon dioxide (CO_2) and methane (CH_4) was 33 $TgCO_2$-eq/yr over the historical period. Wetland ecosystems in Alaska were projected to be a net carbon sink ranging from 3.0 to 6.8 TgC/yr and an increased methane source ranging from 37 to 90 $TgCO_2$-eq/yr by 2099, yielding a GWP of 17 to 64 $TgCO_2$-eq/yr.

- Temperate forests in south-central and southeast coastal Alaska store 1,018 teragrams of carbon (TgC) in live and dead tree biomass. If managed with the current management plan (with forest harvesting) and assuming no climate change, the forest carbon could increase by 1 percent by the end of the century. Forest carbon could increase by 8 percent and 27 percent under the scenarios of climate change with and without management, respectively.

- The total net carbon flux (coastal export plus CO_2 emissions from rivers and lakes minus burial in lake sediments) from inland waters of Alaska was approximately 41.2 TgC/yr (ranging from 30 to 60 TgC/yr in terms of 5th and 95th percentiles). Total carbon yield based on total land surface area was 27 $gC/m^2/yr$ (uncertainty of 20 to 40 $gC/m^2/yr$).

- Putting it all together, we estimate that between 1950 and 2009 the upland and wetland ecosystems of the State sequestered an average of 3.7 TgC/yr, which is almost 2 percent of the net primary productivity (NPP) of the upland and wetland ecosystems. We estimate that inland aquatic ecosystems of Alaska lost 41.2 TgC/yr, or about 17 percent of upland and wetland NPP. We estimate that the greenhouse gas (GHG) forcing potential of upland and wetland ecosystems of Alaska was 17.3 $TgCO_2$-eq/yr during the historical period.

- Carbon sequestration of upland and wetland ecosystems of Alaska in the projection period (2010–2099) would increase substantially to 18.2 to 34.4 TgC/yr, primarily because of an increase in NPP of 12 to 30 percent associated with responses to rising atmospheric CO_2, increased nitrogen cycling, and longer growing seasons. Although carbon emissions to the atmosphere from wildfire were projected to increase substantially for all of the projected climates, the increases in NPP would more than compensate for those losses. Our analysis indicates that upland and wetland ecosystems would be sinks for GHGs for all simulations during the projection period.

Limitations of the Assessment Report

The known limitations of the assessment report include the following: (1) So far as substantial progress was made in this assessment in terms of findings from data, remote sensing, and model simulations for Alaska ecosystems, the availability of field data is severely limited relative to the conterminous United States in all but the coastal forest region (North Pacific LCC). This limitation, and implications to uncertainties in the results, applies to analyses of permafrost and soil carbon in chapter 3, analyses of upland and wetland carbon and CH_4 in chapters 6, 7, and 9, and analysis of aquatic CO_2 in chapter 8. (2) The analysis of future forest carbon projections (chapter 5) in the temperate coastal Alaska region did not include all major management and climate change scenarios. (3) The estimates of terrestrial ecosystem carbon stocks and fluxes were based on a static land-cover distribution. Land-cover changes associated with wildfire disturbances that were reported in chapter 2 were not represented in the model simulations conducted in chapters 6 and 7. Instead, the effects of fire disturbances on carbon and CH_4 were simulated internally by the biogeochemical modeling. (4) Similarly, CH_4 emission was simulated based on one wetland distribution map. Given the high sensitivity of modeled CH_4 emission to the inundation area, the current assessment did not quantify the uncertainty associated with wetland mapping. (5) The assessment included wildfires as the major disturbance regime in assessing its effects on carbon and CH_4 dynamics in boreal and arctic regions of Alaska. However, effects of other major disturbances, such as forest insects in temperate and boreal regions, and thermokarst disturbances associated with ice-rich permafrost thaw in lowland boreal and arctic regions, were not included in the assessment. (6) The process-based models used in this study, although extensively evaluated in this assessment and in previous studies, have substantial conceptual and parameterization uncertainties. (7) The study of inland aquatic ecosystems was not integrated with that of upland and wetland ecosystems in a seamless analysis, which likely would compromise the estimates of heterotrophic respiration because losses of carbon to aquatic ecosystems from upstream ecosystems are not taken into account.

With regard to future assessments, the technical needs for reduction of uncertainties present in this assessment will require enhancements in observation systems, research on landscape dynamics, process-based research, and modeling research. Key enhancements in observation systems include forest inventory measurements in interior Alaska, CO_2 concentration measurements in large lakes, and CH_4 emissions from lakes and wetlands. Key enhancements in landscape dynamics include improved regional datasets on vegetation dynamics, lake dynamics, insect disturbance, and thermokarst disturbance. Key enhancements in process-based research include improved understanding of the transfer of carbon between terrestrial and inland aquatic ecosystems, of CH_4 dynamics of inland aquatic ecosystems, and of controls over insect and thermokarst disturbance. Finally, key enhancements in modeling research include the development of models that can treat terrestrial-aquatic carbon linkages as an integrated system, improved modeling of wetland and lake CO_2 and CH_4 dynamics, and the prognostic modeling of insect and thermokarst disturbance and their impacts on carbon dynamics. Although there are substantial uncertainties in our analyses, the analyses themselves represent state-of-the-art science, and this assessment provides information for priorities in reducing uncertainties that should improve future assessments.