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Socio-economic Impacts of Climate Change on Rural United States

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Abstract Directly or indirectly, positively or negatively, climate change will affect all sectors and regions of the United States. The impacts, however, will not be homogenous across regions, sectors, population groups or time. The literature specifically related to how climate change will affect rural communities, their resilience, and adaptive capacity in the United States (U.S.) is scarce. This article bridges this knowledge gap through an extensive review of the current state of knowledge to make inferences about the rural communities vulnerability to climate change based on Intergovernmental Panel on Climate Change (IPCC) scenarios. Our analysis shows that rural communities tend to be more vulnerable than their urban counterparts due to factors such as demography, occupations, earnings, literacy, poverty incidence, and dependency on government funds. Climate change impacts on rural communities differs across regions and economic sectors; some will likely benefit while others lose. Rural communities engaged in agricultural and forest related activities in the Northeast might benefit, while those in the Southwest and Southeast could face additional water stress and increased energy cost respectively. Developing adaptation and

Research highlights • Rural U.S. population is more vulnerable to climate change than urban counterparts. • Climate change impacts differ across regions and economic sectors. • Geography and vulnerability of rural communities impact climate change tradeoffs. • Local and regional studies to discern climate impacts on rural U.S. are needed. • A suite of policy actions is needed to enhance coping capacity of rural communities

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mitigation policy options geared towards reducing climatic vulnerability of rural communities is warranted. A set of regional and local studies is needed to delineate climate change impacts across rural and urban communities, and to develop appropriate policies to mitigate these impacts. Integrating research across disciplines, strengthening research-policy linkages, integrating ecosystem services while undertaking resource valuation, and expanding alternative energy sources, might also enhance coping capacity of rural communities in face of future climate change.

Keywords Climate change · Nonmetro · Vulnerability · Coping capacity · Climate change adaptation · Indigenous community

1 Introduction

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (Intergovernmental Panel for Climate Change [IPCC] 2007). In the last decade, there has been a clear consensus amongst scientists that the world is experiencing a rapid global climate change, much of it attributable to anthropogenic activities. The extent of climate change effects (e.g., change in crop yields due to future temperature increase) is difficult to project with certainty, since many uncertainties exist regarding exactly how climate will change as well as the socio-economic factors that will influence the magnitude of such changes (IPCC 2001). However, even if greenhouse gas emissions are reduced significantly over the coming years, significant increases in temperature and sea level rise may still occur.

Although potential threats to urban and rural populations have been described in recent reports (e.g., Karl et al. 2009), information delineating the impacts of climate change specifically on rural communities in the U.S. is scarce. The existing research is largely sector-specific, such as delineating impacts on agriculture, health, transportation, demography, energy, etc., and has rarely addressed how these impacts might differ across urban or rural communities. In addition, few studies have attempted to delineate the severity of impacts across different spatial scales. Examining the capacity and resilience of rural communities to adapt to climate change is largely absent (Flint and Luloff 2005). Similarly, knowledge of the comparative impacts of climate change across different geographical regions, particularly with respect to rural communities in the U.S. is limited. To date we are not aware of any systematic attempt to document the range of climatic impacts faced by rural communities in U.S. There is a need to increase our understanding of how social and economic systems could be affected by climate change in the context of other stresses (Rosenzweig and Willbanks 2010)

With the above in mind, this article represents the first effort to compile a portfolio of climate impacts faced by rural communities in different U.S. geographic regions. A review of the current state of knowledge is undertaken to bridge this knowledge gap and delineate the potential impact of climate change on rural communities and to make inferences about their vulnerability to climate change. Policy prescriptions for mitigating climate risk and improving rural communities' adaptation capacities are also explored. The impacts of climate change on rural communities in U.S. through exploring three intertwined objectives, namely:

1. To compare rural and urban communities vulnerability to climate change

2. To analyze socioeconomic impacts of climate change on rural communities
3. To identify key policy directions for increasing rural communities' capacity to cope with future climate change issues and questions for future research

We analyze these objectives based on widely recognized perception that there are 'winners' and 'losers' associated with climate change processes (O'Brien and Leichenko 2000). This has important policy implications, especially for the rural communities that are likely to experience the consequences of climate change.

The impacts of climate change can be broadly grouped under three headings: ecological, social, and economic. The ecological impacts of climate change include shifts of vegetation types and associated impacts on biodiversity (National Assessment Synthesis Team [NAST] 2001; Elliott and Baker 2004); change in forest density and agricultural production (Adams et al. 1990; Smith et al. 2007); expansion of arid land (Woodhouse and Overpeck 1998; Karl et al. 2009); decline in water quantity and quality (Gutowski et al. 2008; Milly et al. 2008); effects on aquatic species and ecosystems (Environmental Protection Agency [EPA] 2007, 2008); and stresses from pests, diseases and wildfire (Alig et al. 2004; Gan 2004). Social impacts may include changes in equity, risk distribution, human health impacts, and relocations of populations (Karl et al. 2009). Economic impacts include increased risk and uncertainty of forest and agricultural production (Smith et al. 2007); alteration in productivity for crops and forest products (Feng and Hu 2007); changes in supply of ecosystem goods and services (Sohngen and Sedjo 2005; Adams et al. 2009); altered cost of utilities and services (Scott and Huang 2007). In this paper, however, we only focus on social and economic impacts of future climatic variability on rural communities in the U.S.

This paper is organized as follows. The second section elucidates data, methods, assumptions, and limitations of analysis. The third section compares U.S. urban and rural communities and their vulnerability to climate change. The fourth section discusses social and economic impacts of changing climate on rural communities. The fifth section documents policy directions for increasing rural communities' capacity to cope with future climate change. The last section summarizes the discussions.

2 Data and methods

The insights from existing knowledge sources are used to discern climate change impacts on rural communities. The information to sum up the current state of the research are sourced from peer reviewed journal articles, government reports and websites, and other publications. Since much of the climate change literature doesn't specifically address social and economic effects of climate change, we make inferences about these effects from national or sector level impact assessments dealing largely with ecological impacts.

The inferences in this paper are based on Global Climate Models (GCMs) under three SRES (Special Report on Emissions Scenarios) namely relatively low (B1), high (A2), and even higher (A1F1) emission trajectories. These IPCC scenarios model projections assume enacting no explicit climate policies. The projections for the three emissions scenarios provide a range of future pathways that can be used to assess climate uncertainty and the impact on rural communities. We draw our inferences only when change climate variable (for e.g. precipitation) trends can be established in particular region through all three emission scenarios projections. We do not draw inferences when there is divergence among these three scenarios projections. This approach is consistent with the approach used in Karl et al. (2009). In cases where inferences are drawn from publications that use other GCMs, we categorically mention which GCM has been used by the relevant authors.

One difficulty in analyzing the impacts of climate change on rural communities is the lack of a clear demarcation between rural and urban areas, as evidenced by the wide variety of definitions of "rural" employed by researchers and policymakers. For example, the United States Department of Agriculture Economic Research service [USDA ERS] (2010a) lists as many as nine definitions for "rural". Whether an area is categorized as rural or urban depends in large part on whether urban spaces are defined in terms of administrative boundaries, land-use patterns, or economic influence, and the minimum population thresholds established for delineating areas as urban or rural (Cromarties and Bucholtz 2008). Administrative definitions identify urban space along municipal or other jurisdictional boundaries. Definitions based on land use demarcate urban areas based on population density, while economic definitions incorporate the influence of cities beyond densely settled cores and demarcates based on broader commuting areas. The Office of Management and Budget (OMB) identifies counties as rural if they are not core counties (core counties contain one or more urban areas of 50,000 people or more) or economically tied to the core counties, as measured by the share of the employed population that commutes to and from core counties. We follow the OMB definition and discuss impacts of climate change on non-metro (rural) areas comprising about 2,052 counties in U.S based on the future projections of three GCM scenarios.

Another limitation is that of the SRES scenarios themselves and the assumptions therein. Variation amongst these scenarios projections can be attributed to assumptions regarding changes in population, rate of policy adoptions for climate ameliorations, economic growth, technological growth and other reasons. Thus, there can be many more alternate futures with an array of uncertainty surrounding them as emissions can change less than the one projected by these scenarios, or they can lead to dissimilar impacts in different regions and result in a complex geography of climate change. It remains beyond the scope of this article to examine the wide range of rural vulnerability in detail (i.e., the extent, historical evolution, and effectiveness of each climate vulnerability factors). These very well remain important directions for future inquiry.

3 Vulnerability of rural communities

Rural regions contain about 17% of the U.S. population but extend across 80% of the land area (Fig. 1). The communities residing in these areas differ from their urban counterparts in terms of demography, occupations, earnings, literacy, poverty incidence, and dependency on government funds. These differences tend to shape economic and socio-cultural conditions across rural counties and provide insights on why rural populations may exhibit different vulnerabilities to climate change than their urban counterparts. Vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC 2007). It is a function of the character, magnitude and rate of climate change and the variation to which a community is exposed, its sensitivity and its adaptive capacity (IPCC 2007). The community adjusts (adapts) in response to actual or expected climatic stimuli or their effects, in order to mitigate (moderate) adverse impacts or exploit beneficial opportunities. The higher a community's adaptive capacity, the lower is its vulnerability to climate change.

Since 19.6% of non-metro counties are farming dependent counties (counties that have either 15% or more of average annual labor and proprietors' earnings derived from farming

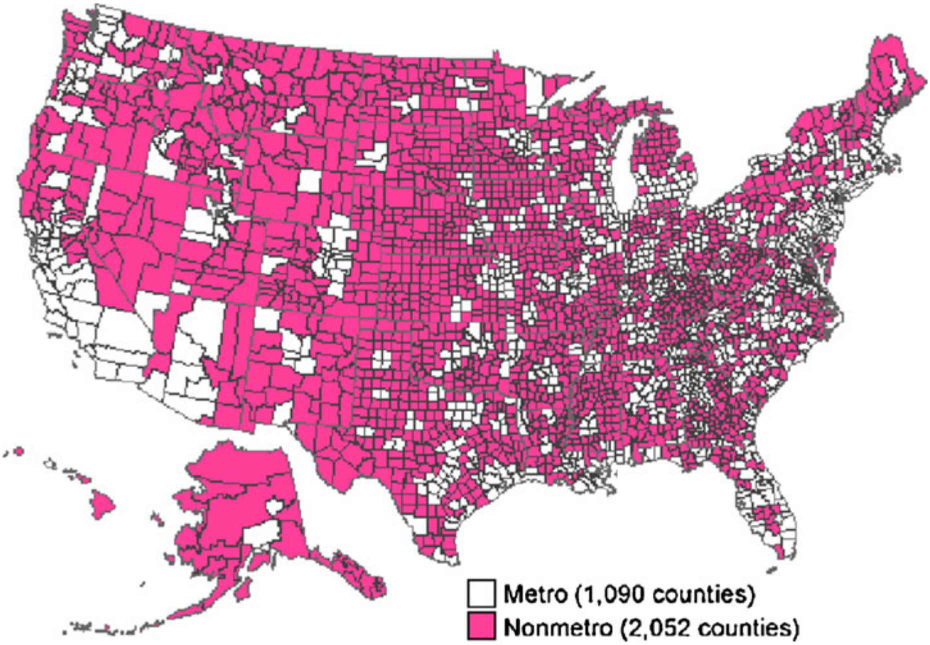

Fig. 1 Location of Non-metro and metro counties in the United States in 2003. Source: United States Department of Agriculture Economic research Service (2010b). Office of Management and Budget (OMB) identifies counties as non-metro if they are not core counties (core counties contain one or more urban areas of 50,000 people or more) or economically tied to the core counties, as measured by the share of the employed population that commutes to and from core counties

or 15% or more of employed residents who work in farm occupations. See USDA ERS 2010c, 2010d for details) as compared to just 3.4% of metro counties, rural communities are expected to disproportionately experience the adverse climatic impacts on agriculture (USDA ERS 2010c) (Fig. 2). However, the specific impacts will vary geographically. For example, the Midwest and Great Plains regions where farming is the predominant land use should experience larger agricultural impacts compared to other regions such as the Southeast, Northeast or Lake States.

Rural counties tend to be poorer than their urban counterparts. The per capita income in urban areas ($32,077) far exceeded per capita income in micropolitans, counties with cities of 10,000 to 49,999 residents and socio-economically tied to adjacent counties ($23,338), and non-core counties with neither a city over 10,000 residents or socio-economically tied to a city of that size, ($21,005) areas (ERS 2010e). The lower rural earnings levels reflect lower shares of highly skilled jobs and lower returns to college degrees in rural labor markets (USDA ERS 2010f). Unemployment is also often higher in rural areas. For example, 396 of the 460 counties classified as having low employment (those where less than 65% of residents 21–64 years old were employed in 2000. See USDA ERS (2010h) for details) were rural (Whitener and Parker 2007). The rural regions in the Southeast stand out as being plagued by high unemployment, suggesting lower coping capacities to the adverse impacts of climate change.

The urban rural income gap has been widening recently (USDA ERS 2010e). For example, between 1993 and 2004, rural areas averaged 0.5% annual growth in real earnings compared to 1.2% per year in urban areas (USDA ERS 2010h). The rural/urban income gap

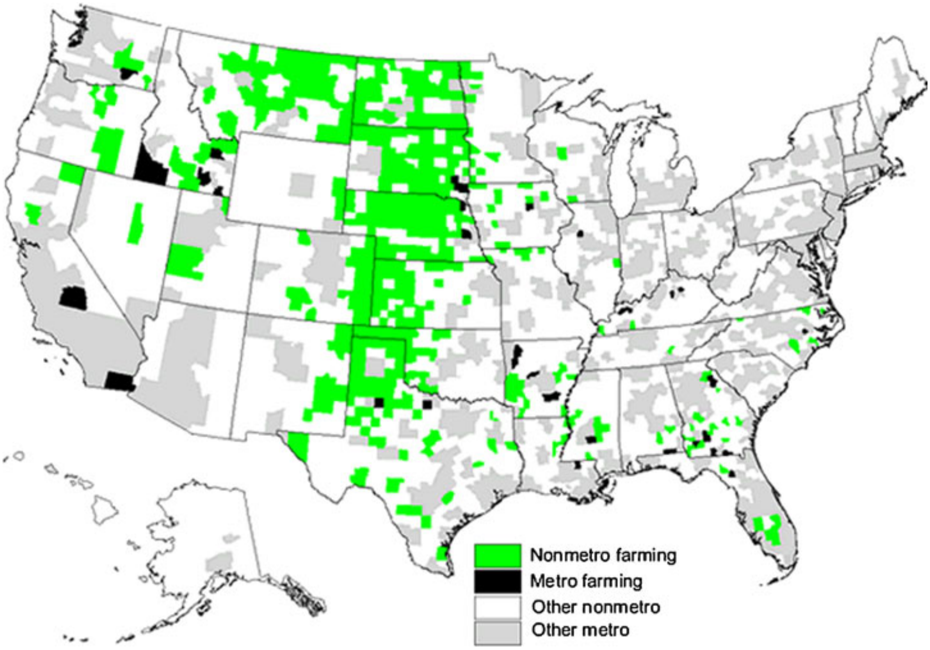

Fig. 2 Location of farming-dependent counties in the United States in 1998–2000. Source: United States Department of Agriculture Economic Research Service (2010d). Farming dependent counties have either 15% or more of average annual labor and proprietors' earnings derived from farming or 15% or more of employed residents who work in farm occupations

is associated with reasons such as lower educational attainment, less competition for workers among employers, and fewer highly skilled jobs in the rural occupational mix (Miller and Rowley 2002). As climate vulnerability is strongly influenced by income levels (Yohe and Tol 2002), the rural communities vulnerability to climate related risk is expected to be higher. For example, Turner et al. (2003) suggest that the poor and marginalized in the U.S. have historically been most at risk from weather shocks than their wealthier counterparts. Because rural communities tend to suffer from higher incidence of persistent poverty (Fig. 3), they might also be more vulnerable to climate change.

Rural communities in the South and West account for approximately 59% of the total rural population in the country and have highest poverty rates in the country (USDA ERS 2010i). Thus, we would expect these areas to have generally lower adaptive capacity to cope with future climate risks (Fig. 4).

Another factor that adds to the vulnerability of rural areas is their dependence on government transfer payments. Based on 2001 data, USDA ERS (2010k) calculated that government transfer payments averaged $4,365 per person per year in rural, non-metro areas compared to $3,798 for metro areas. Federal and state government transfers accounted for about one fifth of rural income as compared to just one eighth of metro income. Unless government transfer payments to rural areas are able to keep pace with vulnerability resulting from climate change impacts, rural communities in regions such as Southeast and Midwest might be more vulnerable than their urban counterparts.

Most outdoor recreation areas in the U.S. are in rural counties; for example, according to Whitener and Parker (2007) rural counties in 2003 comprised 334 of the 368 (91%)

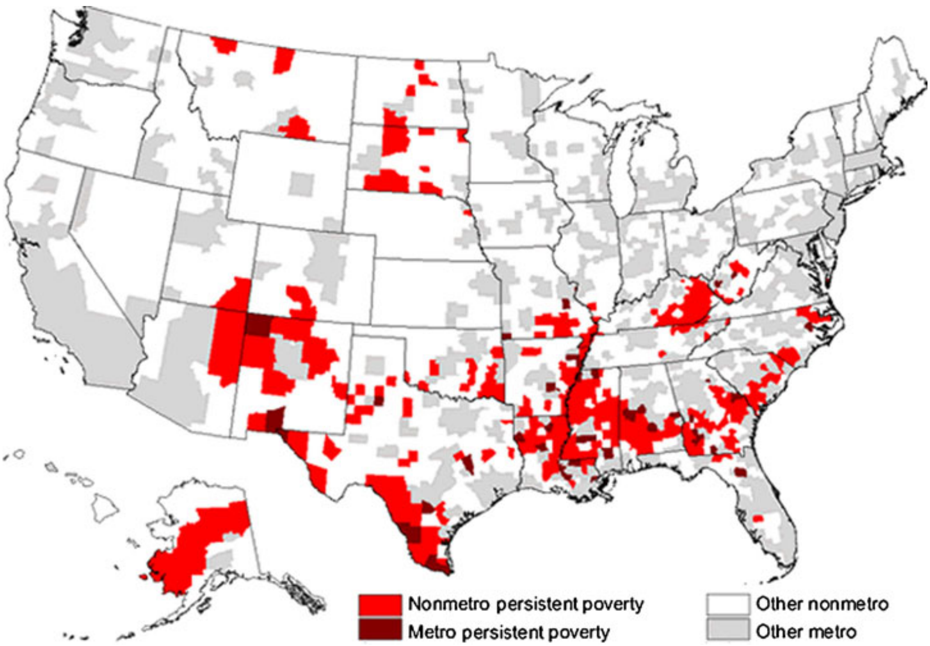

Fig. 3 Location of persistent poverty counties in the United States from 1970 to 2000. Source: United States Department of Agriculture Economic research Service (2010i). Persistent poverty counties are those in which 20% or more residents were poor as measured by last four censuses 1970–2000. See USDA ERS (2010h) for details

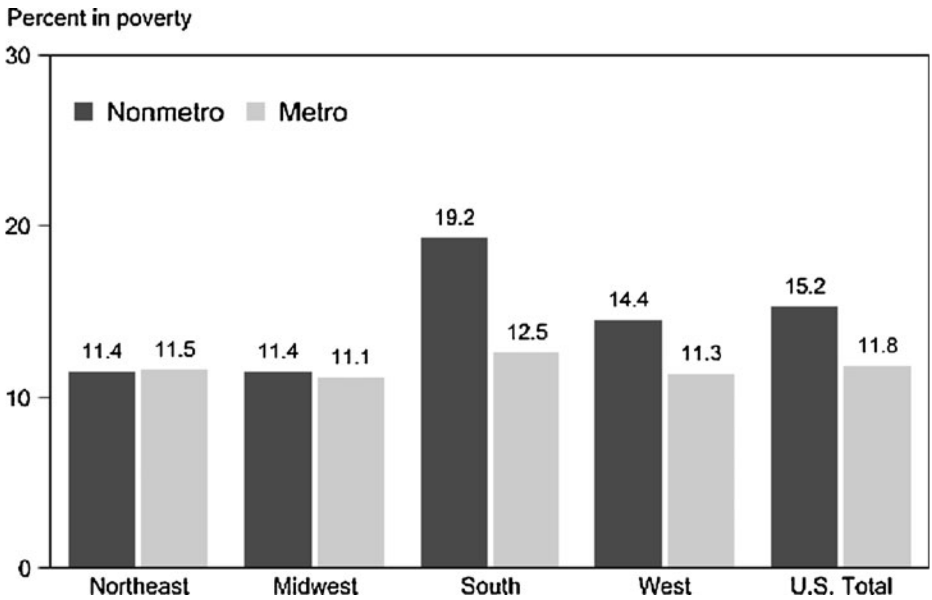

Fig. 4 Poverty rates by region and metro status in the United States in 2006. Source: United States Department of Agriculture Economic research Service (2010j)

recreation dominated counties (classified by USDA ERS using a combination of factors including share of employment or share of earnings in recreation-related industries in 1999, share of seasonal or occasional use housing units in 2000, and per capita receipts from motels and hotels in 1997. See USDA ERS 2010g for details) (Fig. 5). Many of the jobs that are usually associated with recreation, such as those in hotels and restaurants, often are low paying with few fringe benefits (Deller et al. 2001). However, in rural areas even these low paying jobs are often important for the livelihoods of communities. If climate change dramatically alters or shifts job opportunities in recreation, most of the impact will be felt by rural communities, where most of the recreation employees reside (Morello et al. 2009; Whitener and Parker 2007). There will be regional winner and losers in tourism as well as winter recreation such as skiing activities can be reduced, but summer recreation such as golf or hiking could increase (Grossling and Hall 2006; Loomis and Crespi 1999; Scott 2006a, b; Richardson and Loomis 2005).

Rural residents tend to have higher rates of age-adjusted mortality, disability, and chronic disease than their urban counterparts, though mortality and disability rates vary more by region than by metro status (Jones et al. 2009). Furthermore, as young adults move out of small, rural communities, many rural communities tend to reflect an increasingly vulnerable demographic of very old and very young people, placing them more at risk for climate change effects than urban communities. Emergency response systems are often less effective in rural areas due to the dispersed and geographically isolated populations. Rural residents also tend to face higher financial and travel costs to access health care and pay a greater share of household income for health care than their urban counterparts (Jones et al. 2009). Climatic impacts, coupled with demographic shifts

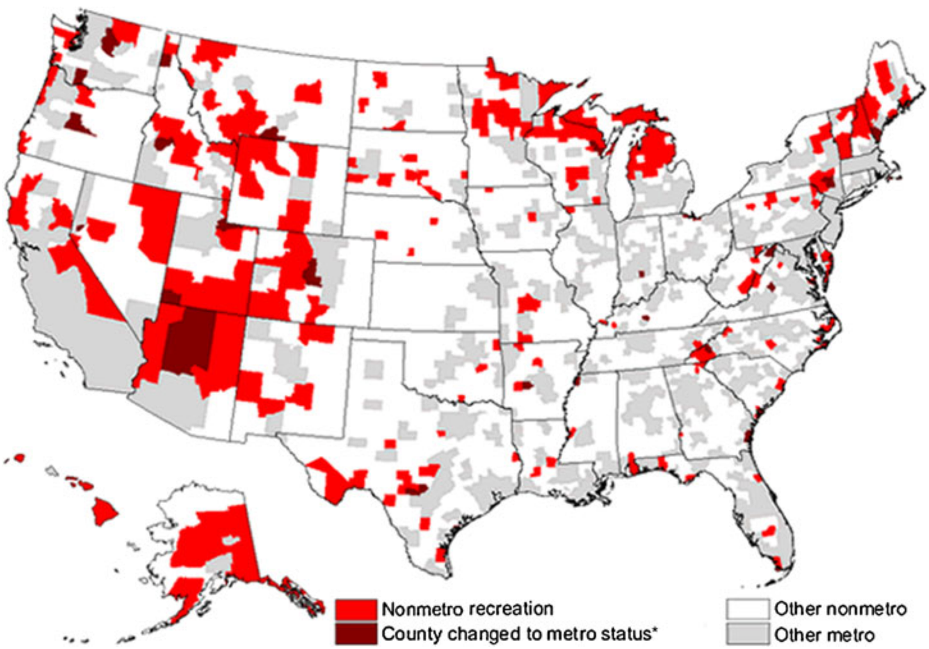

Fig. 5 Location of non-metro recreation counties in the United States in 1999. Source: United States Department of Agriculture Economic research Service (20101)

in rural communities, may make it more difficult to supply adequate and efficient public health services and educational opportunities to rural areas (Karl et al. 2009). Therefore, with lower access to health infrastructure and a higher proportion of income spent on health services, rural communities are likely to be more vulnerable to adverse health impacts caused by climate change.

A changing climate will mean reduced opportunities for some activities and locations and expanded opportunities for others, leading to regional differentiation of impacts on rural communities in term of incidence and intensity. Climate change events may also differentially impact the culture and livelihood patterns of indigenous communities in the U.S. These impacts are further discussed in the next section.

4 Impacts on rural communities

Climate change will likely produce a range of impacts depending on the specific attributes of the affected rural communities or industries. These impacts and tradeoffs due to climate change are discussed below.

4.1 Human health

Climate change impacts on human health could occur through both direct (e.g., thermal stress) and indirect (e.g., disease vectors and infectious agents) pathways. Direct impacts could result from increased exposure to temperature (heat waves, winter cold) and other extreme weather events (floods, cyclones, storm-surges, droughts) and increased production of air pollutants and aeroallergens such as spores and molds (Karl et al. 2009).

Rural counties which have smaller built up areas than cities should be less vulnerable to extreme heat events like the Chicago heat wave of 1995 which are expected to become more frequent as a result of climate change. This is due to the fact that concrete and asphalt in cities absorb and hold heat, while tall buildings prevent heat from dissipating and reduce air flow leading to a 'heat island effect'. The larger amounts of vegetation in rural areas also tend to provide more shade and evaporative cooling than in urban areas.

Human health may also be indirectly impacted by an increase in water, food, and vector-borne diseases. Kilpatrick et al. (2008) suggested that increasing temperatures significantly increases dissemination and transmission of viral infection, most likely through increased viral replication. Heavy downpours can lead to increased sediment in runoff and outbreaks of waterborne diseases (Ebi et al. 2008, 2009; Field et al. 2007). Degradation of water quality and increases in pollution carried to lakes, estuaries, and the coastal ocean following heavy downpours, especially when coupled with increased temperature, can also result in blooms of harmful algae and bacteria and increased risk of waterborne parasites such as *Cryptosporidium* and *Giardia*. Projected increases in carbon dioxide (CO_2) can also stimulate the growth of stinging nettle and leafy spurge, two weeds that cause rashes when they come into contact with human skin (Ziska 2003). The health of rural communities will likely be impacted by alterations in distribution and abundance of vector organisms and intermediate hosts, which in turn are affected by changes in physical factors such as temperature, precipitation, humidity, surface water, and wind and biotic factors such as vegetation, host species, predators, competitors and parasites. However, by scaling up localized studies such as Ebi et al. (2008) for making inferences at regional or national levels, we fail to fully comprehend the impact of climate change on vulnerability of rural communities.

4.2 Impacts on indigenous communities

Native American communities, which are predominantly rural, may face disproportionately higher levels of climate change impacts on their livelihoods, rights and access to natural resources, future growth, and cultures, which often depend on traditional ways of collecting and sharing food (Hanna 2007; Nilsson 2008; Tsosie 2007; Karl et al. 2009). Climate change may also reduce the availability and accessibility of traditional food sources for many indigenous communities. For example, many Native Alaskan culture are based on hunting seals whose migration patterns depend on their ability to cross frozen rivers and wetlands (Karl et al. 2009). It is estimated that climate change may increase flooding and erosion on 184 out of 213, or 86%, of Native Alaskan communities (United states General Accountability Office [USGAO] 2003). Native American communities in the Great Plains and Southwest are also vulnerable to climate change effects. Many of these tribes have limited capacity to respond to climate change and already face severe problems with water quantity and quality—problems likely to be exacerbated by climate change.

Relocation options tend to be limited for many Native Americans who live on established reservations and may be restricted to reservation boundaries (National Assesment Synthesis Team [NAST] 2001). Having already been relocated to reservations, these communities have historically been disconnected from their traditional life, prohibited from engaging in important social and cultural practices, and allowed limited participation in land management and planning (Tsosie 2007). Native American communities may be more vulnerable to climate change impacts, as their rights and livelihoods tend to be interwoven with specific lands limiting their relocation options in face of alterations in resource availability (Donoghue et al. 2009).

The melting of permafrost, in some places in Alaska, threatens the economies and cultures of many Alaskan tribes as they may be required to relocate at large economic and cultural cost (National Tribal Air Association [NTAA] 2009). For example, the way of life of the *Inupiaq* tribe in Alaska is threatened due to climate change. The traditional method of food storage of the tribe is being disrupted by warming as “permafrost” melts, leading their below ground storages (*sigulaqs* in native language) to be thawed and sometimes flooded with melt water. The resulting spoiled meat increases the risk of food related illness.

4.3 Economic impacts

Major parts of the rural economies of the U.S. are directly sensitive to climate change, including agriculture, recreation and tourism, forestry, water resources, energy, and fisheries. These are discussed below.

4.3.1 Agriculture

Agriculture will certainly face significant changes due to climate change. Although longer growing seasons and increased CO_2 have positive effects on some crop yields, this could be partially counterbalanced by the negative effects of additional disease-causing pathogens, insect pests, and weeds (Karl et al. 2009). A synthesis of studies for cropping systems undertaken by Howden et al. (2007) indicated potential benefits of adaptation in wheat-growing systems in face of moderate climate change can be substantial (averaging 18%), however, at higher temperatures these adaptations might be limited. Schlenker and Roberts (2009) suggest yields could increase with temperature up to 29°C for corn, 30°C for soybeans, and 32°C for cotton, but temperatures beyond these thresholds could be quite harmful. Hatfield et al. (2008) suggest that higher increases in temperature could decrease yields of corn, wheat, sorghum, bean, rice, cotton, and peanut crops. Some crops, however, benefit from higher temperatures and global warming will likely result in a longer growing season for crops like melon, okra, and sweet potato (Hatfield et al. 2008). Ortiz et al. (2008) suggest that wheat mega-environment could expand as far as 65°N in North America. Significant technological progress might also taper adverse climate change impacts. For example, corn yields have shown an upward trend even in light of variation caused by climate events (Fig. 6). However, Karl et al. (2009) argue that it is difficult to maintain this historical upward trend without continued technological innovations.

Climate change may increase agricultural production costs as well. For example, the expansion of weeds may be exacerbated by climate change as weeds benefit more from higher temperatures and CO_2 levels than traditional crops (Hatfield et al. 2008). With continued warming, invasive weed species are expected to expand northward and increase costs and crop losses. Weed control currently costs the U.S. more than $11 billion a year, with the majority spent on herbicides (Kiely et al. 2004). This cost is likely to increase as temperatures rise (Ryan et al. 2008). The problem is aggravated by the fact that the most widely used herbicide in the country, *glyphosate*, loses its efficacy at CO_2 levels that are projected to occur in the coming decades (Wolfe et al. 2007). Another potential impact of climate change is premature plant development and blooming, resulting in exposure of young plants and plant tissues to late-season frosts. For example, the 2007 spring freeze in the eastern U.S. led to widespread devastation of crops and natural vegetation (Gu et al. 2008). In the Midwest, the projected increases in winter and spring precipitation and flooding are likely to delay planting and crop establishment.

Climate change is projected to increase the intensity of precipitation, resulting in heavy downpours (Kunkel et al. 2008). This excessive rainfall may delay spring planting in the Northeast under high emission scenarios, in turn lowering profits for farmers that paid a premium for early season production of high-value crops such as melon, sweet corn, and tomatoes (Frumhoff et al. 2007). The projected warmer temperatures are expected to increase livestock production costs due to lower feed intake and increased requirements for energy to maintain healthy livestock at higher temperatures. Forage production may also be impacted by climate change. Although rising atmospheric CO_2 concentrations can increase the quantity of forage produced, it could also reduce forage quality as plant nitrogen and protein concentrations often decline with higher concentrations of CO_2 (Hatfield et al.

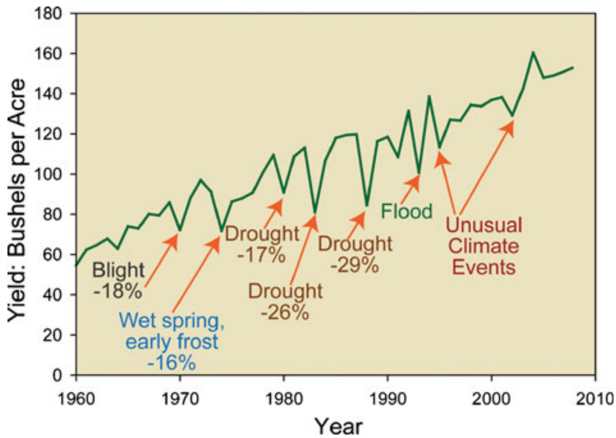

Fig. 6 The trend of corn yield since 1960 in the United States. Source: Karl et al. (2009) based on National Assessment Synthesis Team (2001)

2008). The dairy industry is also quite sensitive to temperature changes, since dairy cows' productivity decreases above 77°F. By late in this century, most northeastern states are projected to face declines in July milk and California could see an annual loss of $287–902 million from its $4.1 billion dairy industry (Karl et al. 2009).

The Northwest and Great Plains region's agriculture might experience detrimental impacts (Motha and Baier 2005; Karl et al. 2009). Also impacted will be specialty crops in California such as apricots, almonds, artichokes, figs, kiwis, olives, and walnuts (Lobbel et al. 2006). By late in this century, winter temperatures in important fruit-producing regions such as the Northeast may be too warm to support fruit production. For example, Massachusetts and New Jersey supply nearly half the nation's cranberry crop. By the middle of this century, these areas may not be able to support cranberry production due to lack of winter chilling (Frumhoff et al. 2007; Wolfe et al. 2007). In contrast, warming is expected to improve the climate for fruit production in regions such as the Great Lakes (Field et al. 2007) and Midwest (Karl et al. 2009). However, even farms and regions that benefit from altered environmental conditions (e.g., carbon fertilization and extended growing season) could risk economic losses if temperatures exceed those preferred by the crops they currently produce (Ruth et al. 2007). Switching to new crops in light of future climate change might also help in hedging climate risk, for example European wine grapes varieties are expected to benefit from warmer winters (Frumhoff et al. 2007).

Deschenes and Greenstone (2007) measured the economic impact of climate change on US agricultural land by analysing the effect of random year-to-year variation in temperature and precipitation on agricultural profits. They estimate that overall impact of climate change will be increase in annual profits in U.S. by $1.3 billion in 2002 dollars or 4%. Although the overall effect is small, there is considerable heterogeneity across the country. Some states with significant farming dependent counties like Nebraska, Iowa, and Montana could lose agricultural profits, while others like Kansas, North and South Dakota could see an increase in their agricultural profits.

4.3.2 Recreation and tourism

Johnson and Beale (2002) identified 329 recreation dependent counties by geographic location, natural amenities, and form of recreation. Recreation counties tend to be rural (Jones et al. 2009). Most of the rural recreation counties are concentrated in the West, the Upper Great Lakes, and the Northeast regions (Reeder and Brown 2005). Increased temperatures and precipitation due to climate change are expected to have a direct effect on the enjoyment of tourism activities, and on the desired number of visitor days and associated levels of visitor spending and employment. Climate change could impact recreation through four pathways: winter activities such as downhill and cross-country skiing, snowshoeing, and snowmobiling; tourism related to activities such as biking, walking, hunting, golf, national park visitation etc.; and water-related sports such as diving, sailing, and fishing.

The impact of climate change on winter sports, ski and snowmobiling industries is expected to be more pronounced in the Northeast and Southwest regions. The ski resorts in the Northeast have three climate-related criteria to remain viable: the average length of the ski season must be at least 100 days; there must be a good probability of being open during the winter holiday between Christmas and the New Year; and there must be enough nights that are sufficiently cold to enable snowmaking operations (Frumhoff et al. 2007; Karl et al. 2009). By these standards, only one area in the region is projected to be able to support viable ski resorts by the end of this century under a higher emissions scenario (Karl et al.

2009). Reduced snowmaking in the Southwest due to climate change is also expected to shorten the ski season substantially, with projected losses of 3 to 6 weeks (by the 2050s) and 7 to 15 weeks (2080s) in the Sierra Nevada of California (Hayhoe et al. 2004; Scott and Jones 2005). Decreases from 40 to almost 90% are likely in end-of-season snowpack under a higher emissions scenario in counties with major ski resorts from New Mexico to California (Zimmerman et al. 2006). In addition to shorter seasons, earlier wet snow avalanches could force ski areas to shut down many runs before the season would otherwise end (Lazar and Williams 2008). The snowmobiling industry is also vulnerable to climate change as it relies on natural snowfall. Some predict that by the 2050s, a reliable snowmobile season will disappear from most regions of the East (Scott et al. 2008; Scott and Jones 2006; Scott and Jones 2005).

The length of the nature tourism season is likely to be enhanced by small near-term increases in temperature. Visits to national parks are projected to increase by 9% to 25% (2050s) and 10% to 40% (2080s) as a result of a lengthened warm-weather tourism season (Scott and Jones 2006). Nearby communities may benefit economically, but visitor-related ecological pressures could be exacerbated in some parks. Activities like hunting and wildlife-related tourism will change as habitats shift and relationships among species in natural communities are disrupted by their different responses to rapid climate change (Karl et al. 2009). Climate-induced environmental changes (e.g., loss of glaciers, altered biodiversity, fire- or insect-impacted forests) may also affect nature tourism, although uncertainty is high regarding the regional specifics and magnitude of these impacts (Richardson and Loomis 2004; Scott and Jones 2006; Scott et al. 2007). Richardson and Loomis (2004) through contingent behavior analysis found that Rocky Mountain National park visitation would increase by about 13.6% under the climate scenario depicted by the Canadian Climate Center GCM and by about 9.9% under the scenario depicted by the Hadley model. Earlier study by Loomis and Crespi (1999) estimated that tourist visitation could increase from warming for activities such as golf (13.6%), for reservoir (9.2%), and for beach recreation activities (14.1%).

The impacts on water related tourism are likely to be exacerbated by rising sea levels and storm severity especially in beach communities and areas projected to get drier, such as the Southwest (Clark et al. 2008; Kleinosky et al. 2005; Williams et al. 2009; Wu et al. 2002). Water sports that depend on the flows of rivers and sufficient water in lakes and reservoirs are already being affected, and much larger changes are expected in the future (Sussman et al. 2008). Higher sea-levels may erode beaches, and along with increasing water temperatures, destroy or degrade natural resources such as mangroves and coral reef ecosystems that attract tourists (Mimura et al. 2007). However, the vulnerability of key recreation areas in the coastal U.S. to climate change events has not been comprehensively assessed (Karl et al. 2009).

Recreational fisheries in many rural counties will also be impacted by climate change. For example, approximately half of the wild trout populations are expected to disappear from the Southern Appalachian Mountains due to rising stream temperatures. Losses of western trout populations may exceed 60% in certain regions. About 90% of bull trout, which live in western rivers, are projected to be lost due to warming. The state of Pennsylvania is predicted to lose 50% of its trout habitat in the coming decades while warmer states such as North Carolina and Virginia, may lose up to 90% (Willliams et al. 2007).

In the longer term, as climate change impacts ecosystems and seasonality becomes more pronounced, the net economic effect on recreation and how it will influence different population groups in different regions is not known with certainty (Wilbanks et al. 2007), and needs further research.

4.3.3 Forestry

The impacts of climate change on forestry are expected to arise from: shifts in forest distribution and types; increased wildfire risk; increased chance of pest attacks and diseases; and adverse impacts on biodiversity. Projected changes in climate and the consequent impact on forests could impact market incentives for investing in intensive forest management (such as planting, thinning, genetic conservation, and tree improvement) and developing and investing in wood-conserving technologies. The effect on rural communities will vary depending on the geography, demographics, and social and economic conditions each community faces; as with agriculture, some may benefit while others lose.

Potential habitats for trees favored by cool environments are likely to shift north (NAST 2001) (Fig. 7). As tree species migrate northward or to higher elevations, habitats of alpine and sub-alpine spruce-fir could possibly be eliminated (IPCC 2007). Aspen and eastern birch communities are also likely to contract dramatically in the U.S. and largely shift into Canada. Potential habitats that could possibly expand in the U.S. are oak/hickory and oak/pine in the East and Ponderosa pine and arid woodland communities in the West. The changing forest distribution is already being observed in many areas. For example, in Colorado, aspen (*Populus tremula*) has advanced into the more cold-tolerant spruce-fir forests over the past 100 years (Elliott and Baker 2004). The northern limit of the lodgepole pine (*Pinus contorta)* range is advancing into the zone previously dominated by the more cold-tolerant black spruce (*Picea mariana*) in the Yukon region (Johnstone and Chapin 2003). In addition, many of the economically valuable timber species in the Midwest-aspen *(Populus tremula)*, jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), and white pine (*Pinus strobus*)—may be lost due to global warming (Easterling and Karl 2001). If the forests in the South and Northeast shift to oak and hickory species in lieu of softwoods, the

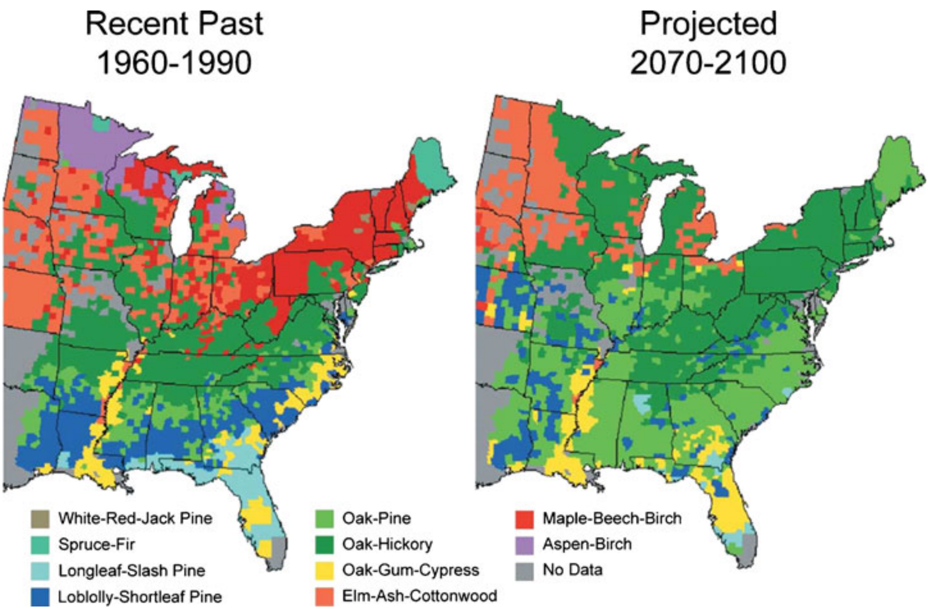

Fig. 7 Projected shift in forest types in eastern United States under a mid-range warming scenario. Source: Karl et al. (2009) based on National Assessment Synthesis Team (2001)

pulp/wood fiber industry could experience large losses (Karl et al. 2009), in turn impacting the rural communities who depend on these industries for their livelihoods.

Warmer summer temperatures and reduced rainfall in the West are projected to extend the annual window of wildfire risk by 10% to 30% (Brown et al. 2004). Westerling et al. (2006) analyzed wildfire trends in the western U.S. and found a six-fold increase in the area of forest burned since 1986 compared with the 1970–86 period. The average duration of fires increased from 7.5 to 37.1 days—mostly because of an increase in spring and summer temperatures and earlier thawing of snow packs. The increased incidences of wildfires could impact communities in a number of ways including loss of forest recreation opportunities and increased costs for fire suppression and recovery. For example, Ruth et al. (2007) predict that the climate change-induced warming will mean that the state of Washington will face fire suppression cost increases of over 50% by 2020 and over 100% by 2040. Since many rural communities reside adjacent to forest or are dependent on forest industries for their livelihood, they tend to be directly impacted by these wildfires.

Climate change is also likely to result in more disturbances from insects, invasive species, and diseases (Alig et al. 2004; Gan 2004; Logan et al. 2003). For example, Ryan et al. (2008) predict an increase in the frequency and intensity of mountain pine beetle (*Dendroctonus ponderosae)* and other insect attacks, further increasing fire risk and reducing timber production. In a changing climate, populations of some pests such as red fire ants, better adapted to a warmer climate, are projected to increase (Cameron and Scheel 2001; Levia and Frost 2004). Invasive weed species that disperse rapidly are likely to find increased opportunities under climate change. Pests can also impact Native American communities by reducing the availability of non-timber forest products (NTAA 2009).

Damages to forest resources from pests can be significant. For example, spruce bark beetle (*Dendroctonus rufipennis*) outbreaks in the Kenai Peninsula of Alaska (Berman et al. 1999) have led to the loss of over five million acres of Spruce forests. The recent spread of Southern pine beetle (*Dendroctonus frontalis*), attributable in part by scientists to climate change, has affected sawtimber and pulpwood production in Alabama, Louisiana, Mississippi, Tennessee, Kentucky, and the Carolinas. On average, annual losses have reached over 1% of gross state product (Ruth et al. 2007).

Changes in temperature and precipitation affect the composition and diversity of native animals and plants through altering their breeding patterns, water and food supply, and habitat availability (Feng and Hu 2007). Therefore, we expect increased extinction of local populations and loss of biological diversity if climate change outpaces species' ability to shift their ranges and form successful new ecosystems. Residents of Alaska are likely to experience the most disruptive impacts of climate change in the near term, including shifts in the range or abundance of wild species crucial to the livelihoods (Houser et al. 2001; Parson et al. 2001). Grassland and plains birds, already besieged by habitat fragmentation, could experience significant shifts and reductions in their ranges (Peterson 2003). Biodiversity impacts of climate change may also alter distribution of prominent game and other bird species (e.g., waterfowl, warblers, perching bird species) in many recreational rural counties. The conversion of forestland, habitat fragmentation, and reduced hunting and bird-watching could have adverse impacts on forest sensitive rural communities in terms of lower employment and income.

Higher levels of atmospheric CO_2 allow trees to capture more carbon from the atmosphere, resulting in higher growth rates in some regions, especially in relatively young forests on fertile soils (Ryan et al. 2008). This increased growth could be tempered, however, by local conditions such as moisture stress, nutrient availability or increased tropospheric ozone (Karnosky et al. 2005; Triggs et al. 2004). In the absence of dramatic increases in disturbance, effects of climate change could result in larger timber inventories (Perez-Garcia et al. 2002). Climate change scenarios predicting increased harvests, however, tend to lead to lower prices and, as a consequence, reduced harvests in higher production cost regions (Perez-Garcia et al. 2002; Sohngen and Sedjo 2005). Warmer winters with more sporadic freezing and thawing are likely to increase erosion and landslides on forest roads, and reduce access for winter harvesting (Karl et al. 2009), in turn increasing cost and reducing supply of forest products. Under these conditions, a contracting forest industry would lead to loss of employment for many rural communities. Furthermore, the economic analysis of forestry did not account for disturbances. We are seeing them have a significant effect on forests, particularly in the Western U.S. (van Mantgem et al. 2009).

The effect of climate change on forest dependent communities will vary regionally. Altered harvesting frequency and associated impacts on forest products prices is expected to be higher in the timber-producing regions of the Southeast and old growth forests of the West. Wildfire risk is expected to be most severe in the Southwest and Northwest, largely due to higher summer temperatures and earlier spring snowmelt, while increased incidences of pest attacks and trees diseases could be felt by rural communities across the U.S.

4.3.4 Water resources

For the past century, total precipitation has increased by about 7%, while the heaviest 1% of rain events increased by approximately 20% (Gutowski et al. 2008). In general, IPCC climate models agree that northern areas are likely to get wetter and southern areas drier (Karl et al. 2009). Impacts of climate change on water resources could result in increasing incidences of droughts, changing precipitation intensity and runoff, lower availability of water for irrigation, changing water demands, and lower water availability for energy production in some regions particularly the Southwest. Limitations imposed on water supply by projected temperature increases in the region are likely to be made worse by substantial reductions in rain and snowfall in the spring months (Milly et al. 2008). The number of dry days between precipitation events is also projected to increase in the Southwest and the Mountain West. Continued population growth in these arid and semi-arid regions could also stress water supplies, though the impact will be more severe for urban centers than rural counties. Floods are also projected to be more frequent and intense as regional and seasonal precipitation patterns change and rainfall becomes more concentrated in heavy events.

Climate change is also projected to cause changes in runoff, the amount of precipitation that is not evaporated, stored as snowpack or soil moisture, or filtered down to groundwater. Milly et al. (2008) suggest the eastern part of the country will experience increased runoff, accompanied by declines in the West, especially the Southwest. This means that wet areas are projected to get wetter and dry areas drier, thus adding to the vulnerability of agricultural and forest dependent communities whose livelihoods (or incomes) in many cases are sensitive to water availability.

Rural communities in the Southwest and engaged in activities like farming are expected to experience additional water stress due to climate change. Current water use in the Great Plains is unsustainable, as the High Plains aquifer continues to be tapped faster than the rate of recharge (Green et al. 2007; Lettenmaier et al. 2008; Backlund et al. 2008; Karl et al. 2009). Similarly, groundwater pumping is lowering water tables, while rising temperatures reduce river flows in vital rivers (Barnett et al. 2008, 2003). The farming dominated counties in Great Plains and Midwest, however, are not expected to experience as large an impact as their Northeastern, Western or Southwestern counterparts (Karl et al. 2009).

4.3.5 Energy

With increasing pressure on existing energy sources, rural communities' access to traditional energy sources could be threatened by climate change. Increased demand for energy as well as lower or uncertain supplies in many areas could accentuate such threats. Scott and Huang (2007) project that temperature increases are likely to increase peak demand for electricity in most regions of the country. The increase in demand will be higher in the South, a region with especially high per-capita electricity use (Scott and Huang 2007). Since the southern region accounts for most of the persistently poor rural counties in the U.S., rural communities in the region might be more vulnerable in light of higher costs associated with increased demand of electricity. As rural areas in north become warmer, they would savings on winter heating, although they will have increased summer cooling costs (Karl et al. 2009). Renewable sources of energy, such as biomass based energy, are being promoted to increase energy supply, create jobs, reduce reliance on fossil fuels, and improve access to rural communities (Dwivedi et al. 2009). The biomass based energy markets could benefit rural landowners in terms of higher product prices as well as increased avenues for employment.

4.3.6 Fisheries

America's coastlines and fisheries are especially at risk from climate change. Fisheries provide livelihood to rural communities and indigenous peoples in many parts of the country. The habitats of some mountain species and coldwater fish, such as salmon and trout, are very likely to contract in response to warming, while some warm-water fishes such as smallmouth bass and bluegill might expand their ranges (Janetos et al. 2008). Apart from changes in species composition and availability of native fish species, aquatic ecosystem disruptions are likely to be compounded by non-native invasive species which tend to thrive under a wide range of environmental conditions.

In Alaska, climate change is already causing significant alterations in marine ecosystems, restricting fisheries and adding to the hardships of the rural people who depend on them (Karl et al. 2009). Historically, warm periods in coastal waters have coincided with relatively low abundances of salmon, while cooler ocean temperatures have coincided with relatively high salmon numbers (Crozier et al. 2008). It has been estimated that as much as 40% of Northwest salmon populations may be lost by 2050 due to climate change (Battin et al. 2007).

Alaska leads the country in term of its commercial and subsistence fishing catch. The state's rural residents harvest an average of 225 lbs of fish per person (United States Fish and Wildlife Service [USFWS] 2010). The warmer water is already leading to lower salmon harvests, creating hardships on the rural people who are dependent on these fishes for subsistence or employment (NTAA 2009).

In the Northeast, lobster fisheries are projected to continue a northward shift and cod fisheries are likely to diminish with increasing ocean temperatures associated with climate change (Karl et al. 2009). Climate change is also expected to reduce coral reefs and associated fish species (Graham et al. 2006). Changes in the species composition of coral reef ecosystems will likely impact both subsistence and commercial fishing in Hawaii, Puerto Rico, U.S. Virgin Islands, Guam and American Samoa (Janetos et al. 2008). Change in fish availability due to climate change may hit Guam and American Samoa particularly hard as communities within the Pacific Islands derive between 25% and 69% of their animal protein from fish (Hotta 2000).

5 Policy considerations and further research

5.1 Sectoral linkages and information coupling

The interdependencies amongst different sectors, regions and population groups in the U.S., and the potentially significant direct and indirect effects of the cost of climate impacts, require that climate analyses adequately account for these inter-linkages. For example, understanding the economic effects of climate change on timber production is constrained by limited scientific understanding of several key factors that control the response of natural and managed forests to climate change. Timber production will depend not only on climatic factors but also on stresses from pollution (e.g., acid rain); future trends in forest management practices, economic demand for forest products; and land-use change. Clarification of the uncertainties concerning how all of these interconnected factors will interact in the face of climate change will permit more informed policy and programmatic responses to reducing the vulnerability of rural communities to the impacts of climate change.

5.2 Regional and local climate analysis

While much data related to climate impacts is freely and readily available to a broad range of users, other socio-cultural and economic data particularly related to rural communities' damage costs, adaptive capacity are scarce. Efforts should be made to solicit such information and make it publicly available. Developing effective data collection systems and analyses of these issues requires agreed-upon baseline indicators and measures of environmental, demographic and economic conditions that can be used to track the effects of changes in climate on rural communities (Karl et al. 2009). A set of region- and sector-specific studies that help guide climate policy and investment, would help to improve our understanding of climate change impacts and the distribution of costs and benefits of the impacts across rural and urban communities in the U.S., and to develop appropriate policies to mitigate the impacts.

5.3 Research-policy linkage

A rural community might be more or less prepared to face challenges from climate change, depending on the degree of adaptive capacity. However, a gap exists between available information about climate change and the development of new public policy guidelines such as housing, transportation, water systems, commercial buildings, energy systems, and health systems. This type of information should be systematically gathered and shared with local, regional or national decision makers to develop suitable adaptation options. Assessment of rural communities' adaptive capacity, costs and effectiveness of adaptation options, implementation impediments, and expected consequences is warranted. Systematic comparison of the reasons as to why a particular adaptation or mitigation strategy was chosen by some rural communities, but not by others and why some of these strategies were successful while others failed, is important. On the basis of detailed comparative studies, general guiding principles and policies may be derived.

5.4 Ecosystem services

A better understanding of the linkage between urban population centers and rural communities through ecosystem services is needed to develop policies to mitigate potential climate change impacts. Monetizing environmental stewardship contributions made by rural communities could result in increased investment in rural areas. Research on how to operationalize ecosystem service markets and regional-level planning strategies may provide avenues for improving understanding and addressing policy needs. Research into how these ecosystem services will change in response to climate change is also needed.

5.5 Alternative energy sources

Adverse climate change effects can be mitigated through increased use of renewable energy sources, such as solar, wind, hydro, and biomass based energy, could potentially mitigate climate change impacts while lessening the vulnerability of rural communities. However, the production of bioenergy from agricultural crops should not be emphasized as these could adversely impact food security. Bioenergy production using crop residues, excess agricultural and wood products, algae, short rotation woody crops, and other second generation cellulosic fuels could be emphasized as there will be little resultant loss of food production (Hill et al. 2006; Smith et al. 2007; Susaeta et al. 2009). Research investments in these sources might foster developing businesses related to improving cellulosic fuel feedstocks, improved energy production systems, or emerging carbon-trading markets (Alavalapati et al. 2011). Cellulosic based energy sources may have benefit rural areas in term of rural job creation, and improving rural economy and quality of life (Alavalapati and Lal 2009; Lal et al. 2011)

5.6 Increased stakeholder involvement

Quantitative climate forecast models provide only one kind of input into the policy process. Another important contribution needs to come from various stakeholder communities (including rural communities) expected to be impacted by climate change and which need to develop and prioritize among alternative mitigation and adaptation actions. Concerted efforts are needed to expand stakeholder capacity to provide policy makers and the public with relevant information on climate change and its impacts. A regional case study approach at different spatial scales (national, regional and local) could render stakeholder involvement a more doable and more productive component in the assessment process as well as increase confidence amongst affected communities. Integrating the adaptation insights of indigenous peoples in terms of access, process, and the outcomes of climate policy and planning should be helpful in reducing climate change impacts (Nilsson 2008). Such an approach to policy design might facilitate smoother implementation of sustainable climate mitigation and adaptation strategies.

6 Conclusions

Climate change will affect rural communities through changes in availability or access to climate-sensitive resources that occur at local, regional or national levels. The vitality of local communities (Hutton 2001; Jensen, 2009; Wall et al. 2005), changes in economic conditions (Ikeme 2003), status of emergency facilities and preparedness and planning (Murphy et al.

2005), condition of the public health system (Kinney et al. 2001), all have the potential to either exacerbate or ameliorate the vulnerability of rural communities to climate change.

A significant difference in infrastructure needs between rural and urban areas suggests that research focusing on assessing rural communities' adaptive capacity, costs and effectiveness of adaptation options, implementation impediments, and expected consequences is warranted. Vulnerability to climate change tends to be greater for rural communities who typically have fewer resources and fewer alternatives than urban areas. The impact of climate change on rural communities depends on complex interactions among different sectors, regions and population groups and the environment. However, there is a dearth of information and literature on how the myriad, socio-economic and demographic factors will react to the bio-physical changes accompanying climate change and virtually none on how the interconnected socio-economic/ecological systems will respond. Most of the current literature is based on such coarse temporal and spatial resolution as to offer only very general guidance for investment and policy-making.

The potential impacts of climate change on rural communities include increased risks to human health, changes to the agricultural and forestry sectors, stress on water resources and fisheries, impacts on recreation and tourism, adverse effects on indigenous communities, and additional impacts related to an increase in adverse weather events. The climate risk mitigation and adaptive capacity of rural communities remains an important area for public-policy interventions and future research. However, public discussion about adaptation is at an early stage in the U.S. (Moser 2005).

A suite of adaptation and mitigation policy options needs to be developed to reduce the vulnerability of rural communities under a variety of climate change scenarios. An active dialogue among stakeholders and political institutions could help clarify the opportunities for adapting and coping with climate change. A set of regional studies is needed to improve our understanding of climate change impacts and the distribution of costs and benefits of the impacts across rural and urban communities in the U.S., and to develop appropriate policies to mitigate the impacts. Integrating research across disciplines and information coupling, strengthening research-policy linkages, integrating ecosystem services in valuation, and expanding alternative energy sources could also enhance coping and adaptive capabilities of rural communities.

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