Ecosystems

SUBSECTORS

Coral Reefs

Shellfish

An ecosystem is a community of organisms interacting with each other and their environment. People, animals, plants, microbes, water, and soil are typical components of ecosystems. We constantly interact with the ecosystems around us to derive and maintain services that sustain us and contribute to our livelihoods. Clean air and water, habitat for species, and beautiful places for recreation are all examples of these goods and services. With the diversity of ecosystem types in the U.S. being so great—from the tidal marshes of the East Coast to the desert valleys of the Southwest to the temperate rainforests of the Pacific Northwest—climate change is likely to fundamentally alter our nation's landscape and natural resources.[1]

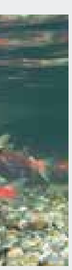
HOW ARE ECOSYSTEMS VULNERABLE TO CLIMATE CHANGE?

Ecosystems are held together by the interactions and connections among their components. Climate is a central connection in all ecosystems. Consequently, changes in climate will have far-reaching effects throughout Earth's ecosystems. Climate change can affect ecosystems and species in a variety of ways; for example, it can lead to changes in the timing of seasonal life-cycle events, such as migrations; habitat shifts; food chain disruptions; increases in pathogens, parasites, and diseases; and elevated risk of extinction for many species.[2]

Climate change directly affects ecosystems and species, but it also interacts with other human stressors on the environment. Although some stressors cause only modest impacts by themselves, the cumulative impact of climate and other changes can lead to dramatic ecological impacts. For example, coastal wetlands already in decline due to increasing development will face increased pressure from rising sea levels.

WHAT DOES CIRA COVER?

CIRA analyzes the potential benefits of global GHG mitigation on coral reefs and freshwater fisheries in the U.S., focusing on changes in recreational use of coral reefs and recreational fishing. This section also examines the projected impacts of ocean acidification on the U.S. shellfish market. Lastly, CIRA quantifies the physical and economic impacts of climate change on wildfires and terrestrial ecosystem carbon storage. Climate change will affect many species and ecosystems beyond what is explored in this report; consequently, CIRA captures only a glimpse of the potential benefits of GHG mitigation on this sector.



Freshwater Fish

Wildfire

Carbon Storage

Coral Reefs

KEY FINDINGS

1. Coral reefs are already disappearing due to climate change and other non-climate stressors. Temperature increases and ocean acidification are projected to further reduce coral cover in the future.

2. Without global GHG mitigation, extensive loss of shallow corals is projected by 2050 for major U.S. reef locations. Global GHG mitigation delays Hawaiian coral reef loss compared to the Reference scenario, but provides only minor benefits to coral cover in South Florida and Puerto Rico, as these reefs are already close to critical thresholds of ecosystem loss.

3. GHG mitigation results in approximately $22 billion (discounted at 3%) in recreational benefits through 2100 for all three regions, compared to a future without emission reductions.

Climate Change and Coral Reefs

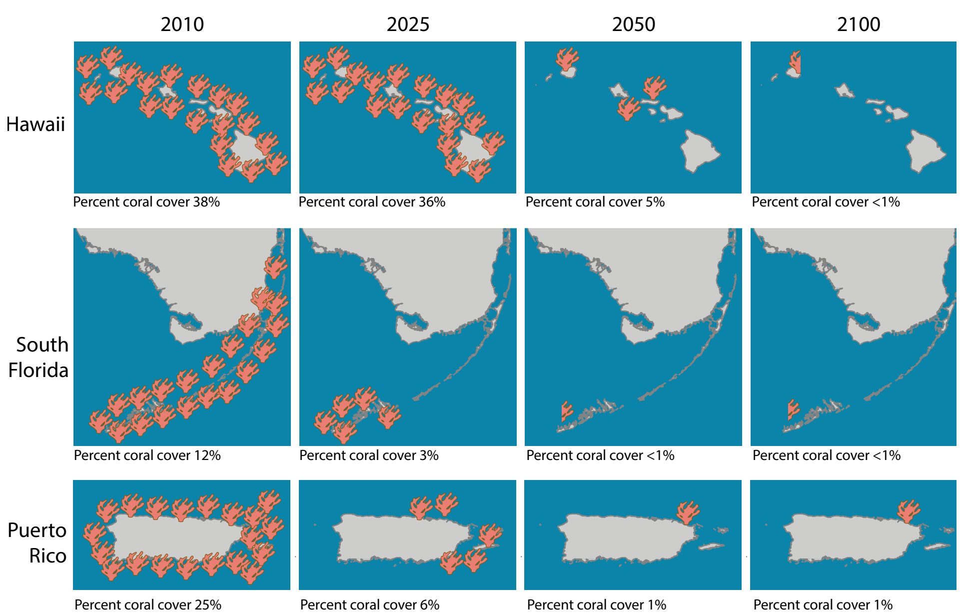
Coral reefs, including those found in Hawaii and the Caribbean, are unique ecosystems that are home to large numbers of marine plant and animal species. They also provide vital fish spawning habitat, protect shorelines, and are valuable for recreation and tourism. However, shallow-water coral reefs are highly vulnerable to climate change.[3] High water temperatures can cause coral to expel the symbiotic algae that provide nourishment and vibrant color for their hosts. This coral bleaching can cause the coral to die. In addition, ocean acidification (ocean chemistry changes due to elevated atmospheric CO_2) can reduce the availability of certain minerals in seawater that are needed to build and maintain coral skeletons.

Risks of Inaction

Without GHG mitigation, continued warming and ocean acidification will have very significant effects on coral reefs. For major U.S. reefs, projections under the Reference show extensive bleaching and dramatic loss of shallow coral cover occurring by 2050, and near complete loss by 2100. In Hawaii, coral cover is projected to decline from 38% (current coral cover) to approximately 5% by 2050, with further declines thereafter. In Florida and Puerto Rico, where present-day temperatures are already close to bleaching thresholds and where these reefs have historically been affected by non-climate stressors, coral is projected to disappear even faster.[4] This drastic decline in coral reef cover, indicating the exceedance of an ecosystem threshold, could have significant ecological and economic consequences at regional levels. These projections of shallow coral loss for major U.S. reefs are consistent with the findings of the assessment literature.[5]

Figure 1. Projected Impact of Unmitigated Climate Change on Coral Reef Cover in the U.S.

Approximate reduction in coral cover at each location under the Reference scenario relative to the initial percent cover. Coral icons do not represent exact reef locations. Results for 2075 are omitted as there is very little change projected between 2050 and 2100.

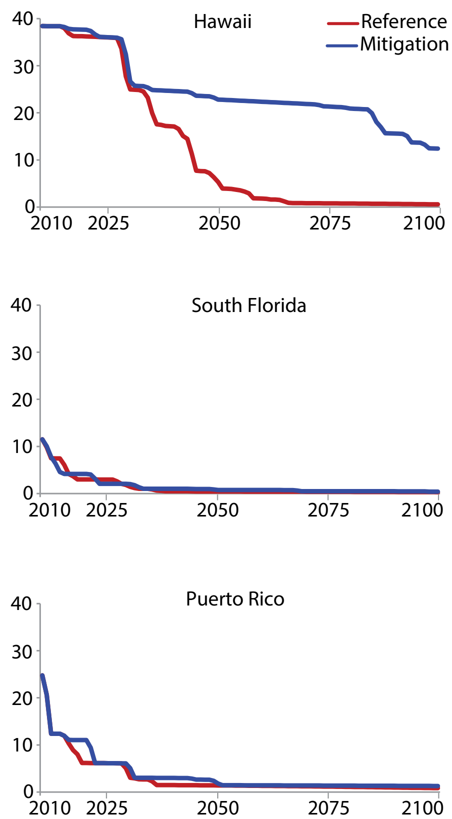


Reducing Impacts through GHG Mitigation

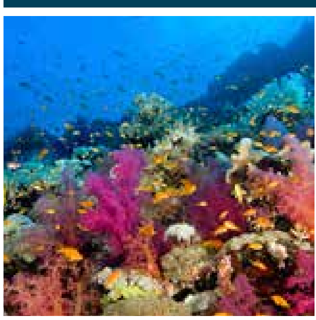
Mitigating global GHG emissions can reduce only some of the projected biological and economic impacts of climate change on coral reefs in the U.S. Figure 2 shows projected coral reef cover over time in Hawaii, South Florida, and Puerto Rico under the Reference and Mitigation scenarios. In Hawaii, the decline in reef cover slows under the Mitigation scenario compared to the Reference, as some of the extensive bleaching episodes and effects of ocean acidification are avoided. But even under the Mitigation scenario, Hawaii is projected to eventually experience substantial reductions in coral cover. In South Florida and Puerto Rico, the projected GHG emission reductions associated with the Mitigation scenario are likely insufficient to avoid multiple bleaching and mortality events by 2025, and coral cover declines thereafter nearly as fast as in the Reference.

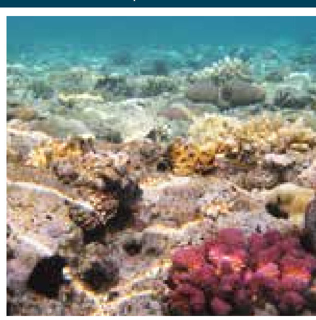
The delay in the projected decline of coral results in an estimated $22 billion in economic benefits for recreation across the three sites through 2100 (discounted at 3%). The majority of these recreational benefits are projected for Hawaii, with an average value through 2100 of approximately $20 billion (95% confidence interval of $10-$30 billion). In Florida, where coral reefs have already been heavily affected, recreational benefits are also positive, but notably lower at approximately $1.4 billion (95% confidence interval of $0.74-$2.1 billion). In Puerto Rico, benefits are estimated at $0.38 million (95% confidence interval of $0.20-$0.57 million), but only represent recreational benefits for permanent residents, and therefore are not directly comparable to the other locations where visits from nonresident tourists are also included. Including the economic value of other services provided by coral reefs, such as shoreline protection and fish-rearing habitat, would increase the benefits of mitigation.

Figure 2. Percent Change in Coral Reef Cover with and without Global GHG Mitigation at Major U.S. Reefs



CORAL COVERAGE | REPRESENTATIVE PHOTOS OF CORAL REEF DECLINE


HEALTHY REEF
40-75% live coral cover


SEVERELY DEGRADED REEF
10-25% live coral cover


NEARLY DEAD REEF
<10% live coral cover

APPROACH

The CIRA analysis examines the physical and economic impacts of climate change and ocean acidification on coral reefs in Hawaii, South Florida, and Puerto Rico. Using the COMBO (Coral Mortality and Bleaching Output) model,[6,7] the analysis first estimates declines in coral reef cover (a measure of coral reef health and density) using projections of future ocean temperature (from the IGSM-CAM) and chemistry under the CIRA Reference and Mitigation scenarios.[8] The effects of future bleaching events are also estimated.

Next, the analysis quantifies the economic impacts associated with coral reef cover loss based on declines in reef-based recreation. The analysis estimates these impacts using a benefit-transfer approach; that is, it draws on reef-related recreation benefits measured in previously published studies conducted at a range of coral reef sites to estimate the value of reef-related recreation benefits in the areas considered in this study.[9] Projected impacts to recreation at each site are provided with confidence intervals based on the 95% interval for per-trip recreational values.

For more information on the CIRA approach and results for the coral reef sector, please refer to Lane et al. (2013)[10] and Lane et al. (2014).[11]

Shellfish

KEY FINDINGS

1. Without global GHG mitigation, the harvests of some shellfish in the U.S. are projected to decline by 32%-48% by the end of the century due to ocean acidification, though estimated impacts vary by species.

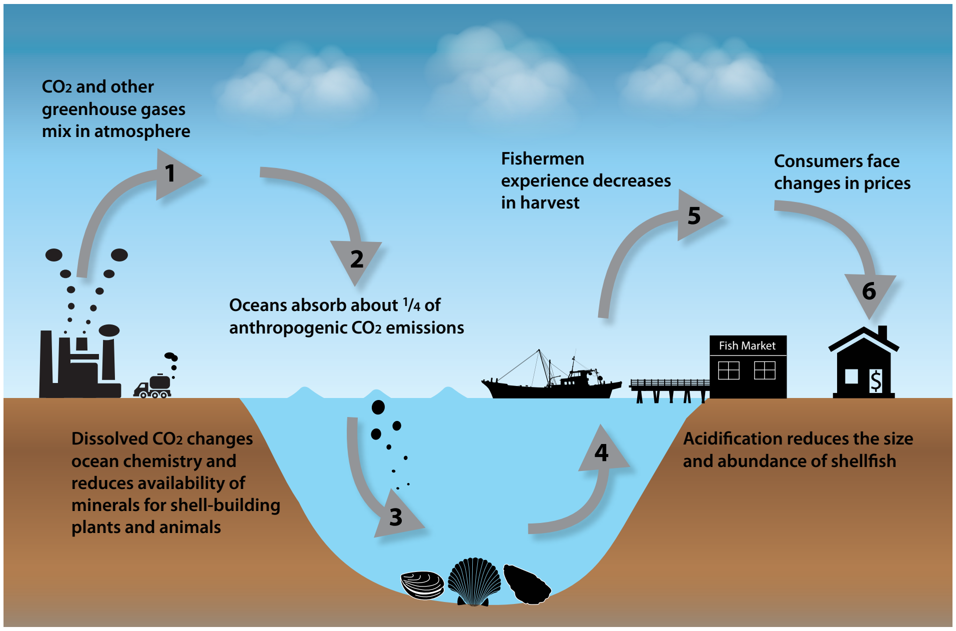
2. Demand for shellfish is projected to increase through the end of the century with a growing population and rising incomes, exacerbating the economic impacts in this sector.

3. Global GHG mitigation is projected to avoid $380 million in consumer losses in 2100 compared to the Reference scenario by preventing most of the decreases in the supply of select shellfish and the resulting price increases.

Ocean Acidification and Shellfish

The ocean absorbs about one quarter of the CO_2 released into the atmosphere by human activities, primarily from the combustion of fossil fuels. Although the ocean's ability to absorb CO_2 prevents atmospheric levels from climbing even higher, measurements made over the last few decades have demonstrated that marine CO_2 levels have risen, leading to an increase in acidity (Figure 1).[12] Ocean acidification is projected to adversely affect a number of valuable marine ecosystem services by making it more difficult for many organisms to form shells and skeletons.[13] Some shellfish are highly vulnerable to ocean acidification[14] and any impacts to these species are expected to negatively affect the economy. Certain species have high commercial value; for example, each year in the U.S., oysters, clams, and scallops supply 170 million pounds of seafood valued at $400 million.[15]

Figure 1. Ocean Acidification Impact Pathway for Shellfish



Risks of Inaction

The pace of ocean acidification is accelerating. Since the Industrial Revolution, the average pH of surface ocean waters has fallen by 0.1, representing a nearly 30% increase in acidity.[16] Under the Reference scenario, ocean acidification is projected to cause pH to drop an additional 0.3, representing a 100% increase in acidity from pre-industrial times. Continued ocean acidification is estimated to reduce the supply of oysters, scallops, and clams in 2100 by 45% (13 million pounds per year), 48% (21 million pounds), and 32% (31 million pounds), respectively (Figure 2). These decreases in supply are projected to result in price increases by 2100 of approximately $2.20 (a 68% increase from 2010), $9.10 (140%), and $1.30 (123%) per pound, respectively, and lead to consumer losses of roughly $480 million per year by the end of the century. These projections are consistent with the findings of the assessment literature, which describe reduced growth and survival of U.S. shellfish stocks due to unmitigated ocean acidification.[17]

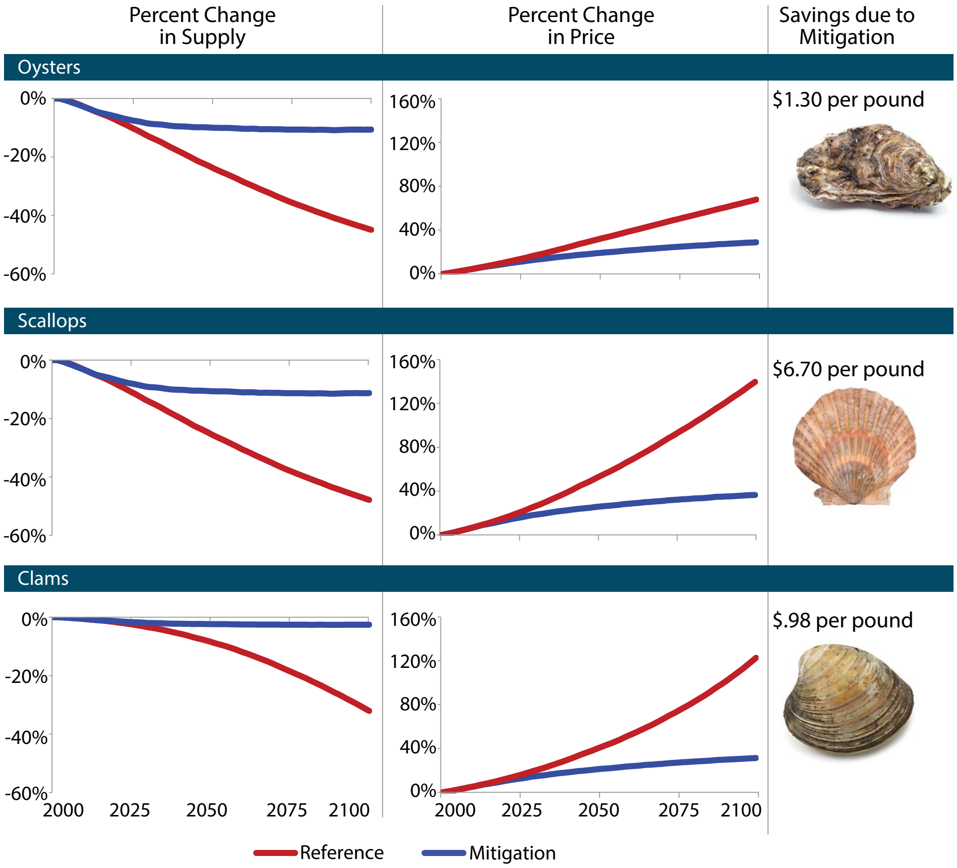
Reducing Impacts through GHG Mitigation

Reducing global GHG emissions can mitigate the ecological and economic impacts of ocean acidification. Figure 2 shows how the supplies of oysters, scallops, and clams are projected to fall with ocean acidification under the Reference and Mitigation scenarios. Although supplies are estimated to decrease under both scenarios relative to present-day supplies, the Mitigation scenario avoids a majority of the impacts, particularly for clams. In 2100, global GHG mitigation is projected to avoid the loss of 54 million pounds of oysters, scallops, and clams, or 34% of the present-day U.S. oyster supply, 37% of the scallop supply, and 29% of the clam supply.

Figure 2 also indicates how the increase in demand and the decrease in supply are estimated to affect prices by 2100 for these shellfish under the two scenarios. Consumers are likely to substitute away from these shellfish as their prices increase, but not entirely, and not without some decrease in satisfaction. The Mitigation scenario keeps prices much closer to current levels, as indicated in Figure 2, resulting in smaller consumer losses in the shellfish market. In 2100, the benefits to shellfish consumers from global GHG emissions reductions under the Mitigation scenario are estimated at $380 million. The cumulative benefits over the century are estimated at $1.9 billion (discounted at 3%).

Figure 2. Estimated Impacts on the U.S. Shellfish Industry

Projected changes in the supplies and prices of oysters, scallops, and clams through 2100 under the Reference and Mitigation scenarios relative to the base period.



APPROACH

The CIRA analysis models the entire "impact pathway" shown in Figure 1, which can be divided into biophysical and economic components. The biophysical impacts are estimated using the CIRA CO_2 and sea surface temperature projections from the IGSM-CAM in the CO2SYS model[18] to simulate seawater chemistry conditions through the 21st century. These conditions are then used to estimate how the growth rates of oysters, scallops, and clams will change over time.

The economic analysis uses the projected growth rates of these species to estimate changes to the U.S. supply of shellfish. A consumer demand model of the shellfish market, described in Moore (2014),[19] projects changes in prices and consumer behavior under the Reference and Mitigation scenarios. This model does not estimate producer or supply-side welfare effects, which could also show benefits of mitigation. Comparing the model results under the two scenarios provides an estimate of the benefits to the shellfish market of avoiding significant amounts of CO_2 from being added to ocean waters. By considering impacts to these three species, this approach estimates just a fraction of the potential economic damages from ocean acidification, but, nonetheless, provides some insight into the benefits of global GHG mitigation.

In addition, by preventing the loss of shellfish populations, global GHG mitigation would preserve ecosystem services provided by these species (e.g., water filtration). Inclusion of these effects would likely increase the total benefits of GHG mitigation in this sector.

For more information on the CIRA approach to estimating the economic impacts of ocean acidification in the shellfish market, see Moore (2015).[20]

KEY FINDINGS

1. Warming waters and changes in stream flow due to climate change will likely alter the distribution of freshwater fisheries across the country. Without global GHG mitigation, coldwater species are projected to be replaced in many areas by less economically valuable fisheries over the course of the 21st century, especially in the Mountain West and Appalachia.

2. Habitat suitable for coldwater fisheries is estimated to decline nationally by approximately 62% through 2100 under the Reference, but by only 12% under the Mitigation scenario. Global GHG mitigation is projected to preserve coldwater habitat in most of Appalachia and the Mountain West.

3. GHG mitigation avoids an estimated $380 million to $1.5 billion in total recreational fishing damages through 2100 compared to the Reference (discounted at 3%).

Climate Change and Freshwater Fish

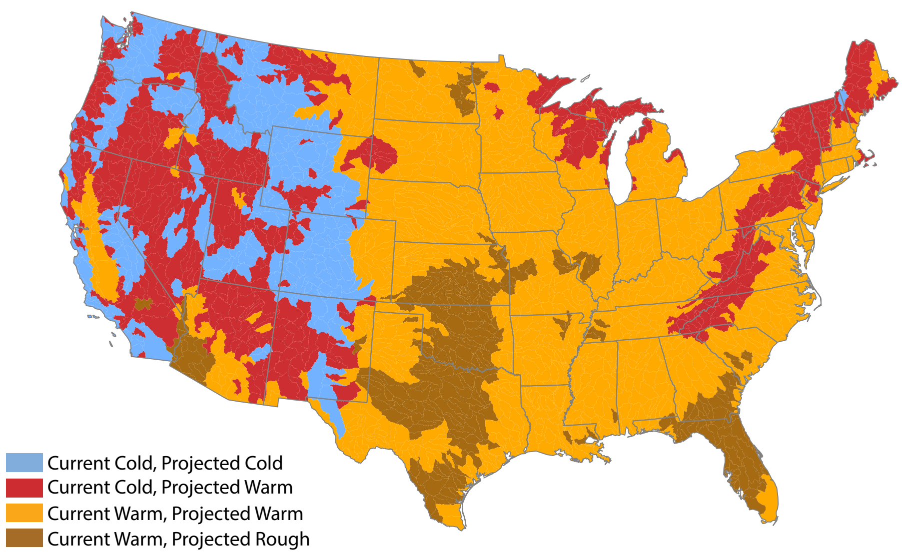
Freshwater fishing is an important recreational activity that contributes significantly to local economies in many parts of the country. Most fish species thrive only in certain ranges of water temperature and stream flow conditions. For example, trout and salmon can only tolerate coldwater streams, while shad and largemouth bass thrive in warmwater habitats (see below infographic). Climate change threatens to disrupt these habitats and affect certain fish populations through higher temperatures and changes in river flow.[21]

Risks of Inaction

Without GHG mitigation, climate change is projected to have a significant impact on freshwater fishing in the contiguous U.S. Increasing stream temperatures and changes in stream flow are likely to transform many habitats that are currently suitable for coldwater fish into areas that are only suitable for warmwater species that are less recreationally valuable. Under the IGSM-CAM climate projections, coldwater fisheries are estimated to be limited almost exclusively to the mountainous West in 2100, and would almost disappear from Appalachia. In addition, substantial portions of Texas, Oklahoma, Kansas, and Florida would shift from warmwater to rough habitat (Figure 1). Overall, unmitigated climate change is projected to result in a 62% decline in coldwater fish habitat by 2100, which includes approximately 440,000 acres of lost stream habitat. Meanwhile, warmwater and rough stream habitats are projected to increase by 1.3 million and 450,000 acres, respectively. The projected loss of coldwater fish habitat and expansion of warmwater and rough fisheries are consistent with the findings of the assessment literature.[22, 23]

Figure 1. Projected Impact of Unmitigated Climate Change on Potential Freshwater Fish Habitat in 2100

Change in distribution of areas where stream temperature supports different fisheries under the Reference scenario using the IGSM-CAM climate model. Results are presented for the 8-digit hydrologic unit codes (HUCs) of the contiguous U.S.



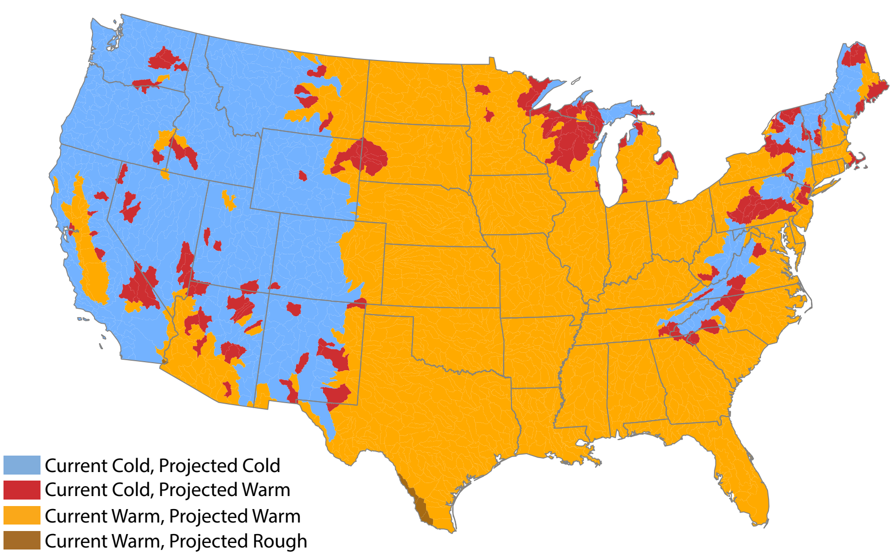
Reducing Impacts through GHG Mitigation

Global GHG mitigation is projected to prevent much of the loss of coldwater fish habitat that occurs in the Reference (Figure 2). Although coldwater stream habitat will likely still be reduced under the Mitigation scenario (by approximately 85,000 acres by 2100), mitigation avoids approximately 81% of the losses incurred under the Reference, preserving an area equal to approximately 360,000 acres of suitable stream habitat nationally. This habitat supports valuable recreational fishing, especially in Appalachia and large areas of the Mountain West. Also, fewer acres are converted to less economically valuable warmwater and rough fisheries under the Mitigation scenario than under the Reference. Specifically, stream habitat suitable for warmwater and rough fisheries increase by 450,000 and 13,000 acres, respectively, under the Mitigation scenario, which is 36% and 3% of the expansions estimated under the Reference.

Compared to the Reference, the Mitigation scenario provides economic benefits of approximately $1.5 billion through 2100 for coldwater fishing only, and $380 million when all three freshwater fishery types (cold, warm, and rough) are considered (discounted at 3%). These results rely upon climate projections from the IGSM-CAM, which projects a relatively wetter future for most of the U.S. compared to the MIROC climate model. The projected benefits of global GHG mitigation through 2100 are lower with the drier MIROC model (not shown) for coldwater fishing only, at approximately $1.2 billion, but higher when all three fisheries are considered, at approximately $1.5 billion (discounted at 3%).[24]

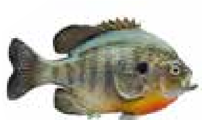
Figure 2. Projected Impact on Potential Freshwater Fish Habitat in 2100 with Global GHG Mitigation

Change in distribution of areas where stream temperature supports different fisheries under the Mitigation scenario using the IGSM-CAM climate model. Results are presented for the 8-digit HUCs of the contiguous U.S.



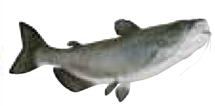
ROUGH FISHERY EXAMPLES

Largemouth Bass



Bluegill

Carp



Catfish

APPROACH

The CIRA analysis assesses the impacts of climate change on the distribution of habitat suitable for freshwater fish across the U.S. and estimates the economic implications of these changes. Water temperature changes are simulated for the CIRA emissions scenarios using the IGSM-CAM and MIROC climate models to estimate changes in suitable habitat (in stream acres) for three types of freshwater fisheries: cold, warm, and rough (species tolerant to warmest stream temperatures). Each fishery type represents a categorization of individual species based on their tolerance for different river and stream water temperatures. This analysis does not evaluate impacts to fisheries in lakes and reservoirs, which are vulnerable to climate change in different ways compared to streams and rivers.[25] As shown at the bottom of this section, the coldwater fish guild contains species that are the least tolerant to increasing stream temperatures, and are therefore the most vulnerable to climate change.

Results from habitat modeling considering projected changes in both water temperature and streamflow serve as input to an economic model to analyze the impacts of habitat change on the value of recreational fishing. The model estimates fishing behavior as the likelihood that an adult in a particular state is an angler and the likelihood that an angler fishes for species in each fishery type. The fishing value for each fishery type is derived by multiplying the number of fishing days by the value of a fishing trip.[26] As implications of changes to the distribution of freshwater fisheries extend beyond recreational use by humans, this analysis underestimates the economic benefits of GHG mitigation.

For more information on the CIRA approach and results for the freshwater fish sector, please refer to Lane et al. (2014)[27] and Jones et al. (2012).[28]

Wildfire

KEY FINDINGS

1. Without global GHG mitigation efforts, climate change is projected to dramatically increase the area burned by wildfires across most of the contiguous U.S., especially in the West.

2. Global GHG mitigation is projected to reduce the cumulative area burned by wildfires over the course of the 21st century by approximately 210-300 million acres compared to the Reference.

3. Global GHG mitigation avoids an estimated $8.6-$11 billion in wildfire response costs and $3.4 billion in fuel management costs on conservation lands (discounted at 3%) through 2100 compared to the Reference. Other impacts, such as property damage or health effects from decreased air quality, are not estimated, but could have large economic implications.

Climate Change and Wildfire

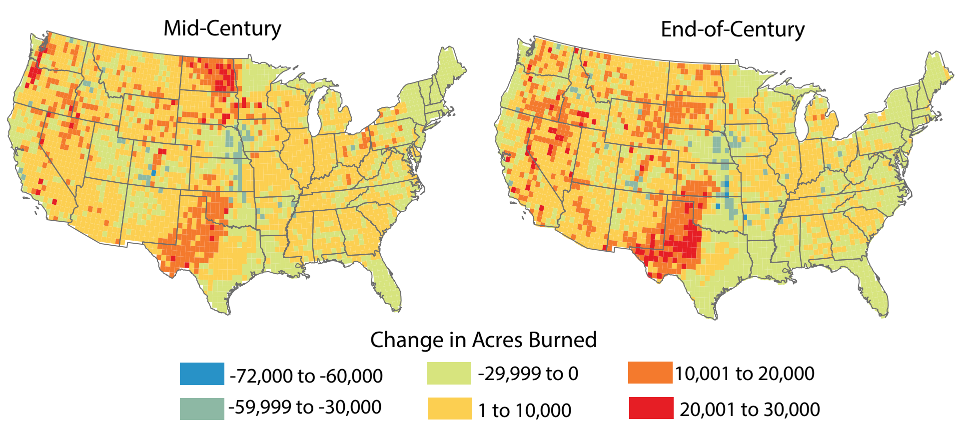
Terrestrial ecosystems in the U.S. provide a wealth of goods and services such as timber, wildlife habitat, erosion management, water filtration, recreation, and aesthetic value. Climate change threatens these ecosystems as heat, drought, and other disturbances bring larger and more frequent wildfires. Wildfires can damage property, disrupt ecosystem services, destroy timber stocks, impair air quality, and result in loss of life.[29] In the last decade (2004-2013), more than 72 million acres of forest have burned due to wildfires, and the U.S. government has spent in excess of $15 billion on wildfire suppression.[30] Additionally, wildfires release carbon stored in terrestrial ecosystems, potentially further accelerating climate change.[31, 32]

Risks of Inaction

Without GHG mitigation, climate change is projected to dramatically increase the area burned by wildfires across most of the contiguous U.S., a finding that is consistent with the assessment literature.[33] Under the Reference using the IGSM-CAM climate projections, approximately 5.3 million[34] more acres—an area greater than the state of Massachusetts—are projected to burn each year at the end of the century compared to today. This represents a doubling of acres burned compared to today's rates.[35] However, the estimated impacts vary across regions and through time (Figure 1). Consistent with the assessment literature,[36] the western U.S.[37] is projected to experience large increases in burned area by the end of the century (an increase of approximately 43%). In particular, the Southwestern region (comprising Arizona, New Mexico, and West Texas) is projected to experience increases of 140% on average.[38] Wildfire in other regions is not projected to change significantly compared to today, and some regions, such as the Northeast, are estimated under the IGSM-CAM projections to experience decreases in wildfire activity.

Figure 1. Projected Impact of Unmitigated Climate Change on Wildfire Activity

Change in average annual acres burned under the Reference scenario by mid-century (2035-2064) and end of century (2085-2114) compared to the historic baseline (2000-2009) using the IGSM-CAM climate model. Acres burned include all vegetation types and are calculated at a cell resolution of 0.5° x 0.5°.

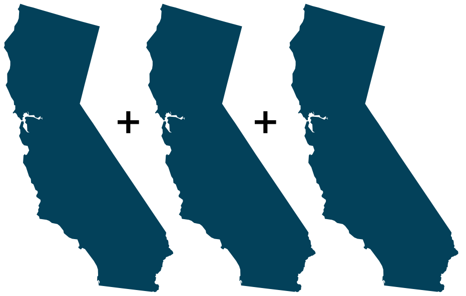


Reducing Impacts through GHG Mitigation

As shown in Figure 2, global GHG mitigation significantly reduces the area burned by wildfire in the U.S. over the course of the 21st century. By 2100, the Mitigation scenario reduces the cumulative area burned by approximately 210-300 million acres, depending on the climate model used. This corresponds to a 13-14% reduction relative to the Reference. As shown, the combined area of wildfires avoided in the contiguous U.S. due to GHG mitigation is equivalent to two to three times the size of California. These benefits of GHG mitigation would largely occur in the West, where approximately 64%-75% of the avoided burned area is located.

Benefits of GHG Mitigation

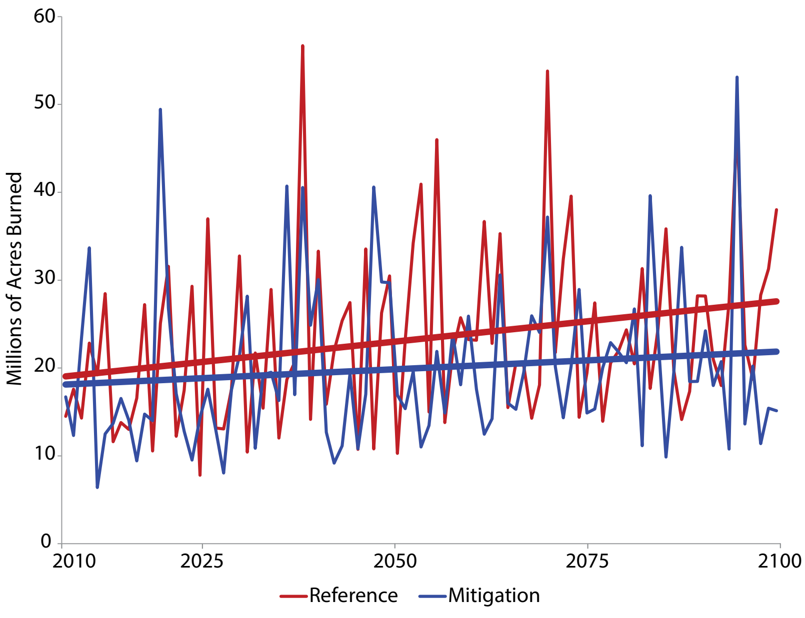
210-300 million fewer acres burned *over the course of the 21st century, an area* ***2-3 times*** *the size of California*



Nationally, the avoided wildfire due to GHG mitigation corresponds $11 billion in reduced wildfire response costs and $3.4 billion[39] in avoided fuel management costs for conservation lands through 2100 (both discounted at 3%). Other economic damages from wildfire that are not estimated in this analysis, such as human health effects from decreased air quality, could have large implications at national and regional scales. These results rely upon climate projections from the IGSM-CAM, which projects a relatively wetter future for most of the U.S. compared to the MIROC climate model (see the Levels of Certainty section of this report for more information). The projected benefits of global GHG mitigation are slightly lower for the drier MIROC model, with wildfire response cost savings estimated at $8.6 billion through 2100 (discounted at 3%).[40]

Figure 2. Estimated Acres Burned with and without Global GHG Mitigation

Estimated acres burned by wildfire in the contiguous U.S. over the course of the 21st century under the Reference and Mitigation scenarios using the IGSM-CAM climate model, with trends shown in bold. The large inter-annual variability reflects simulated periods of fuel accumulation followed by seasons of large wildfire activity.



APPROACH

To estimate the effect of climate change on areas burned by wildfires, the CIRA analysis uses the MC1 dynamic global vegetation model. The model simulates future terrestrial ecosystem cover and burned area across the contiguous U.S. in the 21st century. The vegetation model is driven by changes in future climate (e.g., temperature, precipitation, humidity) based on five initializations of the IGSM-CAM climate model for the Reference and Mitigation scenarios.[41,42] Results presented in this section represent the average of the initializations. Simulations using the drier MIROC model were also performed. Projected changes in fire regime over time are adjusted to account for fire suppression tactics.

The projected impacts of wildfires are summarized by scenario and geographic area, and then monetized using average wildfire response costs for each region. These costs include the costs associated with labor (e.g., fire crews) and equipment (e.g., helicopters, bulldozers) that are required for fire-fighting efforts.[43] Using the approach described in Lee et al. (2015),[44] the analysis also estimates the environmental damages resulting from moderate and severe wildfires on conservation lands (e.g., Forest Service lands, national parks and preserves, and other protected lands) across the contiguous U.S. under the Reference and Mitigation scenarios. To estimate the value of the lost ecosystem services resulting from these wildfires, the analysis quantifies the costs of fuels management needed to offset the injury caused by wildfires. Air quality impacts, property loss, loss of recreation, and the effects of pest infestations (e.g., pine bark beetles) on wildfire activity are additional and important impacts, but are not included in the reported estimates.

For more information on the CIRA approach and results for wildfires, please refer to Mills et al. (2014)[45] and Lee et al. (2015).[46]

Carbon Storage

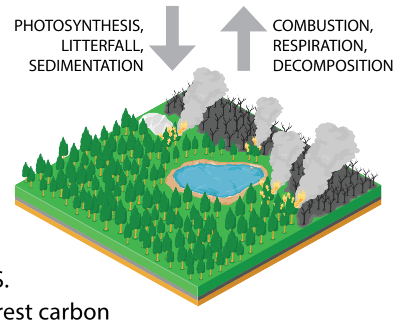
KEY FINDINGS

1. Changes in vegetative carbon storage in the contiguous U.S. are highly dependent on the projected future climate, with the magnitude, regional distribution, and directionality of impacts changing over time.

2. The estimated effect of global GHG mitigation on carbon storage ranges from a decrease in carbon stocks of 0.5 billion metric tons to an increase in carbon stocks of 1.4 billion metric tons by the end of the century, depending on the climate model used. The economic value of these changes in carbon storage ranges from $9 billion in disbenefits to $120 billion in GHG mitigation benefits (both discounted at 3%).

Climate Change and Terrestrial Carbon Storage

Figure 1. Carbon Storage Basics



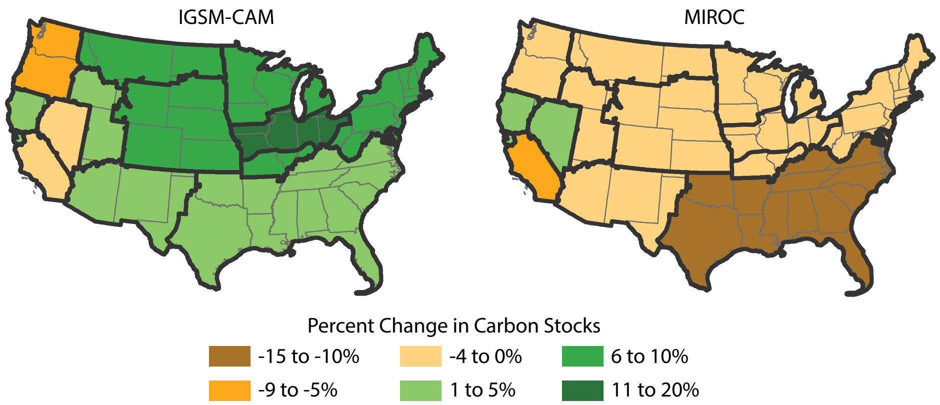
Terrestrial ecosystems influence the climate system through their important role in the global carbon cycle. These ecosystems capture and store carbon from the atmosphere, thereby reducing its climate impact. However, they can also act as a source, releasing carbon through decomposition and wildfires (Figure 1). Terrestrial ecosystems in the U.S., which include forests, grasslands, and shrublands, are currently a net carbon sink. Today, forests store more than 227 million tons of carbon per year, which offsets approximately 16% of all annual U.S. carbon dioxide emissions from fossil fuel burning.[47] Forest carbon storage has increased due to net increases in forest area, improved forest management, as well as higher productivity rates and longer growing seasons driven by climate change.[48] However, climate-driven changes in the distribution of vegetation types, wildfire, pests, and disease are affecting, and will continue to affect, U.S. terrestrial ecosystem carbon storage.[49]

Risks of Inaction

Climate change impacts on terrestrial ecosystem carbon storage under the Reference are on the order of billions of tons of carbon from 2000 to 2100, with some regions showing substantial changes in terrestrial carbon stocks (total amount of carbon in the vegetation). Under the IGSM-CAM climate projections, terrestrial ecosystem storage across the contiguous U.S. is projected to increase 3.4% from 2000 to 2100 (equal to 2.9 billion metric tons),[50] primarily due to generally warmer, wetter, and CO_2-rich future conditions that are favorable to vegetative growth. Much of the national trend is driven by the Rocky Mountains, South, and East regions, which have the largest projected increases in terrestrial ecosystem carbon. However, as shown in Figure 2, there is substantial regional variation, and projections for carbon storage vary greatly depending on the projected future climate. Results using the drier MIROC climate model project net reductions in stored carbon under the Reference in most regions. These results are consistent with the findings of the assessment literature.[51]

Figure 2. Projected Impact of Unmitigated Climate Change on Stored Carbon in 2100

Simulated changes in carbon stocks from the baseline (2000-2009 average) projected by the IGSM-CAM and MIROC climate models are aggregated by U.S. Forest Service Geographic Area Coordination Center region.



Reducing Impacts through GHG Mitigation

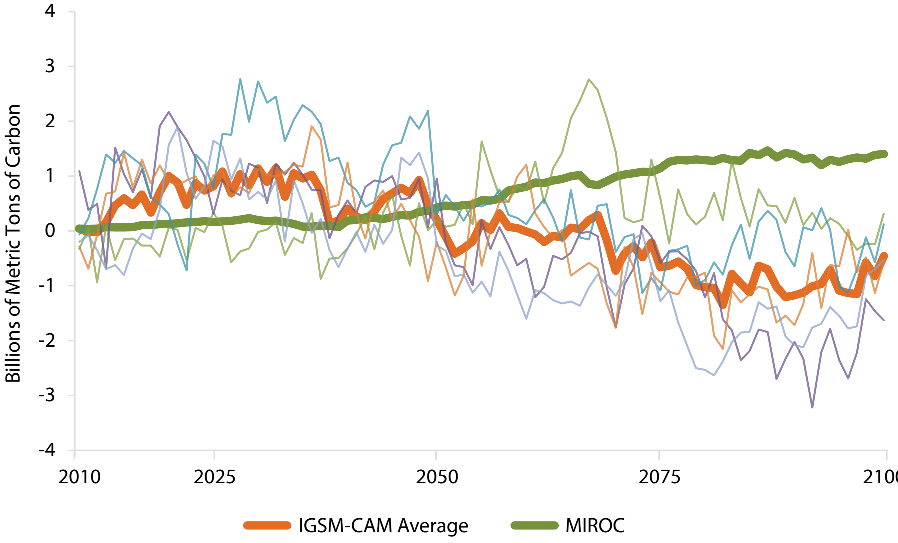
The impacts of GHG mitigation on national terrestrial ecosystem carbon storage are highly dependent upon the projected future climate, with the magnitude and even directionality of impacts varying over time (Figure 3). Across the contiguous U.S., average results across the IGSM-CAM initializations show that GHG mitigation reduces stored carbon compared to the Reference by 0.5 billion metric tons over the course of the century. The economic value of this lost carbon under the Mitigation scenario is an estimated $9.0 billion (discounted at 3%). As shown in Figure 3, carbon stocks under the Mitigation scenario are larger than the Reference in the first half of the century under the IGSM-CAM, but the trend reverses after 2050, as climate conditions under the Reference (generally warmer and wetter) are more favorable for vegetative growth. There is an early savings from the near-term gain in stored carbon of approximately 1.1 billion metric tons, estimated at $170 billion by 2030 (discounted at 3%). However, these initial gains are not large enough to offset projected losses in the second half of the century.

The projected impacts of climate change on vegetative carbon storage and the effects

of GHG mitigation are different when using the relatively drier climate projections from the MIROC model (Figure 3). The MIROC results project a consistent increase in carbon storage benefits when comparing the Mitigation scenario to the Reference, with a carbon stock increase of 1.4 billion metric tons by 2100. The economic value of this carbon gain under the Mitigation scenario is an estimated $120 billion (discounted at 3%). Results using IGSM-CAM projections show much more variability over time than the MIROC results, which is primarily a reflection of the climate projection method.[52]

Figure 3. Projected Impact of Global GHG Mitigation on Carbon Stocks in the Contiguous U.S.

Estimated change in the size of terrestrial ecosystem carbon stocks under the Mitigation scenario compared to the Reference. Positive values indicate larger carbon stocks under the Mitigation scenario compared to the Reference, and vice versa. The thin lines represent estimated changes in carbon stocks under the different initializations of the IGSM-CAM climate model.



APPROACH

To estimate climate change impacts on terrestrial ecosystem carbon storage, the MC1 dynamic global vegetation model was used to simulate terrestrial vegetative growth and cover (e.g., grasses, shrubs, hard and softwood forests) for the contiguous U.S. from 2000 to 2100.[53] Vegetative cover estimates from MC1 reflect simulated changes in climate, biogeography, biogeochemistry, and fire dynamics. MC1 was run using the five initializations of the IGSM-CAM climate model for both the Reference and Mitigation scenarios (see the CIRA Framework section of this report for more information).[54] The results described in this section represent the average of these initializations. Because IGSM-CAM projects a wetter future for a majority of the nation, MC1 was also run using the MIROC climate model. These drier climate projections for the U.S. were used to capture a broader range of possible precipitation futures under the same GHG emissions scenarios.

Projected annual changes in terrestrial carbon storage for non-agricultural, non-developed lands across the contiguous U.S. were summarized by scenario and geographic area, and then monetized using the central estimate of the U.S. Government's updated social cost of carbon (SCC) values for the years 2010-2050, with extrapolation to 2100.[55]

This analysis did not consider the effects of future changes in ozone, pests, and disease, which could influence the ability of U.S. terrestrial ecosystems to store carbon.

For more information on the CIRA approach and results for carbon storage, please refer to Mills et al. (2014).[56]