Duke NICHOLAS INSTITUTE
National Ecosystem Services PARTNERSHIP

ACES A Community on Ecosystem Services

USDA

Tracking the Benefits of Natural and Working Lands in the United States: Dataset Evaluation and Readiness Assessment

Katie Warnell, Sara Mason, and Lydia Olander

Nicholas Institute for Environmental Policy Solutions nicholasinstitute.duke.edu

Tracking the Benefits of Natural and Working Lands in the United States: Dataset Evaluation and Readiness Assessment

CONTENTS

Version 1.2, April 2022

Results from the "Tracking the Benefits of Natural & Working Lands in the United States" workshop, January 31–February 3, 2022

Report compiled by Katie Warnell, Sara Mason, and Lydia Olander, Nicholas Institute for Environmental Policy Solutions at Duke University and National Ecosystem Services Partnership

This research was supported in part by the US Department of Agriculture, Office of Environmental Markets, under a cooperative agreement.

Duke NICHOLAS INSTITUTE National Ecosystem Services PARTNERSHIP

ACES A Community on Ecosystem Services

USDA

Executive Summary

OBJECTIVES

Natural and working lands (NWL) in the United States provide many benefits, including food, climate change mitigation and resilience, recreational opportunities, jobs, and many more. Here, natural and working lands are defined quite broadly and inclusive of, but not limited to forests, wetlands, coastal areas, grasslands, farmlands, working forests, rangelands, and urban greenspace. There is currently no coordinated approach in the United States to track how provision of NWL benefits is changing across these landscapes over time. This project begins to fill this gap and seeks to inform a national status and trends assessment of NWL benefits, which can support initiatives such as America the Beautiful and natural capital accounting. Specifically, we addressed five objectives:

(1) To identify datasets that can be used to track the status and trends of NWL benefits (i.e., ecosystem services) and assess their capacity for use in a national assessment

(2) To prioritize benefits datasets that are ready to use in the near-term and aligned with state and national priorities

(3) To identify how we can aggregate and summarize benefits data in useful ways for key stakeholders using existing data as filters or overlays

(4) To consider what adjustments are needed to make datasets identified in objectives 1 and 3 ready to use for tracking status and trends or for summarizing results

(5) To prioritize data gaps and limitations that need to be addressed to generate useful national datasets

BENEFITS AND DATASETS REVIEWED

Our review identified 137 datasets that could be used to track the status and trends of 13 NWL benefits: air quality and human health, biodiversity, energy conservation, energy production, fire risk reduction to communities, flood risk reduction to communities, food, forest products, greenhouse gas fluxes and carbon stocks, NWL-related jobs, recreation, water quality, and water quantity. These datasets are compiled in a database available online.

Each of the 137 datasets was categorized using a set of five attributes:

- ability to quantify a benefit
- geographic extent
- spatial resolution
- frequency of updates
- level of preparation needed to use the data

These attribute ratings are included in the benefits database and described in detailed dataset summaries in Appendix D.

DATASET PRIORITIZATION

One of the objectives of this work was to prioritize which datasets should be used in the near term to track status and trends of benefits provided by NWL. While it would be ideal to include as many benefits as possible, for feasibility it made sense to prioritize benefits on the basis of (1) whether the benefit had datasets that were ready to use (readiness) and (2) whether the benefit aligned with state and national priorities (importance).

Readiness

Datasets were defined as "ready to go" for use in a national status and trends assessment within the next 12 months based on the following attributes:

(1) **Ability to quantify a benefit to people:** Ideally, the data quantify a final benefit (the use by people is quantified, e.g., avoided health impacts due to air pollutant removal by trees) or provide a monetized value of the final benefit (e.g., value of avoided health impacts due to air pollutant removal by trees). If this type of data was not available for a given benefit, we also included datasets that identify the geographic area providing a final benefit to specific communities or people (e.g., tree cover in urban areas with high air pollutant concentrations).

(2) **Geographic extent:** data are, or could be, available for the conterminous US or even better, the entire US and territories.

(3) **Spatial resolution:** data are, or could be, available at a county or ideally finer scale.

(4) **Level of preparation required:** data are, or could be, ready to use—without intensive modeling.

We identified 37 ready-to-go datasets, including 19 datasets that quantify a final benefit, 17 datasets that identify the area of NWL contributing to a benefit, and one dataset (NWL greenhouse gas fluxes and carbon stocks) that quantifies an intermediate ecosystem service that is commonly used as a proxy for the final benefit. While all 13 NWL benefits have at least one ready-to-go dataset, four (flood risk reduction, fire risk reduction, water quantity, and water quality) don't quantify the final benefit (Table 1). The status and trends of most NWL benefits are not fully represented by ready-to-go datasets due to the datasets' limited geographic extent or missing facets of benefits within datasets (see Data Gaps and Limitations section below).

Importance

A dataset was defined as important if the benefit represented by the dataset aligns with federal and state conservation initiatives that recognize the multitude of benefits provided by natural and working lands.[1] These efforts include the America the Beautiful report and several state and regional 30x30 initiatives, which aim to protect 30% of lands and oceans by 2030. The America the Beautiful report raises three target areas for conservation action: biodiversity, climate change mitigation and resilience, and equitable access to nature's benefits[1]. At least eight states and multistate regions are in the process of developing their own 30x30 initiatives; while specific areas of focus vary from state to state, common threads include (1) protection of biodiversity and habitats, (2) climate change mitigation and resilience to climate change

1. https://www.doi.gov/sites/doi.gov/files/report-conserving-and-restoring-america-the-beautiful-2021.pdf; https://togetherbayarea.org/wp-content/uploads/2021/08/Land_Conservation_Advisory_Panel_Summary_v3_508.pdf; https://www.ilga.gov/legislation/publicacts/fulltext.asp?Name=102-0618; http://www.legislature.mi.gov/documents/2021-2022/resolutionintroduced/House/pdf/2021-HIR-0025.pdf; https://www.leg.state.nv.us/App/NELIS/REL/81st2021/Bill/7487/Text; https://www.governor.state.nm.us/wp-content/uploads/2021/08/Executive-Order-2021-052.pdf; https://legislation.nysenate.gov/pdf/bills/2021/S6191; https://www.dcr.virginia.gov/conservevirginia/; https://www.chesapeakeconservancy.org/2020/10/09/chesapeake-bay-30-x-30-conserving-30-of-the-chesapeake-bay-watersheds-lands-by-2030/

risks such as flooding and fires, and (3) public access to nature and outdoor recreation. Several states also emphasize the economic importance and cultural and historic preservation of natural and working lands. Some states without 30x30 initiatives have plans for natural and working lands management with similar goals.[2] Almost all natural and working land benefits included in this project are highlighted by at least one of the federal or state 30x30 initiatives. The America the Beautiful report's emphasis on equitable access to nature's benefits, in particular, is inclusive of the majority of the benefits considered, including all regulating services (e.g., water quality improvement) and cultural services (e.g., recreation). Therefore, all 13 benefits were deemed important given their alignment with state or national priorities.

Table 1. Facets of NWL benefits that can be mapped using ready-to-go datasets and could be included in a national assessment within 12 months

Benefit	What facet of the benefit can be mapped using ready-to-go datasets
Air quality and human health	Avoided health impacts due to pollutant removal by trees, value of avoided health impacts due to pollutant removal by trees
Biodiversity	Imperiled species richness (total and rarity-weighted)
	NWL with rare species and habitats
	NWL with high resilience to sustain biodiversity with climate change and serving as corridors for species movement in response to climate change
Energy conservation	Avoided spending on cooling costs due to temperature reduction by urban trees
Energy production	Solar, wind (including offshore wind), hydropower, and geothermal energy generation capacity
Fire risk reduction	NWL treated for fire risk reduction on US Forest Service lands
Flood risk reduction	NWL areas that are likely to reduce runoff in high flood risk watersheds, annual runoff reduction due to trees in high flood risk watersheds, population at risk of flooding in high flood risk watersheds
Food	Value of crops created by wild pollinators
Forest products	Timber harvested from all forests (public and private)
Greenhouse gas fluxes and carbon stocks	Net GHG fluxes (sequestration and emissions) and carbon stocks from forests, agriculture, and coastal wetlands
Jobs	Employment in forestry, agriculture, and commercial fishing by NAICS code
Recreation	Visitors to federal public lands for a wide range of recreational activities (e.g., hiking, boating, hunting, bicycling, various types of camping). Types of recreation specified varies by federal agency (see database for details).
	Recreational birding days
	Publicly accessible open space (public and private) in Census-defined urban areas

2. https://deq.nc.gov/media/17743/download

Water quality	Important watersheds for production of clean drinking water, based on land cover and water yield, potential threats to surface drinking water from insects and disease, wildfire, climate change, and land-use change
Water quality	Important watersheds for production of clean drinking water, based on land cover and water yield, potential threats to surface drinking water from insects and disease, wildfire, climate change, and land-use change

Note: Dark green shading indicates datasets that quantify the benefit of NWL to people; rows with light green shading are datasets that identify the area of NWL likely to provide the benefit. The unshaded row for greenhouse gas fluxes and carbon stocks indicates that this benefit quantifies an intermediate service that serves as a proxy for its final benefit as described above.

DATA FILTERS

We explored using data filters to categorize the benefits data into subsets that represent benefits within a defined geographic area. Doing so would make the data more relevant to different user groups and stakeholders by providing multiple ways to view and summarize the data for communication and analysis. Data filters include jurisdictional boundaries (e.g., state, county, parish), watersheds, ownership type (public/private), management status, and type of NWL. For example, a dataset quantifying timber harvest in the US could be summarized with a state filter to show timber harvest in North Carolina, or with an ownership filter to show timber harvest from public lands. Twenty-five filter ideas (Table 4) were generated through expert engagement and workshop discussion, and 60 datasets that could be used to define the filters were collected in a separate tab of the database.

DATA GAPS AND LIMITATIONS

Overarching data gaps and limitations identified by the project team and the workshop discussions include:

- The majority of identified datasets do not cover the entire US. Even many "national" datasets are limited to the conterminous US. Given the large proportion of NWL in Alaska, and the unique benefits (especially biodiversity and cultural benefits) provided by NWL in Alaska, Hawaii, and US territories, this is a significant limitation.
- Continual updates to datasets are critical for tracking status and trends over time. Many of the datasets are not part of a program that ensures regular updating of the data. Thus, funding and capacity to maintain and update the datasets will be needed.
- Data for NWL benefits provide a spectrum of metrics at this time. Many only identify areas that are important for final benefits, without quantifying them. Others quantify benefits to people but cannot distinguish the contribution of lands from human inputs. Data that provide measures of final benefits of NWL over time will best inform how conservation and management of US lands affect human welfare.
- Continual improvement of existing datasets and generation of new datasets related to NWL benefits should be encouraged but pose a challenge to tracking benefits over time. Changes to dataset methodology can disrupt a consistent time series and obscure the actual changes occurring in the benefits provided. A process to allow continued assessment of status and trends over time as data and methods are updated will be needed.

- There were a few benefits identified during the workshop that represent data gaps. These include human health benefits of greenspace exposure, pest and disease regulation, and cultural ecosystem services. While these are benefits known to be supported by NWL, no national-scale datasets exist to track the status and trends of these benefits.
- Assessing equity of access to NWL benefits was limited by incomplete data on the serviceshed (area where beneficiaries exist) for each benefit and the coarse resolution of socioeconomic and demographic data.

Benefit and filter data gaps and limitations are discussed in Appendix D and E, respectively.

NEXT STEPS

A complete status and trends assessment for the US that includes every benefit is not possible in the near term, given existing data gaps. Nonetheless, there are some benefits datasets that meet the criteria for use in the near term. To use these benefits datasets to produce an initial national status and trends assessment in the next 12 months would require (1) a process to select benefits and related datasets to include, (2) preparation of the selected datasets (Table 3, column 6), (3) assessment of the datasets' quality (uncertainty and validation information), and (4) identification of resources to keep the assessment updated as new datasets become available.

In the longer term, work needs to be done to (1) improve the data used to capture benefits, (2) fill in missing, yet important, facets of benefits, (3) develop data for missing benefits, and (4) improve the interoperability of data and tools to make regular, national status and trends assessments easier and faster to compile in the future. The incomplete nature of the data means they are missing important benefits that lands provide to people and should not be used to assess progress and set priorities over the long term without improvements to fill these gaps.

1. Project Background

Natural and working lands (NWL) in the United States provide many benefits, including food, climate change mitigation and resilience, recreational opportunities, and jobs. Here, natural and working lands are defined quite broadly and inclusive of, but not limited to forests, wetlands, coastal areas, grasslands, farmlands, working forests, rangelands, and urban greenspace. There is no coordinated approach in the United States to track how provision of NWL benefits is changing across these landscapes over time. To address this need, the National Ecosystem Services Partnership (NESP) at Duke University, A Community on Ecosystem Services (ACES), and the US Department of Agriculture (USDA) collaborated on a project to assess how existing datasets can best be used for a national assessment of the status and trends of NWL benefits in the United States.

The project addressed five objectives:

(1) To identify datasets that can be used to track the status and trends of NWL benefits (i.e., ecosystem services) and assess their capacity for use in a national assessment

(2) To prioritize benefits datasets that are ready to use in the near-term and aligned with state and national priorities

(3) To identify how we can aggregate and summarize benefits data in useful ways for key stakeholders using existing data as filters or overlays

(4) To consider what adjustments are needed to make existing datasets discussed in objectives 1 and 3 ready to use for tracking status and trends or for summarizing results

(5) To prioritize data gaps and limitations that need to be addressed to generate useful national datasets

The datasets identified in this project could eventually be used to create a data platform for communicating the benefits of different NWL, tracking how benefits change over time, and understanding how benefits accrue to specific communities and beneficiaries. This could be useful for assessing the impacts of different programs, policies, and stressors. The collated datasets could inform multiple ongoing federal initiatives, such as natural capital accounting and the American Conservation and Stewardship Atlas, both of which require information on the status and trends of NWL benefits over time.

2. Methods

2.1 PROJECT PROCESS

This project was conducted in three phases:

(1) **Dataset compilation and expert engagement:** From October 2021 through February 2022, the project team compiled datasets into a database. The datasets were identified through (1) the past experience of the project team in mapping benefits of NWL, (2) online searches of the scientific literature and published databases, and (3) conversations with 66 experts (Appendix A). The initial expert list was developed by the project team based on their experience working with spatial ecosystem services data in the US and was expanded to include additional people suggested by those experts. Expert engagement consisted of 30- to 90-minute conversations during which the project team shared the goals of the project, benefit categories, and datasets gathered for each benefit and each filter. Experts provided feedback on the benefits list—in some cases suggesting additions or updates to the benefits or filters—and shared additional datasets that could be used. New datasets suggested by experts were added to the database when the project team assessed they captured some facet of an NWL benefit for tracking status and trends or could be used as a filter, as described below.

(2) **Workshop discussion:** The project team hosted a virtual workshop from January 31–February 3, 2022. Each workshop day contained a session ranging from 90–120 minutes. Attendance for each day varied from 18–29 participants, with 35 unique participants attending over the four days. Workshop participants represented federal agencies, environmental non-profits, universities, and the private sector. The majority of participants were federal government employees. For a full attendee list see Appendix B. Throughout the course of the workshop participants were asked to consider benefits and associated datasets, suggest additional benefits datasets, share any key limitations of the datasets, provide input and suggestions on data filters and associated datasets, and think about how to address identified data gaps.

(3) **Post-workshop adjustments and final dataset evaluation:** The project team considered the feedback and insights gathered during the workshop to (1) update database attributes and attribute categories to make the database more informative and reflective of the workshop conversations and (2) define a set of criteria to assess which datasets would be ready to use in the near term to track NWL benefits.

2.2 BENEFITS DATA COMPILATION

Data compilation focused on datasets that could be used to track the status and trends of NWL benefits (Box 1) over time. All datasets, along with additional information (description, originator, public availability, extent, resolution, update frequency) for each dataset, are available in the benefits database. Many benefits have multiple data sources, because individual data sources often only capture specific facets of a benefit; for example, a biodiversity dataset will report the number of rare species occurring in a certain area, but not include other facets of biodiversity (e.g., genetic diversity).

Box 1 does not include all NWL benefits; several benefits (e.g., human health benefits of exposure to greenspace, pest regulation, cultural ecosystem services) are data gaps that currently cannot be quantified at the national scale (see Section 3.4.3). Datasets suggested by experts that were related to ecological uplift (a change in ecological condition due to management actions or restoration), projecting future benefits, prioritizing lands for future protection or management, or identifying threats rather than benefit delivery were added to the database but categorized as "other relevant datasets" to indicate that they may be helpful reference data but are not benefits datasets for tracking status and trends.

Box 1. Benefits of NWL in the US for which datasets were compiled[3]

- Air quality and human health
- Biodiversity
- Energy conservation
- Energy production
- Fire risk reduction to communities
- Flood risk reduction to communities
- Food
- Forest products
- Greenhouse gas fluxes and carbon stocks
- NWL-related jobs
- Recreation
- Water quality
- Water quantity

2.3 ATTRIBUTES FOR DATASET EVALUATION

Each benefits dataset included in the database was categorized using a set of five attributes to better understand each dataset's readiness to track the status and trends of the benefit in the near term. Datasets were reviewed for their:

- ability to quantify a benefit;
- geographic extent;
- spatial resolution;
- frequency of updates;
- level of preparation needed to use the data.

These attributes align closely with suggested data quality assessment characteristics described by the UN.[3] Several additional characteristics recommended by the UN report relate to dataset validation, uncertainty, and attribution of errors; these were not included in the current assessment, but should be evaluated before any dataset is selected for use in a national assessment or other product. In addition, all datasets included in the database were required to have undergone peer review or quality control review and have clear, fully developed metadata.

Datasets were scored high, moderate, or low for each attribute as detailed in Appendix C, Table C1, except for the "ability to quantify a benefit" attribute, which did not fit neatly into this scoring system. Instead the "ability to quantify a benefit" attribute was categorized as shown in Table 2. Dataset categories (Column 1) range from describing a final benefit to describing a condition or quality of natural and working lands relevant to their ability to provide a benefit.

3. UN Earth Observations Report, 2017: https://acems.org.au/sites/default/files/ungwg_satellite_task_team_report_whitecover_0.pdf

Table 2. Categories used to classify the datasets for the "ability to quantify a benefit" attribute

Category	Definition	Example for flood risk reduction benefit [metric]
Final benefit	Also known as a final ecosystem good or service, this has been defined as components of nature that are directly enjoyed, consumed, or used for human well-being.[4] Some datasets include a monetary value for final benefits; these are designated as "final benefit (with value)"	Avoided flood damage to infrastructure due to natural vegetation [avoided flood damage, $]
Area providing benefit	Does not quantify benefit; identifies area of NWL providing the benefit. This could be a habitat type or an area where a specific activity takes place	Floodplain and wetland forests in watersheds with many people at risk of flooding [area]
Intermediate ecosystem service	Attributes of ecological structure or process that influence the quantity or quality of final ecosystem services, but are not directly enjoyed, consumed, or used[5]	Reduced annual runoff due to tree cover [reduced runoff, gallons/year]
Benefit not linked to NWL	Quantifies use/appreciation of benefit by people but is not linked back to provision of benefit by NWL	Change in flood damage over time [change in damage, $/year]
Condition or quality of NWL	Quantifies an aspect of NWL condition or quality that is relevant to its ability to provide a benefit	Wetland water storage capacity [gallons]
Other relevant datasets	Datasets related to ecological uplift, projected future benefits, prioritization for future protection, and threat identification that are not the focus of this project	FEMA flood hazard zones [area at risk of flooding]

Note: Row shading matches shading in Table 1 and the database.

2.4 BENEFITS DATASET PRIORITIZATION

The workshop discussion emphasized the importance of identifying datasets that (1) could be ready to use in a national status and trends assessment in the near term (Section 2.4.1) and (2) were aligned with national and state conservation priorities (Section 2.4.2).

2.4.1 Readiness Assessment

Using the five attributes (Section 2.3), we identified a subset of datasets as ready to go, defined as those datasets that could be ready to use in a national status and trends assessment within the next 12 months. All ready-to-go datasets have high or moderate suitability for geographic extent, spatial resolution, and level of preparation:

4. https://www.epa.gov/eco-research/final-ecosystem-goods-and-services-fegs-glossary-terms

- Geographic extent: Data are or could be ready for at least the conterminous US (ideally the entire US and territories).
- Spatial resolution: Data are or could be ready at the county scale or finer.
- Level of preparation required: Data are or could be ready to use within 12 months, allowing for simple data preparation (e.g., extending an analysis to new geographic areas using existing datasets, overlaying multiple datasets), but not intensive modeling.

The final criterion for identifying ready-to-go datasets was the dataset's ability to quantify a benefit (Table 2). Ideally, all ready-to-go datasets quantify a final benefit. For benefits that do not have any datasets quantifying a final benefit, we considered datasets that identify the area of NWL providing the benefit to be ready to go if they met the other criteria. Update frequency was not considered in the readiness assessment because virtually all of the datasets could be updated for use in a trend assessment given sufficient funding.

2.4.2 Benefit Importance

We assessed each benefit's importance through a review of documents published by state and federal government decision makers (including the federal America the Beautiful initiative and several state and regional 30x30 initiatives), looking for alignment with the natural and working lands conservation priorities outlined in these documents.[5]

2.5 FILTERS FOR SUMMARIZING BENEFITS DATA

During the workshop, we generated a list of data filters that could be used to categorize the benefits data into subsets—representing benefits within a defined geographic area—to make the data more relevant to different user groups and stakeholders by providing multiple ways to view and summarize the data for communication and analysis. For example, a dataset quantifying timber harvest in the US could be summarized with a state filter to show timber harvest in North Carolina, or with an ownership filter to show timber harvest from public lands. In some cases, multiple datasets may need to be combined to define a filter. For example, the "protected working lands with high biodiversity or ecological resilience value" filter could be defined by combining a dataset that identifies protected working lands with a dataset that identifies areas with high biodiversity or ecological resilience value. In the filters section of the database, there is a column that flags filters that may require a combination of datasets, and a column with notes on which aspect of the filter each dataset could inform.

We classified each filter dataset by its geographic extent, spatial resolution, level of preparation required, and information provided (see Appendix C, Tables C1 and C2).

5. https://www.doi.gov/sites/doi.gov/files/report-conserving-and-restoring-america-the-beautiful-2021.pdf; https://togetherbayarea.org/wp-content/uploads/2021/08/Land_Conservation_Advisory_Panel_Summary_v3_508.pdf; https://www.ilga.gov/legislation/publicacts/fulltext.asp?Name=102-0618; http://www.legislature.mi.gov/documents/2021-2022/resolutionintroduced/House/pdf/2021-HIR-0025.pdf; https://www.leg.state.nv.us/App/NELIS/REL/81st2021/Bill/7487/Text; https://www.governor.state.nm.us/wp-content/uploads/2021/08/Executive-Order-2021-052.pdf; https://legislation.nysenate.gov/pdf/bills/2021/S6191; https://www.dcr.virginia.gov/conservevirginia/; https://www.chesapeakeconservancy.org/2020/10/09/chesapeake-bay-30-x-30-conserving-30-of-the-chesapeake-bay-watersheds-lands-by-2030/

3. Findings

3.1 CONSIDERATIONS FOR BENEFITS DATASET USE IN A NATIONAL ASSESSMENT

The expert workshop explored several recurrent themes that merit consideration as datasets are selected for use in a national NWL benefits assessment. These included (1) the importance of focusing on final benefits to people, (2) being comprehensive in dataset inclusion while prioritizing datasets for near-term use, and (3) the need for ongoing funding to keep the assessment up to date.

3.1.1 Focus on Final Benefits to People

Many of the datasets reviewed quantify intermediate ecosystem services supplied by NWL, rather than final benefits used or enjoyed by people (Table 2). For example, the amount of sediments or nutrients prevented from entering a water source by NWL represent intermediate services. Related final benefits would be the amount of additional energy provided by a hydropower dam due to sediment prevented from entering a reservoir as a result of capture by NWL, or the avoided treatment costs by a municipality due to reduced nutrients entering the drinking water supply as a result of filtration by NWL. Workshop participants indicated that information quantifying final benefits to people would be most informative for a national assessment. As described above, when a benefit did not have a ready-to-go dataset quantifying the final benefit, we included datasets specifying the area contributing to the benefit to allow the benefit to be included in an initial assessment. However, datasets quantifying final benefits were prioritized and marked as such in the database.

The concept of servicesheds[6] was also raised at the workshop as a way to understand how changes in NWL benefits affect people. A serviceshed encompasses the extent of the area where a particular benefit is produced and where it is accessed, used, or impacts people. Servicesheds vary by benefit. For example, the serviceshed for the benefit of "fire risk reduction due to fuels management" represents both the area where fuels management takes place as well as the surrounding areas where fire risk is significantly reduced due to that management. Servicesheds can only be delineated for final benefits because they require understanding who is benefitting from the service and where that benefit is being accessed. Many of the final benefits datasets implicitly identify the serviceshed; however, for some it is not fully defined. Having a clearly delineated serviceshed will result in a better understanding of how NWL impact people. The "serviceshed" column in the database describes how datasets that quantify a final benefit or identify areas providing a final benefit characterize the serviceshed.

3.1.2 Be Comprehensive

Workshop participants recommended the project compile and assess a comprehensive set of datasets for each benefit. Individual datasets can be limited in that they capture different important facets of a particular benefit. In combination, the datasets may capture a fuller picture. It is important to note that the ready-to-go datasets often do not capture all facets of each benefit. There are likely other datasets that could complement, or even in some cases replace, the ready-to-go datasets to more fully capture useful information, but these datasets require additional work before they would be ready to use. See Next Steps Section 4.2 for details.

6. Tallis, H., et al. 2015. "Mitigation for One and All: An Integrated Framework for Mitigation of Development Impacts on Biodiversity and Ecosystem Services." *Environmental Impact Assessment Review* 55: 21–34.

3.1.3 Prioritize

The workshop participants recommended that we select a priority set of datasets that could be used for NWL status and trends assessments. To do so, we conducted an initial assessment of both *readiness* of the data for inclusion (Section 2.4.1) and *importance* of the benefits to national and state conservation initiatives (Section 2.4.2). Dataset prioritization for future assessments would depend on the planned uses for the data and end-user interests and needs.

3.1.4 Ongoing Funding Will Be Needed

Workshop participants noted that datasets used for status and trends assessments would need to have dedicated funding available for continual data updates and a process for integrating updated and improved data over time.

3.2 BENEFITS DATASETS PRIORITIZED FOR A NATIONAL ASSESSMENT

We reviewed and scored 137 datasets as discussed in Section 2. The full list with attribute ratings and readiness assessment scores is included in the database. Appendix D contains data summaries describing available datasets for each benefit, limitations, and areas for future work.

3.2.1 Ready-to-Go Datasets

We identified 37 ready-to go-datasets, including 19 datasets that quantify a final benefit and 17 datasets that identify areas of NWL contributing to a benefit (Table 3). While all NWL benefits discussed during the workshop have at least one ready-to-go dataset, four benefits (flood risk reduction, fire risk reduction, water quantity, and water quality) only have ready-to-go datasets identifying the area contributing to a benefit. Almost all of the ready-to-go datasets are publicly available, but a few need to be requested from researchers.

The US National Greenhouse Gas Inventory (NGGI), which quantifies greenhouse gas fluxes or carbon stocks in NWL, was also considered ready to go, even though these are intermediate services that quantify the supply of a benefit by NWL, not its use or value to people. Because greenhouse gas fluxes and carbon storage create a variety of benefits related to climate stabilization that affect people globally, it is not feasible to quantify these final benefits. Greenhouse gas fluxes and carbon stocks are commonly used to assess progress toward climate goals, including for international greenhouse gas reporting. There are many other datasets included in the database that quantify greenhouse gas fluxes or carbon stocks in certain subsets of NWL. Workshop participants supported recommending only the NGGI data for a national assessment because they are continually updated, supported by the US government, and incorporate authoritative data such as US Forest Service's (USFS) Forest Inventory Analysis. The NGGI team is also working to incorporate the entire system of greenhouse gas fluxes from natural and working lands into its inventory, including transitions between carbon pools and habitat types.

Table 3 describes which facets of each benefit are covered by the ready-to-go datasets, and notes what needs to be done to prepare the data for use in a national status and trends assessment. It should be noted that just because a certain dataset is in the ready-to-go category doesn't mean that there aren't ways to improve those data or models. While most ready-to-go datasets are available for multiple time points, several are only available for a single time point and therefore would only be able to provide information about the status, and not the trend, of the benefit in an initial assessment. In addition, there may be datasets that would be better suited for a national assessment, but require significant additional work to

use (see Section 4.2). The data summary for each benefit (Appendix D) describes limitations and areas for improvement in the ready-to-go datasets, and opportunities for future work on datasets that are not yet ready to go.

3.2.2 Dataset Importance

In assessing alignment with federal and state conservation initiatives we observed several themes. The America the Beautiful report raises three target areas for conservation action: biodiversity, climate change mitigation and resilience, and equitable access to nature's benefits. State 30x30 initiatives vary across states in their areas of focus, but common threads include (1) protection of biodiversity and habitats, (2) climate change mitigation and resilience to climate change risks such as flooding and fires, and (3) public access to nature and outdoor recreation. Several states also emphasize economic importance and the need for cultural and historic preservation. Some states without 30x30 initiatives have plans for natural and working lands management with goals similar to those of the state 30x30 initiatives described above.[7] Almost all of the natural and working land benefits included in this project were highlighted by at least one federal or state 30x30 initiatives. The emphasis on equitable access to nature's benefits in the federal 30x30 initiatives cuts across the 13 benefits considered in this report, including all regulating services (e.g., water quality improvement) and cultural services (e.g., recreation). Therefore, we retained all 13 benefits (Box 1) as potentially aligned with state or national priorities.

7. https://deq.nc.gov/media/17743/download

Table 3. Ready-to-go datasets, grouped by benefit

Benefit	Dataset(s) [ID #]	What facet of the benefit can be mapped using ready-to-go datasets [metric with units]	Ability to quantify a benefit[8]	Multiple time points available?	What, if anything, needs to be done in next 12 months
Air quality and human health	i-Tree Landscape (USFS) [64], Avoided health impacts due to pollutant removal by tree cover (EnviroAtlas) [66, 67]	Avoided health impacts due to pollutant removal by trees [cases avoided/year], value of avoided health impacts due to pollutant removal by trees [avoided health spending, $/year]	Final benefit (with value)	Yes, 2011 and 2020 (will be available soon based on new Census data)	Need to acquire data for multiple years from researchers; may want to run with different benefit models (pollutant to health impact).
Biodiversity	Map of Biodiversity Importance (NatureServe) [2,3,119]	Total imperiled (ESA threatened or endangered and NatureServe G1 or G2 species) species richness [number of imperiled species], rarity-weighted imperiled species richness [index incorporating number of imperiled species and the total range size of each species]	Final benefit[9]	No	
	Resilient and Connected Networks—high biodiversity areas (TNC) [1]	NWL with rare species and habitats [area]	Area providing benefit	No	
	Resilient and Connected Networks—resilient areas, climate corridors and flow zones (TNC) [27, 30], Climate Refugia and Corridors (Dreiss et al. 2022) [28, 31], AFT ecological flow map [6], freshwater resilience [32], Resilient Coastal Sites (TNC) [122]	NWL with high resilience to sustain biodiversity with climate change and serving as corridors for species movement in response to climate change [area]	Area providing benefit	No	Overlay with imperiled species richness data to quantify imperiled species richness in areas likely to be resilient to climate change

8. See Table 2 for descriptions and examples.
9. Biodiversity is considered a final benefit due to the existence value of imperiled species. Biodiversity is also an intermediate service supporting many other benefits.

Energy conservation	Heat mitigation by urban trees (Heris et al. 2021) [69]	Avoided spending on cooling costs due to temperature reduction by urban trees [$/year]	Final benefit (with value)	Yes, 2011 and 2016	Adapt model to estimate the avoided spending on cooling costs due to marginal change in urban trees and green space, rather than the additional cooling costs with no urban trees or green space
Energy production	Power plants in the US (EIA) [70], US Wind Turbine Database (USGS) [75]	Solar, wind (including offshore wind), hydropower, and geothermal energy generation capacity [energy generation capacity, MW/year]	Final benefit	Yes, annual 2001-2020	Need to summarize energy generation capacity for each renewable energy source at desired level of aggregation
Fire risk reduction	USFS Hazardous Fuel Treatment (USFS) [49], Fireshed Registry (USFS) [120]	NWL treated for fire risk reduction on USFS lands [area]	Area providing benefit	Yes, annual [49]	Overlay with firesheds to identify areas with lower fire risk due to treatment
Flood risk reduction	NWL in high flood risk watersheds in NC (Duke University) [33], combined with reduction in annual runoff due to tree cover [35, 62], flood vulnerability reduction by freshwater wetlands (Bousquin and Hychka 2019) [134]	NWL in high flood risk watersheds [area], annual runoff reduction due to trees in high flood risk watersheds [avoided runoff, million gallons/ year], population at risk of flooding in high flood risk watersheds [number of people]	Area providing benefit [areas can be ranked based on % wetlands, avoided runoff, and/ or population at risk of flooding]	NWL in high flood risk watersheds: Yes, multiple time points can be created based on land cover data (NLCD available for 8 time points between 2001 and 2019) Avoided runoff reduction due to trees in high flood risk watersheds: No Population at risk of flooding: Yes, based on Census population data (decadal)	High flood risk analysis needs to be extended to rest of US; high flood risk watersheds need to be overlaid with annual runoff reduction dataset
Food	New pollination model (Heris 2022) [86]	Value of crops created by wild pollinators [crop sales, $/year]	Final benefit (with value)	Yes, available for 2008, 2011, 2014, 2017, 2020	NA once data are released (planned for June 2022)
Forest products	FIA Timber Products Output (USFS) [95]	Timber harvested from all forests (public and private) [timber harvested, green tons]	Final benefit	Yes, annual 1993-2020	NA

Greenhouse gas fluxes and carbon stocks	National Greenhouse Gas Inventory (EPA) [7]	Net GHG fluxes (sequestration and emissions) and carbon stocks from forests, agriculture, and coastal wetlands [metric tons CO_2e]	Intermediate service[10]	Yes, annual 1990-2020	Need to acquire data at desired level of aggregation from researchers.
Jobs	Quarterly Census of Employment and Wages (BLS) [108], Employment by NAICS industry (BEA) [104], County business patterns (US Census Bureau) [110]	Employment in forestry, agriculture, and commercial fishing by NAICS code [number of workers]	Final benefit	Yes, BLS data updated quarterly (2017-2021), BEA (1929-2020) and Census data (1986-2019) updated annually	NA
Recreation	National Visitor Use Monitoring Program (USFS), National Park Service Visitor Use Statistics (NPS), Banking on Nature (USFWS), Public Land Statistics Report (BLM) [99-102]	Visitors to federal public lands for a wide range of recreational activities (e.g., hiking, boating, hunting, bicycling, various types of camping) [number of visitors]. Types of recreation specified varies by federal agency (see database for details).	Final benefit	Yes, NPS data updated monthly, BLM and FS data annually, FWS data every 5-6 years.	Datasets need to be combined
	Recreational birding in the southeast US (Warnell 2019) [97]	Number of recreational birding days [number of person-days of birding activity]	Final benefit	Yes, available for 2001, 2006, 2011, 2016 (for southeast). Could be generated annually.	National Survey on Fishing, Hunting, and Wildlife-Associated Recreation needs to be updated, ideally with state-level results. Analysis needs to be extended nationally using NSFHWAR data and eBird observations.
	ParkServe (Trust for Public Lands) [98]	Publicly accessible open space (public and private) in Census-defined urban areas [area]	Area providing benefit	Yes, available for 2020 and 2021	Needs to be summarized at desired level of aggregation

10. The data for greenhouse gas fluxes and carbon stocks are the only ready-to-go datasets quantifying an intermediate service. Removal of greenhouse gases from the atmosphere and long-term carbon storage in NWL creates a variety of benefits for people all over the world related to avoided global climate change and associated risks. It is not feasible to quantify all of these benefits, so the intermediate service included here should be sufficient for a national assessment.

Water quality	Forests to Faucets (USFS) [131]	Important watersheds for production of clean drinking water, based on land cover and water yield, potential threats to surface drinking water from insects and disease, wildfire, climate change, and land use change [area]	Area providing benefit	Yes, 2011 and 2020	Set threshold for identifying watersheds important for producing clean drinking water
Water quantity	Forests to Faucets (USFS) [50]	Important watersheds for surface drinking water provision, based on water yield and number of water supply consumers [area]	Area providing benefit	Yes, 2011 and 2020	Set threshold for identifying watersheds important for drinking water provision

Note: Rows with dark green shading indicate datasets that quantify the benefit of NWL to people; rows with light green shading indicate datasets that identify the area of NWL likely to provide the benefit. For more information about each dataset in the table, including its ratings for individual criteria used in the readiness assessment, see the database.

3.3 DATA FILTERS FOR SUMMARIZING BENEFITS DATA

The project team and workshop participants identified 25 data filter ideas (Table 4) that provide multiple ways to view and summarize spatial benefits data for communication and analysis. Filters were categorized as (1) jurisdictional; (2) land ownership, designation, and use; (3) watersheds; (4) management; and (5) benefit delivery (Table 4). The filter ideas in Table 4 are not meant to be comprehensive of all possible filters, rather they are meant to document those filters that the project team and workshop participants felt would be a useful starting point to summarize benefits data. Workshop participants also indicated that it could be helpful if a future assessment tool allowed users to define and create their own filters to apply to the benefits data. This could be especially useful for filters that are more subjectively defined, such as high-quality agricultural lands, where individual users could have different definitions of "high-quality" for their context.

Data filter ideas shown in **bold text** are straightforward to define and have obvious, ready-to-use data sources. Data filter ideas that are defined subjectively (e.g., high-quality grazing lands, protected working lands with high biodiversity value) or that do not have authoritative and ready-to-use data sources appear in normal text. While we included datasets that could be used to define these filters in the database, these are not definitive. Finally, a few filter ideas (shown in italicized text) were added at the workshop and have yet to have a thorough dataset search completed.

A list of datasets that could be used to create these data filters is included in the database. Summaries of filter datasets can be found in Appendix E.

Table 4. Ideas for filters to summarize the benefits data

Filter category	Filters
Jurisdictional	States
	Counties/parishes
	Census tracts and blocks
Land ownership, designation, use, and ecosystem type	**Federal land (by type)**
	State land (by type)
	Private land
	Tribal lands (**current** and pre-1690)
	Designations (e.g., under a habitat conservation plan, non-attainment zones, zoning categories)
	Land use/land cover
	Ecoregion
	Land with high/moderate/low human modification
	Threats/risks (threats to environment, threats to people, climate threats, probability of future development)
Watersheds	**USGS watershed boundaries**
	Critical watershed areas

Management status	• **IPCC managed/unmanaged land** • Forests managed for timber production • Certified forests • High-quality grazing lands • High-quality agricultural lands • Working lands managed for conservation • 30x30 conserved land (once 30x30 lands are defined) • Activities from project databases (restoration projects, green/blue infrastructure, stream and wetland mitigation) • Protected working lands with high biodiversity or ecological resilience value
Benefit delivery	• Underserved communities • *Lands serving communities who are underserved in terms of a particular benefit (e.g., NWL providing filtration benefits to municipalities with high concentrations of sediment in their drinking water sources)*

Note: Filters shown in bold are easily defined by available data, filters shown in normal text require further discussion to define or develop data sources, and filters shown in italics were suggested during the workshop and do not have identified datasets.

3.4 DATA GAPS AND LIMITATIONS

Gaps and limitations specific to a particular benefit or filter dataset can be found in the data descriptions in Appendices 4 and 5, respectively. Overarching gaps and limitations identified by the project team and raised through workshop discussions are highlighted here.

3.4.1 Most Data Are Limited to the Conterminous United States

First, the majority of identified datasets do not cover the entire United States—even many "national" datasets are limited to the conterminous US. This excludes Alaska, Hawaii, and US territories, which contain large areas of NWL and provide significant benefits related to carbon storage, biodiversity, and cultural benefits. Alaska contains more than half of the US NWL carbon stock[11], and climate change is expected to have substantial impacts on carbon fluxes in Alaskan habitats. Islands such as Hawaii and US territories are global hotspots for biodiversity, and this biodiversity is at risk in part due to the islands' small land mass and isolation.[12] (Hawaii has by far the highest number of listed species of US states.[13]) Hawaii and Alaska are also important destinations for recreation; they are two of the top five states in terms of the percentage of their GDP supported by the outdoor recreation industry.[14] Given the unique benefits provided by NWL in Alaska, Hawaii, and US territories, their exclusion is a significant limitation on our ability to track the status and trends of NWL benefits on a national scale.

11. https://www.usgs.gov/news/national-news-release/usgs-assesses-carbon-potential-alaska-lands
12. https://www.sciencedirect.com/science/article/pii/S2351989421003978
13. https://ecos.fws.gov/ecp/report/species-listings-by-state-totals?statusCategory=Listed
14. https://www.bea.gov/system/files/orsa1121.png

3.4.2 Dataset Updates and Modifications

Continual improvement of existing datasets and generation of new datasets related to NWL benefits pose another challenge to any product created to track benefits over time, as changes to dataset methodology can disrupt a consistent time series and obscure changes occurring in the benefits provided. A process would be needed to allow continued assessment of status and trends over time as data and methods are updated, such as:

- Recalculating the historic data with the updated methodology so the entire time series of status and trends uses the new method. For example, when USGS recently updated the methodology for the National Land Cover Dataset, it re-released the full time series of land cover datasets back to 2001.[15] This approach is likely more appropriate for datasets generated from remotely sensed data for which the raw data remains consistent, and the new methodology can be applied to the older raw data.
- Generating the old and new datasets for several years in tandem (often called benchmarking). The overlapping period of data would be used to calibrate the older data to align it with the new data, allowing data collected before the benchmarking period to be converted to estimates comparable to the new data. NOAA has used this approach to transition several of their fishing surveys to new methods.[16]

3.4.3 Equity of Access to Benefits

Equity of access to the benefits provided by NWL is emphasized in the America the Beautiful report and several state 30x30 initiatives. Assessing equity of access to benefits, and tracking changes in equitable access over time, is possible by overlaying socioeconomic and demographic data on the servicesheds for individual benefits (the areas in which people or communities have access to the benefit). This allows evaluation of areas with low benefit provision and their overlap with other inequities, such as impoverished communities. However, servicesheds are not well defined for all benefits, and socioeconomic and demographic data are often available at coarser resolution (such as Census tracts) than service provision occurs. This limits our understanding of benefit equity and our ability to identify and address inequities.

3.4.4 Benefits That Are Missing Data

Benefits identified during the workshop that did not have datasets at the national or large region (e.g., multistate) scale include human health benefits of greenspace exposure, pest and disease regulation, and cultural ecosystem services.

Human Health Benefits of Greenspace Exposure

While it is understood that greenspace exposure can have beneficial impacts on physical aspects of human health,[17] we do not know of any datasets that capture these benefits nationally or that could be scaled to do so.

15. https://www.mrlc.gov/
16. https://www.fisheries.noaa.gov/recreational-fishing-data/marine-recreational-information-program-research#calibrating-new-and-historical-catch-estimates
17. Kondo, Michelle C., et al. "Urban green space and its impact on human health." International journal of environmental research and public health 15.3 (2018): 445; Zhang, Lin, et al. "Impacts of individual daily greenspace exposure on health based on individual activity space and structural equation modeling." *International journal of environmental research and public health* 15.10 (2018): 2323.

Pest and Disease Regulation

Pest and disease regulation is a known benefit provided by NWL, and one whose importance has been highlighted by the COVID-19 pandemic.[18] However, we do not know of any datasets that are able to track status and trends of this benefit at a national scale.

Cultural Ecosystem Services

It is inherently difficult to collect standardized data and map cultural ecosystem services because these benefits are nontangible and value based by definition.[19] Cultural services are typically locally specific and can differ between stakeholder groups. In some cases, people object to quantifying cultural services because they feel the data can never truly capture the nuance of the value that these types of services provide. The database includes a single cultural ecosystem service benefit: recreation. While important, recreation does not represent the variety of cultural ecosystem services valued by people across the US Cultural ecosystem services, while difficult to measure, are often the benefits provided by NWL that people find most meaningful and can be integral to people's sense of place, spirituality, mental health, or culture.[20] We do not want to deemphasize the significance of these benefits provided by NWL, but currently do not have the data to track status and trends of these benefits at a national scale.

18. Lawler, Odette K., et al. "The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health." *The Lancet Planetary Health* 5.11 (2021): e840-e850; Alexandridis, N. et al. "Models of natural pest control: Towards predictions across agricultural landscapes." *Biological Control* 163 (2021). https://www.sciencedirect.com/science/article/pii/S1049964421002309

19. Daniel, Terry C., et al. "Contributions of cultural services to the ecosystem services agenda." *Proceedings of the National Academy of Sciences* 109.23 (2012): 8812-8819; Milcu, Andra Ioana, et al. "Cultural ecosystem services: a literature review and prospects for future research." *Ecology and society* 18.3 (2013).

20. Hirons, Mark, Claudia Comberti, and Robert Dunford. "Valuing cultural ecosystem services." *Annual Review of Environment and Resources* 41 (2016): 545–574.

4. Next Steps

4.1 STEPS FOR A NEAR-TERM STATUS AND TRENDS ASSESSMENT

A complete status and trends assessment that includes every benefit is not possible in the near term, given gaps in the data. However, there are enough benefits datasets that meet criteria for use in the near term to begin assessing status and trends. To produce an initial national status and trends assessment of benefits provided by NWL in the next 12 months, a few things would need to occur.

First, the benefits to be included in an assessment would need to be selected. Workshop participants urged the project team to develop a priority list of benefits datasets for inclusion in an initial status and trends assessment of NWL benefits. In response, we suggested a prioritization process that considers both dataset *readiness* for use in the next 12 months (Section 3.2.1), as well as *importance* of the benefits that the datasets represent (Section 3.2.2). Any future status and trends assessment effort would need to agree upon and formalize a prioritization process, which could build upon the one we have laid out in this report. For example, individual federal agencies may want to identify which benefits would be most valuable for them to include in a national assessment.

Second, once benefits were selected for inclusion, the next step would be to prepare the datasets for use in a status and trends assessment. Preparation would include activities such as acquiring data from a researcher, aggregating the data at a different scale, or overlaying multiple datasets to obtain a more useful metric. The last column of Table 3 identifies what, if any, work would need to be done to prepare each dataset for use in the near term.

Third, uncertainty and validation information should be assessed for datasets selected for inclusion and an approach should be developed to make this information available in the assessment, in order to facilitate appropriate use and interpretation of the assessment.

Fourth, resources would need to be identified to keep datasets included in the assessments up to date. While most of the ready-to-go datasets are available for multiple time points, several are only available for a single time point, such that they provide information about the status of the benefit, but not its trend over time. Allocating resources to update these datasets would allow the addition of trend information in future assessments.

4.2 WORK REQUIRED TO QUANTIFY ADDITIONAL FACETS OF NWL BENEFITS

While each NWL benefit discussed during the workshop has at least one dataset that could be used in a national status and trends assessment in the next 12 months, these ready-to-go datasets do not address all facets of the benefits. Some benefits would need new datasets to capture all facets. Still other benefits could be more fully described with additional work to existing datasets as summarized in Table 5 and described in more detail in the benefits data summaries in Appendix D.

Table 5. Additional work required to create datasets for facets of benefits that currently do not have ready-to-go datasets

Benefit	Additional work required
Biodiversity	Map additional types of biodiversity (phylogenetic, functional) at higher resolutions.
Energy production	Run an existing wind power production model to estimate actual energy generation (rather than capacity) by existing wind turbines. Develop new methods to link biomass energy and biofuel production to NWL supplying feedstocks.
Fire risk reduction	Run high-resolution fire hazard models with NWL fuel management actions to quantify the effect of these actions on fire hazards and damage
Flood risk reduction	Run high-resolution flood hazard models with and without NWL vegetation to quantify NWL effects on flood hazards and damage.
Food	Develop methods to estimate the value of crop and livestock production attributed to NWL soil and vegetation resources (separate from anthropogenic inputs). Develop new data sources and methods for quantifying subsistence hunting activity.
Forest products	Develop methods to link end products back to the NWL from which the timber was harvested.
GHG fluxes and carbon stocks	Incorporate additional field data to improve estimates of grassland carbon fluxes, methane emissions from natural and working lands, and effects of management on greenhouse gas fluxes.
Jobs	Apply BEA methods for outdoor recreation satellite accounts at smaller scales to quantify employment supported by outdoor recreation. Develop methods for estimating employment from NWL restoration and management using existing employment data.
Recreation	Develop methods to use human mobility data to consistently assess recreational use of all NWL, being mindful of privacy issues.
Water quality	Develop methods to connect NWL retention of pollutants to enhanced suitability of water for final use or reduced treatment cost due to improved water quality
Water quantity	Develop methods to connect water use (for agriculture, industry, domestic, etc.) back to the NWL providing the water.

APPENDIX A. EXPERTS ENGAGED PRE-WORKSHOP

Renee Albrecht, *Defenders of Wildlife*

Jeff Allenby, *Lincoln Institute for Land Policy*

Mila Alvarez Ibanez, *USFS*

Emily Anderson, *SFI*

Ken Bagstad, *USGS*

Lisa Beers, *Silvestrum*

Naanibah Begay, *Defenders of Wildlife*

Andrew Bowman, *Land Trust Alliance*

Renate Bush, *USFS*

Brett Butler, *USFS*

Andrew Carter, *Defenders of Wildlife*

Roger Claassen, *USDA NRCS*

Anne Clawson, *NAFO*

Jennifer Conje, *USFS*

Steve Crooks, *Silvestrum*

Jimmy Daukas, *American Farmland Trust*

Steve DelGrosso, *USDA ARS*

Grant Domke, *USFS*

Tyler Erickson, *Google*

Mike Evans, *Defenders of Wildlife*

Lori Faeth, *Land Trust Alliance*

Joe Fargione, *The Nature Conservancy*

Tim Foley, *Southern Group of State Foresters*

Artis Freye, *Land Trust Alliance*

Suzy Friedman, *NAFO*

Keith Gaddis, *NASA*

Nicole Gentile, *Center for American Progress*

Monica Goldberg, *Defenders of Wildlife*

Josh Goldstein, *The Nature Conservancy*

Wes Hanson, *USDA*

Chris Hartley, *USDA*

Linda Heath, *USFS*

Erin Heskett, *Land Trust Alliance*

Jimmy Kagan, *Oregon State (retired)*

Jake Leizear, *Chesapeake Conservancy*

Kavita Macleod, *Environmental Policy Innovation Center*

Jacob Malcom, *Defenders of Wildlife*

Tim Male, *Environmental Policy Innovation Center*

C. Martin, *USFS*

Susan Minnemeyer, *Chesapeake Conservation Innovation Center*

Bianca Moebius-Clune, *American Farmland Trust*

Siddharth Narayan, *East Carolina University*

Anne Neale, *EPA*

Jessie Norriss, *Environmental Policy Innovation Center*

David Nowak, *USFS*

Clint Otto, *USGS*

Mary Pfaffko, *Defenders of Wildlife*

Sheila Reddy, *The Nature Conservancy*

Guy Robertson, *USFS*

Lindsay Rosa, *Defenders of Wildlife*

David Saah, *University of San Francisco*

Mindy Selman, *USDA ARS*

Darren Sleep, *SFI*

Regan Smyth, *NatureServe*

Terry Sohl, *USGS*

Ann Sorensen, *American Farmland Trust*

Shelby Swizer, *US Digital Service*

Dave Theobald, *Conservation Planning Technologies*

Wayne Thogmartin, *USGS*

Casey Thornbrugh, *SE and NE CASC*

Paul Trianoski, *SFI*

Woody Turner, *NASA*

Dean Urban, *Duke University*

Leo Viana, *SFI*

Sara Ward, *US Fish and Wildlife Service*

Katie Walker, *Chesapeake Conservancy*

Chris Woodall, *USFS*

APPENDIX B. WORKSHOP PARTICIPANTS

Anne Neale, *EPA*

Bill Salas, *Regrow Ag*

Chris Hartley, *USDA*

Christopher Woodall, *USFS*

Daniel Mullarkey, *USDA*

Darren Sleep, *SFI*

David Saah, *UCSF*

Emily Frances McGlynn, *UC Davis*

Emily Pindilli, *USGS*

Frank Casey, *USGS*

James Holmquist, *Smithsonian*

Jeff Allenby, *Lincoln Institute of Land Policy*

Jimmy Kagan, *OSU*

Joe Fargione, *The Nature Conservancy*

John Fay, *Duke*

Kenneth Bagstad, *USGS*

Kristin Sleeper, *NAFO*

Lindsay Rosa, *Defenders of Wildlife*

Lisa Beers, *Silvestrum*

Mark Anderson, *The Nature Conservancy*

Mark Wiltermuth, *USGS*

Meri Holm, *USFWS*

Molly McCormick, *USGS*

Phil van Mantgem, *USGS*

Rebecca Chaplin-Kramer, *Stanford*

Sarah Carter, *USGS*

Steve Crooks, *Silvestrum*

Steve Delgrosso, *USDA*

Suzy Friedman, *NAFO*

Andreas Moshogianis, *USFWS*

Karyn Vandervoort, *DOT*

Wes Hanson, *USDA*

APPENDIX C. ATTRIBUTE DETAILS FOR BENEFIT AND FILTER DATASET EVALUATION

Each benefits dataset included in the database was categorized using a set of five attributes to better understand that dataset's readiness to track the status and trends of the benefit in the near term. Datasets were scored high, moderate, or low for each attribute as detailed in Table C1, except for the "ability to quantify a benefit" attribute that did not fit neatly into this scoring system. Instead the "ability to quantify a benefit" attribute was categorized as described in the main text (Table 2). See the database for attribute rankings for each dataset.

Table C1. Attributes used to evaluate dataset suitability for tracking status and trends of NWL benefits

	Suitability for tracking status and trends of NWL benefits		
Attributes	**High**	**Moderate**	**Low**
Geographic extent	National (including AK and HI)	Conterminous US only, or national but only covers a subset of land (e.g., USFS lands)	Regional- or state-level, but could be extended
Spatial resolution	Raster, point, or polygon data; not aggregated	Aggregated to relatively small spatial unit (county, Census tract or block group, HUC-12, park boundary)	Aggregated to larger spatial unit (state, multistate region)
Update frequency	Has been updated regularly in the past (if applicable) and plans to update regularly in the future	Has been updated regularly in the past (if applicable); future updates not currently planned, planned at irregular intervals as needed, or unknown	One-off dataset (e.g., created as part of a research paper) with no past updates; future updates not currently planned or unknown
Level of preparation required	None; dataset is ready to use	Some data preparation is required (e.g., combining multiple datasets, acquiring data from researchers, selecting a subset of the dataset such as species of interest, or defining assumptions)	Extensive data preparation is required (e.g., running a model, cleaning/processing raw data)

Filter datasets were also classified as having high, moderate, or low suitability using the attributes in Table C1. They were also ranked on the additional "information provided" attribute discussed in Table C2.

Table C2. Description of the "information provided" attribute for evaluating the suitability of datasets for defining filters

	Suitability for defining filter for NWL benefits data		
Attribute	**High**	**Moderate**	**Low**
Information provided	Information provided is directly related to the filter definition and identifies specific areas.	Information provided is not directly related to the filter definition, but could be used as a proxy, and identifies specific areas.	Information provided does not identify specific areas that meet the filter definition. For example, it may provide the area of forest managed for timber within a county, rather than identifying the forests that are managed for timber.

APPENDIX D. BENEFITS DATA SUMMARIES

APPENDIX D. CONTENTS

The benefits data summaries below include (1) a short definition of the benefit; (2) a description of the ready-to-go datasets for that benefit, including the serviceshed encompassing the area where the benefit is accessed or used (if applicable); (3) a description of models that could be used to quantify the benefit; and (4) a description of datasets that need additional work to achieve ready-to-go status and more fully describe the benefit. More detailed information about each dataset mentioned (in blue text with ID # in brackets) in the summaries can be found in the database.

Air Quality and Human Health

Vegetation on NWL traps and reduces the concentration of air pollutants that adversely affect human health. This causes people nearby to be exposed to lower concentrations of pollutants and experience fewer health impacts. Vegetation has very localized effects on air quality and health, so the people benefiting from improved air quality must be co-located with the NWL providing the service.

Ready to Go

The USFS i-Tree Landscape [63-64] tool estimates both the amount of air pollutants removed by trees and the value of avoided health impacts due to air pollutant removal. The models underlying i-Tree combine data on pollutant concentrations, weather, and leaf area to estimate pollutant removal and use health effect information from the EPA's BenMAP tool. While these estimates are provided at relatively fine scales (Census block groups or counties), they are only updated every 10 years to align with Census data releases, which update the population data underlying the health effect estimates.

EnviroAtlas [66, 67] also has estimates of (1) air pollutants removed by trees, (2) avoided health impacts due to pollutant removal, and (3) value of avoided hospital admissions due to pollutant removal. These estimates were developed using the same underlying models as i-Tree Landscape, but used one-meter land cover data to generate higher-resolution estimates, which were then summarized to the Census block group level. These data are only available for 2020 in EnviroAtlas communities (30 urbanized areas containing more than 1,400 cities and towns); future updates depend on interest and resources.

Additional Work Required

There are sophisticated models such as InMAP [68] that can be used to quantify health effects of air pollution at fine scales but do not include air pollutant removal by vegetation. It may be possible to integrate components of the i-Tree models with a more sophisticated health effects model to generate more timely and higher-resolution estimates.

Biodiversity

Biodiversity refers to the variety of life supported within a certain area; species diversity is a frequently used proxy for biodiversity, but it can also incorporate genetic diversity and diversity of functional types of species. While biodiversity supports many other ecosystem services, it can also be considered a final benefit in itself, especially for existence value of at-risk or rare species. Because existence value does not require direct interaction between people and the valued species, we assume that biodiversity benefits all people, and no specific serviceshed is defined for this service.

Ready to Go

NatureServe's Map of Biodiversity Importance is a set of related biodiversity datasets derived from predicted distributions of more than 2,200 species. The summed range-size rarity of imperiled species [2] dataset, which incorporates information about the total number of imperiled species (species listed as threatened or endangered under the Endangered Species Act and species classified as G1 or G2 on NatureServe's global conservation status) in an area and the total range size of each species, quantifies the importance of specific areas for supporting the persistence of at-risk species. Several experts indicated that they would select this dataset if they had to choose just one to represent importance of different areas to biodiversity. The underlying total imperiled species richness dataset [119] may be useful for communication because it uses a more intuitive metric (number of imperiled species, rather than an index incorporating the total range size of each species). Both NatureServe datasets have nested datasets for individual species groups that may be useful for a national assessment. Another derivative, a protection-weighted version of the range-size rarity dataset [3] covers areas that are not currently protected, so may be useful for conservation planning. The NatureServe datasets combine information on individual species distributions to generate composite indices of biodiversity that can be difficult to interpret for specific areas. NatureServe plans to update these datasets every three to five years, depending on funding. Limitations to the predicted species distribution approach include sampling bias (species occurrence data are often collected in places with easy access, so public lands are overrepresented) and bias in taxa represented (70% of species included in the NatureServe predictions are plants). In addition, using these datasets to identify areas most important for imperiled species habitat or to quantify an area's value as imperiled species habitat does not consider the effect of landscape configuration (e.g., larger and less fragmented areas are more valuable for long-term species persistence).

The Nature Conservancy's (TNC) Resilient and Connected Networks dataset [1] identifies land with high biodiversity value, based on the presence of rare species, intact habitats, unique natural communities, and areas identified in state wildlife action plans. Its objective is to identify a set of representative habitats across the United States, which can be complementary to the species-based datasets described above. While TNC plans to update this dataset as needed based on input data, its binary approach (land either has high value for biodiversity, or doesn't) makes it less useful for tracking trends over time. The American Farmland Trust's forthcoming ecological flow map [6] is another habitat-based dataset that identifies agricultural land with high value for wildlife, based on the type, frequency, and intensity of disturbance associated with agricultural activity on the land.

The NatureServe datasets described above provide spatially continuous information about species diversity. It may also be useful to quantify and track biodiversity within ecologically resilient areas that are likely to remain suitable for a wide variety of species under climate change. This can be achieved by overlaying a biodiversity dataset, such as the NatureServe total imperiled species richness dataset

[119] with an ecological resilience dataset that identifies areas likely to act as climate refugia or climate corridors. There are several options for resilience datasets. TNC's Resilient and Connected Networks [30] identifies high-resilience areas based on high microclimate diversity and local connectedness, and climate corridors and flow zones [27] that will allow species to move between high-resilience areas. A recently published research paper took a slightly different approach to identifying climate refugia and corridors [28, 31], combining information from the TNC dataset with additional information about climatic stability, climate refugia for certain species groups (trees and birds), and connectivity between current climate zones and where those same climate conditions are projected to exist in the future. These all focus on terrestrial climate resilience. The Nature Conservancy is developing a freshwater resilience dataset [32] that identifies resilient waterways based on their connectivity, habitat diversity, flow alteration, and watershed condition. This is currently available for the northeastern United States, but is being extended nationally. TNC's Resilient Coastal Sites dataset [122] identifies coastal habitat areas with high resilience to sea level rise, and could be used as an overlay with species richness data in coastal areas instead of or in addition to the terrestrial resilience datasets.

Additional Work Required

The species distribution data [4] underlying the NatureServe imperiled species richness datasets described above may be of interest for conservation planning and land management, or for tracking status and trends of individual species of interest, such as species of concern for particular states. It could also be used to quantify gamma diversity (total species richness across a region) and beta diversity (ratio of local species richness to regional species richness), as well as alpha diversity (local species richness) for imperiled species. NatureServe has this dataset, but it is not publicly available. Users would need to select species of interest and contract with NatureServe to perform a custom analysis to obtain it.

Map of Life [5] is a global dataset with information on species richness and rarity for major vertebrate groups, three insect classes, and three plant groups, plus relative indices for species, phylogenetic, and functional diversity for birds and mammals only. While Map of Life is valuable as a consistent global source of biodiversity information, includes facets of biodiversity other than species richness, and makes the underlying maps for individual species publicly available, it is based on expert range maps, and therefore only available on a two-degree grid to avoid overestimating species richness—much coarser than the 990-m NatureServe datasets. It was also noted during the workshop that wildlife migration and dispersal corridors—separate from the climate corridors discussed above—are a data gap, particularly at large scales. There is also a global dataset of marine imperiled species richness [123], but its approach using mapped species ranges instead of species distribution modeling will make it difficult to keep updated for status and trends assessment.

The South Atlantic Conservation Blueprint [121] identifies coastal and marine areas with high biodiversity value (based on species richness or the presence of rare or endemic species), but does not quantify species richness, similar to the high biodiversity areas in the Resilient and Connected Networks dataset [1] described above. This dataset currently only covers the south Atlantic United States and would need to be extended before use in a national assessment.

Energy Conservation

Shading and evapotranspiration by trees can reduce temperatures, allowing less energy to be used to cool buildings. This effect is especially important in urban areas, which have higher temperatures due to heat trapped by pavement and buildings, as well as high concentrations of buildings that require cooling. The cooling effect of trees is highly localized, so people benefiting from the reduced temperatures must be co-located with the NWL providing the service.

Ready to Go

The Heris et al. 2020 [69] model developed to pilot natural capital accounts in the United States quantifies avoided spending on building cooling costs due to temperature reduction by urban trees. Estimates are available for all US municipalities with at least 50,000 people for 2011 and 2016. The underlying open-source model uses publicly available, remotely sensed data inputs and could be run for later years by the original developer, or externally. This model operates at 30-m resolution, which is coarser than would be ideal to capture the cooling effects of the very patchy, urban tree canopy. While the cooling estimates represent the difference between cooling costs with the current tree canopy and cooling costs with no tree canopy, it may be more useful to track the marginal benefits of increases (or costs of decreases) in urban trees and green space over time.

Energy Production

NWL can be used for solar, wind, hydropower, or geothermal power generation, and provide inputs for biomass power generation and biofuel production. The serviceshed for energy production includes (1) the NWL from which raw material used for energy production is generated (this can be co-located with the energy production facility as for solar or wind energy, or separate as for feedstocks grown on NWL and transported to biomass power plants); (2) the energy production facility; and (3) the communities using the electricity after generation.

Ready to Go

The energy generation capacity of solar, wind, hydropower, biomass, and geothermal power plants in the United States is available from the Energy Information Administration's power plants in the US database [70], which is updated monthly and includes all power plants with at least 1 MW generation capacity. There is also a more detailed US Wind Turbine Dataset from USGS [75], updated quarterly, which has point locations and production capacity for each individual wind turbine (rather than a group of turbines comprising a power plant). Offshore wind turbines are included in both datasets, but there are very few in the United States. Neither dataset includes data on the actual energy generated by each power plant. While these datasets provide information about where energy is generated (and the NWL providing the raw material, in the case of solar, wind, and geothermal energy), they do not include information about who uses the generated electricity, or where feedstocks used for biomass power generation are grown.

Modeling Needed

The WIND toolkit [76] from National Renewable Energy Laboratory (NREL) estimates wind power plant production based on meteorological conditions and power curves for wind turbines. While it has been used previously to estimate potential energy generation by wind turbines during planning processes, it could be applied to existing wind turbines and observed weather data to estimate actual energy generation by wind turbines (both land-based and offshore).

Additional Work Required

Estimates of solar energy production are not currently available, although it seems possible to develop a model building on resources such as NREL's solar supply curves [71], which provides estimates of the potential for solar energy generation for a grid of points across the US, and Google's Project Sunroof [72], which estimates the potential for rooftop solar energy generation at the parcel level.

Biomass power generation and biofuel production use feedstocks grown on NWL as inputs. The biomass power plants in the EIA database do not link back to the NWL providing those inputs. Other EIA biofuels reports [80-82] include some information about the type of feedstocks used to produce biofuels, but the information is summarized to multistate regions or at a national scale, and similarly does not link back to NWL where feedstocks were grown. NREL has a set of biomass resource maps [83] that estimate the solid biomass resources (including crop, forest, and mill residues) available at the county scale, but they have not been updated since 2014. It may be possible to combine the biomass resource information with biomass power plant and biofuels data to estimate where the feedstocks used for biomass production originate.

Finally, geothermal resources can be directly used for building heating and cooling, rather than for electricity generation. This use is not captured in the EIA's power plants database; the US Department of Energy releases an annual geothermal report [84] including heat pump use, but only the national total is available.

Fire Risk Reduction

NWL can be managed to reduce fire risk by minimizing hazardous fuel conditions through prescribed fire, mechanical removal, and chemical vegetation treatment. The serviceshed for fire risk reduction includes the areas of NWL where management actions to reduce fire risk take place and the land and communities where fire risk is reduced.

Ready to Go

There is currently no dataset that comprehensively quantifies management actions to reduce fire risk or the effect of those actions on fire risk. The USFS tracks hazardous fuel treatment [49] on their lands in a dataset updated annually; this could be used to track where USFS is acting to reduce fire risk, but does not quantify fire risk reduction. Similar fuel treatment data are not available for non-USFS lands, including other federal agency lands and privately owned land. Another USFS data product, the Fireshed Registry [120], identifies areas where fuel treatments are needed to reduce fire risk to communities; this information could be overlaid with fuel treatment data to provide information about where fire risk is reduced due to treatment.

Additional Work Required

High-resolution fire risk modeling, including burn probability, flame length, and exposure of structure to fires, can estimate fire hazard and potential property damage, but has not been used to quantify the effect of NWL management on fire risk. These models, including Pyregence's PyreCast [47] and the FSIM model used by the USFS's Wildfire Risk to Communities [45] resources, incorporate information on vegetation and fuel characteristics, so it should be possible to use them to estimate fire risk with and without NWL management actions aimed at reducing hazardous fuels. However, this would require additional data on where those management actions occur (as noted above, this information is currently only available for USFS lands), as well as additional modeling work.

Flood Risk Reduction

NWL vegetation and wetlands slow water movement and promote infiltration, resulting in less water flowing downstream. This flood attenuation reduces the risk of property damage and hazard to people. However, there is a limit to this effect; large storms with intense precipitation can overwhelm the natural system's capacity. The serviceshed for flood risk reduction encompasses NWL upstream of areas at risk of flooding and the communities benefiting from reduced flood risk.

Ready to Go

A simple approach to tracking flood risk reduction is by identifying NWL likely to contribute to flood attenuation where it is needed. As part of the North Carolina NWL Action Plan, Duke University mapped floodplain forest and wetlands in watersheds with at least 3,000 people living in the floodplain (Warnell 2020 [33]). This analysis could easily be extended nationally by overlaying land cover, floodplain, and population data. However, the dataset does not quantify reduced flood risk or avoided flood damage due to NWL. A simple extension to this analysis would be to overlay the high flood risk watersheds with estimates of reduced annual runoff due to tree cover (from i-Tree Landscape [62] or EnviroAtlas [35]) to rank the high flood risk watersheds based on how much runoff is avoided due to trees. The total number of people at risk of flooding within each watershed (part of the analysis to identify high flood risk watersheds) may also be useful for ranking watersheds based on the number of potential beneficiaries of reduced flooding. While this analysis identifies communities at risk of flooding that benefit from flood attenuation by NWL, it operates on individual watersheds and does not identify all upstream NWL contributing to flood risk reduction for a community, or all at-risk communities downstream of NWL that benefit from flood risk reduction.

A similar approach employed in the academic paper Bousquin and Hychka 2019 [134] calculated the percentage of wetlands and number of people living in flood-prone areas for HUC-12 catchments in the conterminous US. This information could be used to identify catchments with high supply and demand for flood risk reduction. Once identified, the catchments could be overlaid with reduced annual runoff estimates as described above to further assist with ranking catchments by their level of benefit provided. The paper also extended the analysis for one county to include wetlands upstream and people in flood-prone areas downstream of each catchment. It may be possible to expand this more inclusive analysis to broader geographic scales, given sufficient computing resources to perform the upstream and downstream analysis for each catchment.

Modeling Needed

The InVEST urban flood risk mitigation model [37] is designed to quantify avoided flood damage due to runoff retention in urban areas. It uses a simple curve number approach to estimate runoff production and runoff retention based on land cover and soil characteristics for a storm with a specified rainfall depth. Building footprint data and potential damage loss information are combined to estimate the potential economic damage of the storm and the avoided damage due to runoff retention. The model's simplicity and limited input data requirements make it feasible to run for many cities within the United States, although it would need to be run individually for each city. Because this is a very simple model, the avoided damage estimate should be used as an indicator of potential avoided damage for comparing flood attenuation benefits over time, rather than an absolute estimate of avoided damage. It is also only designed for urban areas, and therefore will not capture the effect of NWL in rural areas upstream of cities. Modeling the value of coastal wetlands for flood damage reduction [124] and the value of coral reefs for flood damage reduction [136] has been done at large scales (multiple states) for observed storms

like Hurricane Sandy, as well as for synthetic storms. This approach combines a hydrologic storm model for flooding with asset exposure information and damage functions. According to the lead researcher for the coastal wetland modeling, it would be possible to use these methods to estimate avoided damages due to coastal habitats at the national scale to create a time series, but would require significant resources (time and computing power). While the academic papers applying these methods use proprietary asset exposure information and damage functions from the insurance industry, there may be public sources of this data (such as tax assessments), or other private sources such as Zillow data.

Additional Work Required

High-resolution flood hazard modeling is increasingly able to estimate property damage by historic floods or model storms under future climate conditions but has not been used to quantify the effect of NWL on flooding and property damage. First Street Foundation's Flood Factor [39] model estimates the risk of flooding due to rainfall, riverine flooding, and coastal surge, as well as the number and types of properties (residential, commercial, social infrastructure) at risk of flooding. Because the model incorporates land cover effects, including the effect of vegetation on NWL on slowing water flows, it would be possible to adapt the model to run with and without the NWL effects in order to estimate the reduced flood risk and avoided damage of NWL. However, quantifying the flood risk reduction benefit of NWL would require significant additional work and engagement with the model developers, as it is not currently part of their plan for model development.

Food

NWL support the production of crops through fertile soils and wild pollination, production of seafood through aquaculture, and provision of wild game and seafood for subsistence hunters/fishers and commercial harvesters. The serviceshed for food includes (1) the NWL where crops are produced or hunting occurs and (2) the communities where the food is consumed, which can be very close to the food source (e.g., local subsistence hunting) or much farther (e.g., crops shipped across the country).

Ready to Go

A forthcoming, open-source wild pollination model [86] (Heris; planned for release by June 2022) uses information on pollinator habitat, wild pollinator flight distance, and crop type to estimate wild pollinator activity on pollinator-dependent cropland and the crop value created by wild pollinators, which can be traced back to NWL providing pollinator habitat. Results at 30-m resolution will initially be available for 2020, 2017, 2014, 2011, and 2008; the model could be re-run annually given sufficient resources. This dataset identifies the NWL supporting crop production, but not where the crops are ultimately used after harvest.

Additional Work Required

NWL also contribute to the production of crops through their soils, but the many anthropogenic inputs to crop production (fertilizer, irrigation, etc.) make it difficult to distinguish the value created by NWL. A recent paper by Schroter et al. (2021) [92] developed a model to separate the anthropogenic and natural contributions to crop production, which was applied at a national scale to 67 countries. The modeling approach could be adapted to estimate the natural contributions to crop production at finer resolution, such as county level within the US, using information on crop yield (e.g., USDA Census of Agriculture [88]), agricultural suitability (e.g., American Farmland Trust productive, versatile, and resilient agricultural lands [85]), fertilizer use, and manure use. Similarly, the Census of Aquaculture

[127] provides information about aquaculture sales but does not distinguish natural from anthropogenic contributions. No approaches to separate these inputs for aquaculture have been found.

No current dataset or model quantifies the contribution of NWL to livestock production via soils (to grow forage) or natural vegetation. There are datasets available about the amount of biomass available (Rangeland Analysis Platform [89]) and vegetation status of rangeland (Rangeland condition monitoring assessment [90]), but neither includes information about use of land for livestock grazing or actual production of livestock.

NOAA landings data [128] includes information on commercial seafood harvest, but it is only publicly available at the state level. If higher-resolution, nonpublic data exist, it may be possible to work with NOAA to summarize them in useful ways for a national status and trends assessment, but privacy issues may prevent this.

Food provided via subsistence hunting and fishing on NWL is a data gap. An EnviroAtlas harvestable species richness map [94] shows where hunters might find a variety of wildlife to harvest, but it is not updated regularly and does not link to actual use of areas for hunting or amount of food harvested via hunting. Many states provide game harvest reports [137] that could be compiled and combined to provide information on game harvest. This would require significant work, beginning with an assessment of the information contained by each state's report.

Forest Products

Products harvested from forests include timber, which is used for a variety of end-products, and nontimber forest products such as mushrooms, firewood, and edible plants. The serviceshed for forest products includes the NWL from which products are harvested and where the products are ultimately used.

Ready to Go

The amount of timber harvested from US forests each year is reported by the USFS FIA Timber Products Output program [95], with harvest removals of different types of timber (saw logs, veneer logs, pulpwood, pilings, etc.) reported for each county. Harvest removals are also classified by the tree species group and the owner type (national forest, other public, and private). Due to recent methodology updates, data are currently available for most counties in southeastern and western states, and USFS plans to extend the methodology within a few months. The dataset only provides information on where forest products are harvested, not where they are used.

Additional Work Required

The USFS Timber Products Output dataset does not include information on the final use of harvested timber. Private datasets such as Forisk's North American Forest Industry Capacity Database [96] has data on end products from individual mills, but it is not linked to the NWL from which the timber was harvested. Expanding our ability to trace timber harvest from forest to mill end-products would give a full picture of the forest product benefit provided by NWL. Nontimber forest products are another data gap; these are primarily harvested by individuals and are therefore difficult to track.

Greenhouse Gas Fluxes and Carbon Stocks

NWL can sequester carbon in their soils and biomass and may also emit greenhouse gases under certain conditions. Management of NWL can promote carbon sequestration (e.g., by optimizing forest stocking levels for faster growth) or increase greenhouse gas emissions (e.g., by applying excessive nitrogen fertilizer), as well as preserve existing carbon stocks. The climate effects of greenhouse gas sequestration or emissions affect all people, so no serviceshed is defined for this benefit other than the NWL where greenhouse gas sequestration or emissions occur.

Ready to Go

The annual US National Greenhouse Gas Inventory [7] (NGGI) is designed to track greenhouse gas fluxes from the United States, including from managed NWL. "Managed" NWL is defined very broadly in the NGGI context and includes all farmland and virtually all forests and wetlands in the conterminous states. Only small areas of forest in inland Alaska are not considered to be managed and therefore not included in the NGGI. The NGGI pulls together data and models from a wide range of sources and is a collaborative effort between multiple federal agencies and universities; data and methods are constantly being updated and improved. Currently, NWL information in the NGGI includes greenhouse gas fluxes from forests, agricultural land, and wetlands; the forests section of the NGGI also includes carbon stock information. Short descriptions of what is included, the current calculation approach, and gaps in each of these sectors are below. At present, the NGGI information is published at the national scale, but data developers are able to summarize the results down to the county scale in most cases. The NWL section of the NGGI is moving toward a harmonized spatial approach, where GHG fluxes from NWL will be linked to a 30-m land-use grid. This is expected to be ready in the next few years and will allow higher-resolution summaries. While there are additional ready-to-go datasets for GHG fluxes from forests, agriculture, and wetlands (noted in the sections below), the NGGI's comprehensive approach to accounting for GHG fluxes from NWL, its consistency with international GHG reporting, and its continual updates and improvements seem to make it the best option for a national assessment of NWL GHG fluxes.

Forests

The forests section of the NGGI includes estimates of carbon stock and net carbon flux in live biomass (aboveground and belowground), litter, dead wood, and soils. It also tracks carbon in harvested wood products and greenhouse gas fluxes from forest fires and fertilizer use in forest soils. Methane, which can be emitted from abandoned oil and gas wells in forested areas, is not currently included. The main data source is the USFS's Forest Inventory and Analysis Program [8], which has 350,000 total plots (140,000 of which are forested) sampled for vegetation status, tree species, and biomass, among other variables. This information is combined with remotely sensed data to allow downscaling and socioeconomic surveys to provide additional information on timber products and urban forests. USFS is already working to make the forest carbon data accessible at higher resolution using small-area estimation techniques. As part of the BIGMAP project, 2018 carbon stocks for eight forest carbon pools [20] are available at 30-m resolution.

Additional ready-to-go data sources for forest carbon include Forest Carbon Stocks and Fluxes from the National Forest Carbon Monitoring System [17] (30-m resolution, available for 1990, 2000, and 2010), i-Tree Landscape total carbon stock and sequestration by trees [10-11] (Census block group or county level, last updated in 2011), and a global net forest carbon flux dataset [25] for the 2001–2020 time period

(30-m resolution). There are also several carbon data sources for multiple ecosystem types, including forests, such as a USGS research effort to quantify the carbon balance of terrestrial ecosystems in the US [13], which estimates carbon stocks by land cover type, protection status and ecoregion (30-m resolution, was released in 2018 with work on an updated version in progress) and a global biomass and soil carbon dataset [19] by the UN Environment Programme (300-m resolution). Remotely sensed methane data from the Sentinel-5 satellite [22] may be useful for quantifying methane emissions from point sources such as wells, although it is too coarse to detect low-level, distributed emissions.

Agriculture

The agriculture section of the NGGI includes estimates of soil carbon sequestration and emissions, as well as N2O and CH4 emissions from soils. CH4 uptake by dry soils is not currently included. Agricultural greenhouse gas fluxes from the majority of cropped and grazed land are estimated using the DayCent model, with a combination of remotely sensed data products (related to crop type, vegetation status, weather, and soils) and survey data (related to agricultural management practices) used as inputs. A simpler approach, applying emissions factors, is used for the remaining 15% of agricultural land for which the DayCent model is not well parameterized. There are multiple recognized data gaps, including lack of data on livestock grazing practices, water management practices, biochar, and agroforestry, that improved data collection may help to fill, given sufficient resources. The agricultural greenhouse gas flux estimates can currently be disaggregated to the state level; finer-scale disaggregation is likely to be possible in the future, but proprietary data inputs and privacy concerns may limit the public availability of data at finer than the county level.

Additional ready-to-go data sources for agricultural GHG fluxes include the USDA's CaRPE tool [12], which estimates carbon sequestration or avoided GHG emissions due to agricultural management practices at the county scale, and proprietary data sources such as boomitra's soil carbon dataset [23], which has soil carbon stock information at 10-m resolution and is updated seasonally.

Coastal Wetlands

The coastal wetlands section of the NGGI includes estimates of CO2 sequestration and emissions from biomass, soil, and dead organic matter for tidal estuarine and palustrine wetlands with emergent or scrub/shrub vegetation, as well as dwarf mangroves. It also includes methane emissions from palustrine tidal wetlands and N2O emissions from aquaculture. GHG fluxes from seagrass ecosystems, which would include CO2 sequestration and methane emissions, are not currently included. These estimates are obtained by combining remotely sensed data (NOAA C-CAP) on changes in the extent of different types of coastal wetlands with GHG emissions factors for each coastal wetland type, derived from literature review. While the NOAA C-CAP data on wetland extent are packaged as a 30-m resolution data product, the current methods aggregate wetland extent changes by climate zone, tidally influenced area, and tidal wetland ecosystem type before applying the emissions factors, so the final GHG estimates can only be disaggregated into those areas. Plans for future updates include moving to a pixel-by-pixel analysis to allow finer disaggregation of results, adding GHG fluxes from seagrass ecosystems and impounded waters, and refining estimates of methane emissions in low-salinity areas and CO2 emissions from conversion of coastal wetlands to open water. The emissions factors used to estimate biomass and soil carbon accumulation will also be updated in 2022.

There are several datasets that apply similar techniques to those used in the NGGI that maintain the 30-m resolution of the input C-CAP data, capture carbon stocks as well as fluxes, and have been

published as part of research papers: carbon stocks and GHG fluxes from coastal wetlands for 2018 [14-15], and coastal wetland carbon and methane fluxes for 2006-2011 [16].

Additional Work Required

As noted in the sections above, each NWL sector in the NGGI has some data gaps and limitations that could be addressed in future updates, including grassland carbon and methane emissions from abandoned wells and low-salinity coastal wetlands. There is also a general limitation in our ability to tie GHG fluxes to on-the-ground management practices, especially for agricultural lands. Additional surveys are needed to collect agricultural management practice information more frequently. Expanding long-term monitoring sites would help to reduce uncertainty in GHG flux estimates. There may be ways to incorporate additional monitoring data such as BLM's Assessment, Inventory, and Monitoring data [21] into the NGGI calculations to improve estimates. There is also ongoing work between federal agencies, academics, NGOs, and private companies to continually improve NGGI's information on NWL GHG fluxes. For example, Regrow.ag is working with USDA to incorporate its OpTIS [24] products, which have information on tillage and cover cropping, into the NGGI.

Jobs

NWL support jobs in the agricultural and forestry sectors, as well as a variety of jobs related to outdoor recreation (equipment manufacturing and sales, rentals, and guides). The serviceshed for jobs is the area where employees working in a certain sector live; generally, this is assumed to be co-located with the jobs themselves, although it is possible for employees to live in a different county or state from where jobs are located. None of the datasets described below includes specific information about where the employees reside, but they do specify where the jobs are located.

Ready to Go

Employment related to agriculture and forestry is included in the Quarterly Census of Employment and Wages (QCEW) (Bureau of Labor Statistics) (BLS) [108],[21] which is calculated from state unemployment data and available quarterly at the county level. This dataset is organized by North American Industry Classification System (NAICS) code, and the level of detail available varies by sector—there are many specific subsectors available for forestry (timber tract operations, forest nursery, logging) and agricultural jobs (production of specific crop types; production of beef cattle, dairy cattle, hogs, chickens, etc.; crop harvesting; and farm labor contractors). Employment supported by commercial seafood harvest is also included in this dataset, via NAICS subsectors for finfish, shellfish, and other marine fishing.

Additional data sources with similar information include total full-time and part-time employment by NAICS industry (Bureau of Economic Analysis) [104], Occupational Employment and Wage Statistics (Bureau of Labor Statistics) [109], County Business Patterns (US Census) [110], and Farm Labor Survey (US Department of Agriculture) [111], but these are all released less frequently or summarized for larger geographic areas than the QCEW dataset described above. None of these datasets includes information about where employees live or whether they live in the same geographic area as the jobs summarized in the dataset, but generally, employees are assumed to live relatively close to their job location.

21. This dataset appears both in the ready-to-go category and the "additional work required" category because agriculture and forestry jobs are easily extractable and ready to go, however information on jobs supported by outdoor recreation would require additional work to generate.

Modeling Needed

The IMPLAN model [107] allows employment estimates for smaller geographic areas and is frequently used by the USFS to quantify employment associated with national forests. It requires input data such as number of recreational visits that is not currently available at large scales, but could be used for estimates of jobs provided by specific areas for which data are available.

Additional Work Required

Jobs supported by outdoor recreation are not simple to extract from the Quarterly Census of Employment and Wages (Bureau of Labor Statistics) [108] due to its use of NAICS codes—jobs related to outdoor recreation span several sectors and are combined with other amusement and recreation industries. Recently, the Bureau of Economic Analysis began to release an outdoor recreation satellite account [106], which uses additional modeling to estimate the jobs specifically linked to different types of outdoor recreation, but estimates are only available annually and at the state level.

Jobs associated with NWL restoration and management also don't fit into the standard industry classification sectors, and therefore cannot be easily isolated from the Quarterly Census of Employment and Wages (Bureau of Labor Statistics) dataset [108].

Specific employment information for the agricultural sector and fisheries (commercial and recreational) is available from USDA's Farm Labor Survey [111] and NOAA's Fisheries Economics of the United States report [130], respectively. These are both regularly updated and provide more specific information on the types of jobs supported by these sectors than the BLS data described above, but their high level of geographic aggregation (multiple-state regions for [111], states for [130]) make them less useful for a national status and trends assessment.

Recreation

Many types of outdoor recreation are supported by or take place on NWL, including fishing, hunting, hiking, camping, boating, birdwatching, and skiing. Ideally, a national assessment would track both the number of recreational visits to a particular area and the type of recreational activity that visitors engage in, as well as where visitors come from (i.e., the serviceshed for each NWL area open to the public).

Ready to Go

Visitation Data from Federal Agencies [99-102] based on surveys or vehicle/pedestrian counters is available for certain federal lands, including national parks, national forests, national wildlife refuges, and Bureau of Land Management (BLM) lands. These data are generally available for specific management units, such as a national park. Data are released monthly for national parks, annually for BLM lands, and less frequently (every 5–6 years) for national wildlife refuges and national forests. Visitation data for national forests, national wildlife refuges, and BLM lands is broken down into specific types of recreational activities (e.g., pedestrian, boating, bicycling, hunting, fishing, snowmobiling). The data for national parks only has specific information on types of overnight stays (e.g., tent, RV, or backcountry camping). These datasets have some general information about where visitors come from (e.g., residents vs. nonresidents in the NWR data), but do not define a specific serviceshed (geographic area from which visitors travel) for each land unit.

There are many nonspatial data sources for outdoor recreation, such as the National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (NSFHWAR) and the Outdoor Industry Association's

reports on outdoor participation. These nonspatial estimates of specific recreation activities can be combined with spatial data indicating where outdoor recreation occurs to develop spatial models of recreation activity. For example, researchers combined birding participation information from NSFHWAR with eBird reports to map birding days in North Carolina (Warnell 2019 [97]). This approach could be extended to map birding days nationally; however, the NSFHWAR would need to be updated (it has not been updated since 2016, and state-level results have not been available since 2011) to allow this approach to be implemented.

ParkServe [98] is a national database of publicly accessible local parks, which can provide information on the extent of land available for public recreation, especially in urban areas. It does not include visitation or use information. Trust for Public Land, which developed ParkServe, also publishes a ParkScore for each community based on park acreage, access, investment, and amenities, so there may be additional detail about each park that is not publicly available.

Additional Work Required

Currently, there is no national spatial data for recreational visits outside of the specific areas discussed above, either in total or for specific activities. Work is underway by several research groups, including EnviroAtlas [103] to use human mobility data (GPS information from cell phones, which can be purchased from private companies) to estimate visitation to federal lands; this could eventually be extended to additional natural and working lands used for recreation, providing a consistent data source for recreation activity on land under different types of ownership and management. Human mobility data raises privacy issues related to tracking individuals that will need to be addressed prior to broad adoption. This type of data may not be able to differentiate between different types of outdoor activity, but it likely can identify where visitors to different NWL originate from, which can help to define the serviceshed for publicly accessible lands and identify "nature-deprived" communities where residents are not currently accessing outdoor recreation opportunities.

The Recreation Information Database [138] is a database of reservations for recreational activities on federal land, including camping, permits, tickets, activity passes, and timed entry to sites. It would require additional work for use in a national assessment, primarily to determine the type of recreation that some of the entries (particularly those for permits or tickets) represent, and also due to overlap with the ready-to-go visitation data from federal agencies [99-102] described above.

Virginia DCR has developed a nature-based recreation access model [133] to quantify access to land- and water-based recreational opportunities, based on the travel time to publicly accessible protected land or water access points and the number of publicly accessible protected lands and water access points within certain driving distances. Individual metrics are combined into a composite measure of recreation need, which Virginia uses to guide land conservation decisions to expand public access. This approach could be expanded to other states and used to delineate areas with high or low access to recreation, which would be informative for equity analysis as well as tracking status and trends of recreational access.

An annual survey of state park directors [133] provides information on total visitation to state parks by state, broken down by visits to fee and nonfee areas, and by day and overnight use. However, this dataset only reports visitation to all state parks within a state together, not broken down to the individual state park level.

NOAA collects information on recreational fishing effort and catch through its Marine Recreational Information Program [129]; while this dataset is national and updated annually, information is only

available at the state level. It may be possible to work with NOAA to access nonpublic data (broken down into substate regions), but privacy concerns may limit options for using the finer-scale data.

Many states provide game harvest reports [137] that could be compiled and combined to provide information on hunting activity and harvest. This would require significant work, beginning with an assessment of the information contained by each state's report.

Water Quality

NWL improve water quality by slowing water movement, allowing pollutants and sediment to drop out of flowing water, and by trapping pollutants on vegetation. Improvements to water quality are intermediate services; the final benefit is increased suitability of the water for end-uses (e.g., swimming, fishing) or reduced need for treatment (e.g., for drinking water). The serviceshed for water quality includes the NWL over which water flows and the location of the water's end-users.

Ready to Go

The USFS Forests to Faucets dataset [131] ranks HUC12 watersheds on their ability to produce clean drinking water (based on land cover and water yield) and potential threats to surface drinking water (from insects and disease, wildfire, climate change, and land use change). These indices could be used to define watersheds important for supplying clean drinking water. While they are focused on drinking water, this information may be relevant for other uses of water that require high water quality as well. This dataset does not quantify the water quality improvement by NWL within each watershed or identify specific beneficiaries or communities that use the water.

Additional Work Required

Ideally, water quality benefits of NWL would be quantified as enhanced suitability of water for its final use, or reduced treatment cost due to water quality improvement. While there are many datasets and models to quantify the intermediate services of retaining sediment or nutrients (e.g., InVEST nutrient delivery and sediment retention models [52-53], EnviroAtlas avoided sediment yield due to natural vegetation [54]), they do not connect to the end uses of the water or reduced treatment costs. There are also many datasets with pollutant concentration measurements or estimates (e.g., Water Quality Portal [55], USGS SPARROW models [58], Keiser and Shapiro 2018 [59]). These may be useful for future models of how NWL improve water quality to increase suitability for end uses, but do not quantify benefits on their own.

Water Quantity

NWL are sources of water for various anthropogenic uses (agricultural, industrial, domestic, etc.) via surface water and groundwater supplies. The serviceshed for water quantity includes the NWL over which water flows and the location of the water's end-users.

(Note: NWL effects on runoff volume, which can reduce downstream flood risk, are addressed under the reduced flood risk benefit.)

Ready to Go

Information on the importance of watersheds to surface drinking water is available from the USFS Forests to Faucets dataset [50], which incorporates the annual water yield, number of water supply

consumers within the watershed, and number of downstream water consumers to create a normalized (0–100) index that could be used to define important watersheds for drinking water provision. This dataset is at the HUC12 scale and has been updated in the past (most recently in 2020), but the source data are outdated for some locations and would benefit from regular updates. The dataset does not include information on the geographic location of the people who use the drinking water.

Additional Work Required

Water is used for many purposes other than domestic drinking water; several datasets have information on the location and purpose of water use, but do not connect that use back to the NWL providing the water. For example, USGS water use data [60] have average daily use (over an annual period) for public supply, domestic, commercial, industrial, thermoelectric power, mining, livestock, aquaculture, irrigation, hydroelectric power, and wastewater treatment at the county scale; these data are currently released every five years with a time lag of several years, but planned updates should result in increased frequency of data releases and the ability to aggregate by watershed as well as county. EnviroAtlas water use [57] has data at the HUC-12 scale for agricultural, domestic, industrial, and thermoelectric water use. OpenET [56], a new data product that uses remote sensing to quantify evapotranspiration (a proxy for water use) from agricultural lands, has high-resolution (30-m) data updated monthly for the western US and plans to expand nationally. The location and extent of groundwater recharge, which is essential for the continued provision of water for human use, especially in parts of the United States that rely on groundwater, is another data gap related to water quantity.

APPENDIX E. FILTER SUMMARIES

APPENDIX E. CONTENTS

Filters can be used to view and summarize the spatial NWL benefits data in multiple ways and separate the data into useful categories. The summaries below (1) describe filters suggested by experts and workshop participants as useful for summarizing benefits data and (2) give an overview of the available datasets that could be used to define the filters. For filters that cannot be defined by available datasets, we describe the major challenges to acquiring that data or ongoing efforts to develop relevant datasets.

Some of the suggested filters are straightforward to define objectively (e.g., jurisdictional boundaries like states) and have obvious, ready-to-use data sources. These are indicated below with dark blue boxes ■ next to the filter name. Others, like high-quality grazing lands, have a degree of subjectivity and could reasonably be defined in different ways, potentially using different data sources. These are indicated below with light blue boxes ■. Finally, several filter ideas were added at the workshop. In some cases workshop participants suggested relevant datasets for these, but a thorough search for datasets to define these filters has not been completed. These are indicated below with light gray boxes ■.

Jurisdictional

■ States, Counties, and Census Geographies

Jurisdictional boundaries, including states, counties (or parishes), and Census geographies (e.g., tracts and block groups), are commonly used to filter or summarize national-level data. They are also hierarchical (counties are subsets of states and Census tracts are subsets of counties), making it easy to switch between levels of aggregation. Because most of the datasets for NWL benefits that are not available as rasters are aggregated to the Census tract or county level, jurisdictional boundaries are easy to use with those aggregated benefits datasets, as well as disaggregated ones. The Census Bureau's TIGER/Line shapefiles dataset [F1] provides jurisdictional boundaries at all levels for the entire United States.

Land Ownership, Designation, Use, and Ecosystem Type

■ Federal and State Land

Summarizing benefits of NWL in different land ownership categories is likely to be of interest to the landowners (e.g., federal agencies, state governments) and may inform management strategies to enhance benefits on land under different ownership types. The Protected Areas Database of the United States [F6] is likely the most comprehensive source of information on federal and state lands, though completeness and update frequency vary by state. Information on the type of federal and state land (e.g., national or state forests, national or state parks, national wildlife refuges, state game lands, etc.) is also available in these datasets and may be useful for summarizing benefits and considering management options.

Private Land

PAD-US [F6] has information on privately owned conservation land, although this is less complete (see the 30x30 conserved land filter summary for additional detail) and does not include privately owned land that is not considered protected or conserved.

Tribal Lands (Current and Historic)

Lands currently owned and managed by American Indian tribes hold significant cultural value and provide other benefits. Including tribal lands, identified using the US Census Bureau's Current Federal American Indian Reservations and Off-Reservation Trust Lands data [F31], as a filter can improve recognition of the importance of tribal management. Some benefits datasets do not cover tribal lands due to privacy concerns, and it is important to recognize sensitivities around sharing information about tribal management practices and cultural resources.

Virtually all land in the United States is the historic homeland of one or more tribes. Native Land Digital curates a global map of native territories [F32] that includes the US; however, it is a crowd-sourced work in progress that is not intended to represent official or legal boundaries or indigenous nations.

Designations

Workshop participants suggested that specific land designations, including areas under habitat conservation plans, non-attainment zones for air pollutants, and zoning designations, would be useful ways to summarize NWL benefits data. There are many designations, so additional discussion to select specific ones and identify data sources would be needed. Certain designations, such as habitat conservation plans, do not currently have spatial data available, and so cannot be implemented in the near term. Others, such as key biodiversity areas [F61] designated using standard criteria by the IUCN and partners, have datasets that are ready to use.

Land Use/Land Cover

Land use and land cover are widely used to summarize NWL information. While many land-use/land-cover datasets exist, two federal datasets are the authoritative sources for land-use/land-cover information in the United States: the National Land Cover Dataset (USGS) [F3] for all lands, and the C-CAP (NOAA) [F4] for coastal areas. While the NLCD covers coastal areas, it has less detail on coastal habitat types, so it may make sense to combine the two datasets and use C-CAP for coastal areas and NLCD for non-coastal areas. Both datasets are available at 30-m resolution and are updated regularly (currently every 3–5 years, but moving toward more frequent updates in the future). The newly released LCMAP dataset (F59] may be an alternative to NLCD for a national status and trends assessment, due to its annual release schedule, but it has fewer land cover classes than NLCD.

Land with High/Moderate/Low Human Modification

Classifying land by its degree of human modification improves understanding of how human actions influence NWL benefits. The precise definition of human modification and delineation between low, moderate, and high degrees of modification will require additional discussion. Currently, the only national-scale human modification dataset [F21] in the database incorporates information on a variety of stressors, including built-up areas, agriculture, oil and gas production, mining, power generation, transportation, electrical infrastructure, logging, and air pollution.

Ecoregions

Categorizing land by the type of ecosystem present may be useful for conservation planning (assessing how much of each ecoregion is conserved or protected), as well as quantifying the benefits provided by

different ecosystem types. Ecoregions, or areas with generally similar ecosystems and type, quantity, and quality of environmental resources, are an established way to categorize land by ecosystem type. The EPA's level III and level IV ecoregions datasets [F60] have this information at two levels of detail (there are 105 level III ecoregions and 967 level IV ecoregions in the US), both of which may be useful for a national assessment.

Threats/Risks

It may be useful to identify areas where particular threats or risks to people or the environment exist, both for benefit summarization and to guide management actions to reduce existing risks or avoid future threats. There are types of threats and risks that could be used to define filters; additional discussion will be needed to select focal threats and risks, and relevant datasets, to define filters. Risk of future development was suggested during the workshop as a threat that might be useful to include. Datasets quantifying this risk are available from the EPA [F14] and USGS [F40], but may not sufficiently consider the social, economic, and climate factors that drive development. Unsustainable use of agricultural and grazing lands was also recognized during the workshop as a threat to ecological condition and the continued supply of benefits from these lands, but no datasets were identified to quantify unsustainable use or delineate lands that are being managed unsustainably. Climate change risks include coastal and inland flooding and more intense and frequent heat waves. Climate velocity was suggested as a useful aggregate index of relative climate change risk.

Watersheds

USGS Watershed Boundaries

Watersheds are areas of land that drain to a single point, such as a lake or river outlet, and are often used to summarize environmental data because they are natural boundaries for many ecosystem processes. Watersheds can be defined at multiple scales, with smaller watersheds nested within larger ones. The US Geological Survey's Watershed Boundary Dataset [F2] defines watersheds, or hydrologic units, at six scales,[22] from 2-digit HUCs covering multiple states to 12-digit HUCs that are each less than 40,000 acres.

Critical Watershed Areas

While the USGS watershed boundaries described above are useful for dividing the entire US into watersheds, a separate filter identifying critical watershed areas that are particularly important for use or face significant threats may be useful for tracking the status and trends of water-related benefits. The USFS Forests to Faucets dataset [F7] includes an index of importance to surface drinking water, as well as ratings for potential threats to the watershed from wildfire, insects, disease, land use change, and water yield decrease. There are many potential ways to identify critical watershed areas using the Forests to Faucets dataset or other data sources, so defining this filter for use in a national assessment would require additional discussion.

Management Status

IPCC Managed/Unmanaged Land

The meaning of the term "managed land" varies by context, making it difficult to select a common definition and relevant data to identify land meeting that definition. However, "managed land" is an important concept for international greenhouse gas reporting, and we use that definition to align with

22. https://www.usgs.gov/media/images/watershed-boundary-dataset-structure-visualization

the US National Greenhouse Gas Inventory. The IPCC guidelines require greenhouse gas emissions and associated carbon stock changes from land use and management activities to be reported for all managed land within a country. While countries use different approaches to identify their managed land for greenhouse gas reporting, the US definition focuses on direct interventions to land as well as its accessibility.[23] All land used for crop production, all settlements, forests with fire or timber management, grasslands in counties with livestock present, protected land managed for recreational use or where natural disturbances are suppressed, and grassland and forests within 10 km of roads and railroad networks are considered managed. The US Environmental Protection Agency develops the managed land area dataset [F5] in support of the US National Greenhouse Gas Inventory; the dataset is not publicly available but can be requested from the EPA. In total, less than 5% of land within the US is designated as unmanaged,[24] with the vast majority of unmanaged lands located in Alaska. Given managed lands encompass almost the same area as total national lands, applying this filter to a benefits dataset would not give much more specific information about the benefit than the unfiltered version.

More specific types of land management, such as forests managed for timber harvest, are included as additional NWL filters (Table 4).

Forests Managed for Timber Production

Given that forests managed for timber production may provide different benefits than forests that are managed for other objectives, a "forests managed for timber production" filter can enhance understanding of what differences exist and inform decisions to encourage or incentivize different types of forest management. Most datasets that identify forests managed for timber production come from USFS. The Forest Inventory and Analysis database [F16] includes annual harvest information, and the National Woodland Owner Survey [F15] asks forest owners about their objectives for owning forestland (timber production is one of the response options). However, both of these national datasets can only be summarized at the county level, so they are not ideal for creating a filter that can specifically identify areas of forest managed for timber production. Within USFS-owned lands, more specific information is available on timber harvest activities [F20], silviculture stand improvement activities [F17], and silviculture restoration program activities [F18]. There is also a research effort using remote sensing to distinguish pine plantations from natural (nonplantation) forest in the southeastern US [F19], but this only identifies a subset of forests managed for timber production and may not be applicable to other parts of the United States where timber is harvested from nonplantation forests.

Certified Forests

Forests certified as sustainably managed by organizations like FSC, SFI, or TreeFarm may provide different benefits than forests that are not certified or sustainably managed; a filter to summarize the benefits of certified forests can increase recognition of these benefits and promote improved forest management more broadly. Initial conversations with forest certification organizations showed that while those organizations have information on the total area of forest land they certify and may be able to break that information down to the state level, they do not yet have the spatial data on certified forests that would be needed to create a filter. Some organizations are beginning to collect spatial data, but it will be dependent on landowners opting in to share more detailed information on their property, and there may be confidentiality issues that limit data sharing once the data have been collected.

23. https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-018-0095-3
24. https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-018-0095-3/figures/4

High-Quality Grazing Lands

All pasture lands would be identified in the land-use/land-cover filter, but it may also be useful to identify a subset of high-quality grazing lands as an additional filter, to provide information on what proportion of grazing land benefits are generated by smaller areas of high-quality lands, and to consider possible management approaches to enhance benefits from different categories of grazing lands. There are many possible ways to define and identify high-quality grazing lands; one possibility is using information about forage biomass, based on data sources such as USFS's RPA Assessment [F9] or USDA's Rangeland Analysis Platform [F12]. Information about the use of rangeland for grazing or management actions to improve range vegetation may also be useful, but is currently only available at a broad scale for USFS lands, through the USFS Range Allotment dataset [F11] and USFS Range Vegetation Improvement dataset [F13]. Due to the subjectivity of defining high-quality grazing lands, another approach may be allowing users to define their own filter for high-quality grazing lands by setting threshold values (e.g., for forage biomass) or by selecting specific characteristics to define high-quality lands.

High-Quality Agricultural Lands

All agricultural lands would be identified in the land-use/land-cover filter, but it may also be useful to identify a subset of high-quality agricultural lands as an additional filter, to understand what proportion of agricultural land benefits are generated by a smaller area of high-quality agricultural lands, and to consider possible management approaches to enhance benefits from different categories of agricultural lands. There are many possible ways to define and identify high-quality agricultural lands; one possibility is using American Farmland Trust's productive, versatile, and resilient agricultural lands data [F8], which provides a continuous ranking of agricultural land quality. Using this dataset would require establishing a threshold to define "high-quality" agricultural lands. Another approach may be allowing users to define their own filter for high-quality agricultural lands, for example, by changing the threshold for high-quality lands or by selecting specific characteristics to define high-quality lands.

Activities from Project Databases

As work to improve the condition of NWL and enhance the benefits provided by NWL expands, it would be useful to track the benefits from lands where such projects occur. These could include restoration projects, nature-based solutions, green or blue infrastructure projects, and mitigation projects. Data on these projects have not been compiled in one location, but are scattered across multiple datasets focused on specific project categories. For example, the SAGE Mapper [F54] tracks coastal resilience projects, including living shorelines, while ProMap [F55] has information on US Army Corps of Engineers projects under its "engineering with nature" program. EnviroAtlas has several datasets with information on different types of mitigation projects (forest carbon, imperiled species and habitats, watersheds, and wetlands and streams) [F50-53]. Having up-to-date information on projects will be critical as new projects are constantly being implemented; these datasets will likely require additional resources to stay updated.

30x30 Conserved Land

Defining what counts as conserved land is a topic of ongoing discussion, especially relevant to federal and state efforts to meet acreage-based targets such as 30x30. Land identified as GAP 1 or 2 in the Protected Areas Database of the United States (PAD-US) [F6] has permanent protection from conversion and a management plan to maintain a natural state. GAP 1 or 2 land is often the assumed starting point for defining protected lands. However, many organizations have proposed alternatives, particularly related to how conserved lands and conservation activities on multiple use or working lands are classified

(for example, California 30x30,[25] Environmental Policy Innovation Center,[26] Center for American Progress,[27] The Nature Conservancy,[28] Defenders of Wildlife[29]). This project will not directly engage in the discussion to define protected lands or conserved lands, but some of the datasets included in the database may be useful for identifying lands that meet criteria proposed by various groups.

It is also important to note that the PAD-US dataset has several limitations relevant to its use in a national status and trends assessment, especially if it is used to quantify progress toward acreage-based targets. PAD-US has a "date of establishment" field that could be used to track land conservation over time, but this information is incomplete—56% of records in PAD-US version 2.1 do not have a date of establishment. Because PAD-US is compiled from many sources, including local, state, and federal government agencies and nongovernmental organizations, completing the date of establishment field for all properties is a daunting, if not impossible, task. The PAD-US dataset does not yet include all conserved land in the US, and its level of completeness varies by owner type (federally owned land is very well represented in PAD-US; land owned by land trusts is less complete, especially for small land trusts lacking geospatial resources) and by geographic location (some states have more complete datasets to feed into PAD-US and provide more regular updates than other states).

Conserved Working Lands with High Biodiversity or Ecological Resilience Value

Several experts engaged in this project expressed concern about how conserved land might be defined through the 30x30 process, and specifically whether the value of working lands would be recognized. Many working lands are included as GAP 3 or GAP 4 in the PAD-US dataset [F22], meaning they are managed for multiple uses or have no known conservation mandate. Other working lands are not captured by the PAD-US dataset. A soon-to-be-released Protected Agricultural Land Database from American Farmland Trust [F25] may help to fill some of the gaps in PAD-US related to working lands. Some experts suggested that conserved working lands with particular value for biodiversity or ecological resilience be identified as a separate filter. This could be achieved by overlaying conserved working lands (from the two datasets mentioned above) with additional data on biodiversity or ecological resilience—there are several options for each, including TNC's Resilient and Connected Network [F23], areas with low human modification [F27], NatureServe's imperiled species richness data [F29], and ecological flow and agricultural land connectivity maps from American Farmland Trust [F26, F28].

Working Lands Managed for Conservation

Experts also recommended identifying working lands that are managed using conservation-friendly practices, which may not be recognized in the PAD-US GAP classifications. Several datasets are available to identify agricultural lands in stewardship easement programs [F36] or permanent protection [F39]. There is also information about specific agricultural and forest management practices through Regrow's OpTIS data [F38], USDA's Census of Agriculture [F37], USDA's Natural Resources Inventory [F40], and USFS's National Woodland Owner Survey [F41], although the USDA and USFS datasets can only provide data at the county level or higher and are less useful for identifying specific working lands managed for conservation. USFS has much more specific data on its own lands, including areas with

25. https://togetherbayarea.org/wp-content/uploads/2021/08/Land_Conservation_Advisory_Panel_Summary_v3_508.pdf
26. https://www.policyinnovation.org/publications/getting-to-30x30-recommendations-to-supportgreater-private-investment-in-private-lands-conservation
27. https://www.americanprogress.org/article/much-nature-america-keep/
28. https://www.nature.org/en-us/what-we-do/our-insights/perspectives/thirty-percent-protect-best-biodiversity-on-earth/
29. https://defenders-cci.org/files/30x30_conserve_definition.pdf

special designations that only permit certain management [F46-49] and areas restored through specific programs [F43-45].

Benefit Delivery

Underserved Communities

Identifying historically underserved communities allows assessment of how NWL benefits are distributed relative to those communities, and how management actions are increasing or decreasing inequities in who is benefitting from NWL. While several federal datasets such as EPA's EJSCREEN [F33] and CDC's Social Vulnerability Index [F35] and academic datasets such as the Index of Deep Disadvantage [F58] combine socioeconomic and demographic factors to identify communities that are disadvantaged or socially vulnerable, the Justice40 initiative is currently in the process of defining and identifying disadvantaged communities at the Census tract level to ensure that at least 40% of federal climate and clean energy investments benefit these communities. Since NWL management relates to both climate and clean energy, it seems most useful to align with Justice40 and use their forthcoming disadvantaged communities designation (a beta version of the Climate and Economic Justice Screening Tool that identifies disadvantaged communities [F56] was released in February 2022) in a national assessment of NWL benefits as well.

Underserved Communities for Specific NWL Benefits

Underserved communities could also be identified for each NWL benefit, flagging communities that are not currently receiving each benefit mapped as part of the national status and trends assessment. This would essentially be the inverse of the serviceshed for a benefit—rather than identifying where the benefit is being delivered (and to whom), underserved communities for a benefit are the areas where the benefit is not being delivered. This would only be possible for benefits with datasets that specify serviceshed areas.

Author Affiliations

Katie Warnell, Nicholas Institute for Environmental Policy Solutions

Sara Mason, Nicholas Institute for Environmental Policy Solutions

Lydia Olander, Nicholas Institute for Environmental Policy Solutions

Citation

Warnell, K., S. Mason, and L. Olander. 2022. "Tracking the Benefits of Natural and Working Lands in the United States: Dataset Evaluation and Readiness Assessment." NI R 22-03. Durham, NC: Duke University.

Acknowledgements

Funding for this project came from the USDA Office for Environmental Markets. We would like to sincerely thank Chris Hartley at USDA for his input and guidance, and all those who participated in our expert engagement process and the project workshop.

We would also like to thank the eight anonymous reviewers who provided insights, comments, and clarifications for this text.

Publication Number: NI R 22-03

Nicholas Institute for Environmental Policy Solutions

The Nicholas Institute for Environmental Policy Solutions at Duke University is a nonpartisan institute founded in 2005 to help decision makers in government, the private sector, and the nonprofit community address critical environmental challenges. The Nicholas Institute responds to the demand for high-quality and timely data and acts as an "honest broker" in policy debates by convening and fostering open, ongoing dialogue between stakeholders on all sides of the issues and providing policy-relevant analysis based on academic research. The Nicholas Institute's leadership and staff leverage the broad expertise of Duke University as well as public and private partners worldwide. Since its inception, the Nicholas Institute has earned a distinguished reputation for its innovative approach to developing multilateral, nonpartisan, and economically viable solutions to pressing environmental challenges.

Contact

Nicholas Institute
Duke University
P.O. Box 90335
Durham, NC 27708

1201 Pennsylvania
Avenue NW
Suite 500
Washington, DC 20004

919.613.8709
nicholasinstitute@duke.edu