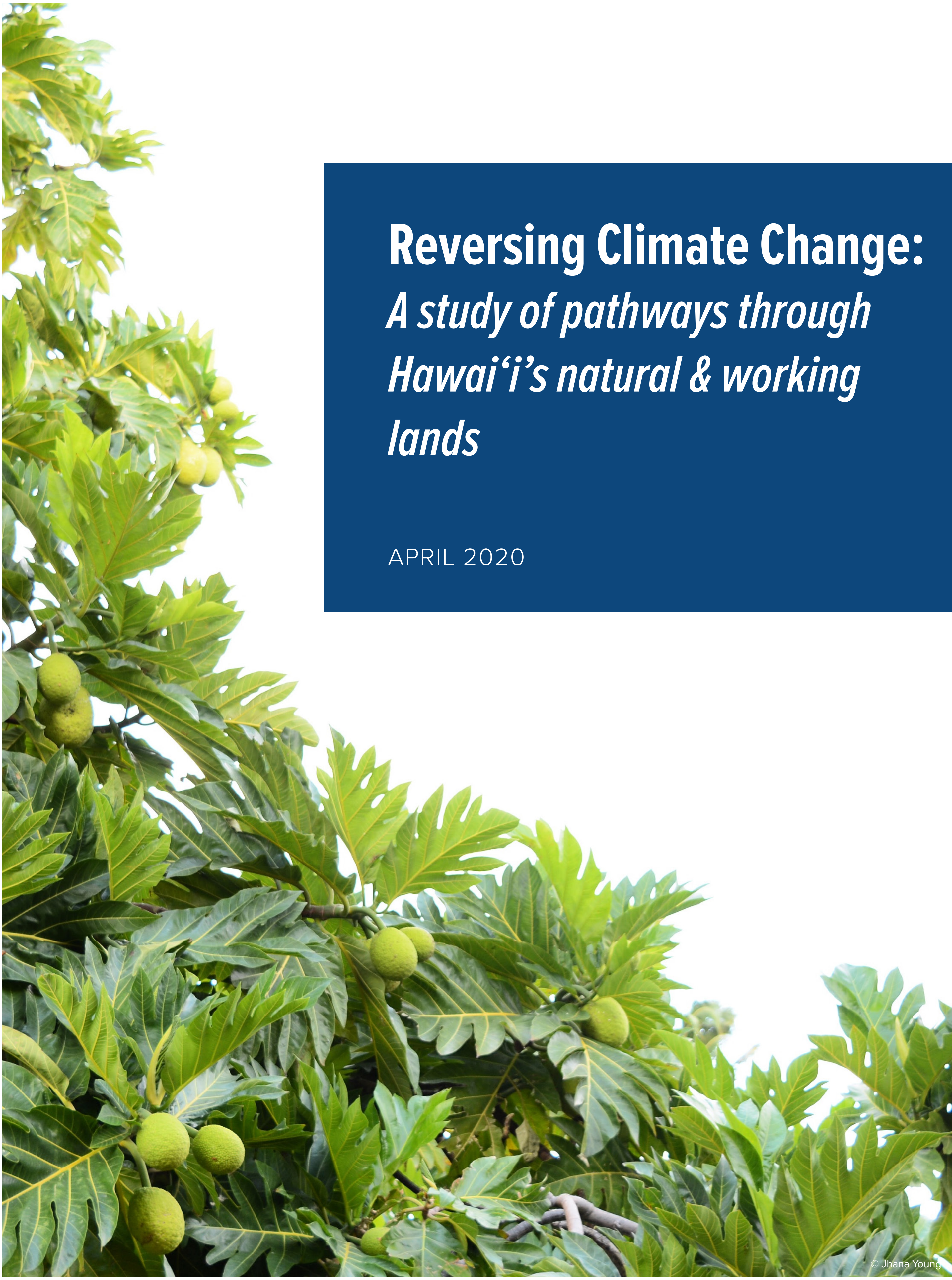
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Reversing Climate Change:
A study of pathways through Hawai'i's natural & working lands

APRIL 2020

Report produced by Conservation International for the State of Hawai‘i Office of Planning on behalf of the Hawai‘i Greenhouse Gas Sequestration Task Force.

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REPORT DESIGN

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EXECUTIVE SUMMARY

Ten Years Left to Act

According to the United Nations' Intergovernmental Panel on Climate Change (IPCC), the citizens, corporations, and governments of all nations of this shared planet have only ten years left to avoid the worst impacts predicted from the continued acceleration of climate change.[1] These extreme impacts include the complete loss of coral reefs and other ecosystems, sea level rise that consumes entire Pacific islands, increases in drought, floods, and extreme heat around the planet, and poverty for hundreds of millions of people.[2]

Need for Rapid and Far-Reaching Transitions

Avoiding the most extreme effects of climate change will require drastically changing current behaviors to reduce the net human-caused emissions of greenhouse gases by forty five percent by 2030 and reach "net zero" emissions by 2050.[3] To reach "net zero," any emissions that cannot be avoided must be balanced by removing carbon dioxide from the air.[4] Meeting these challenges will require "rapid and far-reaching transitions in energy, land, urban, and infrastructure (including transport and buildings), and industrial systems."[5] The land sector in particular provides opportunities to both reduce greenhouse gases released into the atmosphere (emissions) and remove carbon dioxide from the air and store it (sequestration).

Opportunities in Hawai'i's Land Sector

To explore these opportunities in Hawai'i's land sector, this study was requested by the Greenhouse Gas Sequestration Task Force to identify, analyze, evaluate, summarize, and compare key metrics for various greenhouse gas sequestration pathways specific to Hawai'i's natural and working lands and nearshore waters.

Study Scope and Approach

The Task Force framed the scope for this study in reference to greenhouse gas sequestration solutions that had been defined by Project Drawdown, a nonprofit research organization and global coalition of scholars, scientists, entrepreneurs, and advocates that is mapping, measuring, modeling, and communicating about substantive solutions to global warming, with the goal of reaching drawdown.[6] Project Drawdown defines "drawdown" as "the point in time when the concentration of greenhouse gases in the Earth's atmosphere begins to decline on a year-to-year basis."[7]

This desktop study focused on Project Drawdown's solutions from the Food and Land Use Sectors that have potential application in Hawai'i on lands currently used for agriculture, agroforestry, aquaculture, forestry, ranching, and urban forestry.

1 IPCC, Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].
2 *Id.* at 7-9.
3 *Id.* at 12.
4 *Id.* at 95-97.
5 *Id.* at 15.
6 Drawdown.org, Frequently Asked Questions, https://www.drawdown.org/frequently-asked-questions (last visited Mar. 17, 2020) [herein after Frequently Asked Questions].
7 *Id.*

Food and Land Use Solutions from Project Drawdown Potentially Applicable to Hawai‘i Lands

Food Sector Solutions	Land Use Sector Solutions
Silvopasture	Tropical Forests Restoration
Regenerative Annual Cropping	Temperate Forests Restoration
Perennial Staple Crops	Peatland Protection and Rewetting
Conservation Agriculture	Tree Plantations (on degraded land)
Tree Intercropping	Bamboo Production
Managed Grazing	Forest Protection
Abandoned Farmland Restoration	Indigenous Peoples’ Forest Tenure
Multistrata Agroforestry	Coastal Wetland Protection
Perennial Biomass Production	Coastal Wetland Restoration
Nutrient Management	
Farm Irrigation Efficiency	
Biochar Production	

These twenty-one solutions, as defined by Project Drawdown, provide a starting point to understand which activities they involve, which land types they are recommended for, and how they have been prioritized by Project Drawdown for action at the global scale. Using available data, research, and information for Hawai‘i, these twenty-one Project Drawdown solutions were reviewed for their potential to:

- be adopted across the state of Hawai‘i,
- increase greenhouse sequestration,
- reduce greenhouse gas emissions,
- generate co-benefits, and
- limit risks and unintended consequences.

This study also considered Hawai‘i-specific factors that would likely impact the economic feasibility of each solution.

RESULTS

Highest Performers Based on Greenhouse Gas Benefits Alone

If the Project Drawdown solutions that were fully analyzed for this study were ranked based on their potential greenhouse gas benefits to Hawai‘i alone, the top performers appear to be the *forest protection* solution, the *multistrata agroforestry* solution, the *perennial staple crops* solution, and the *tree plantations (on degraded land)* solution (see Appendix B for full table):

GHG-only Ranking	Solution	Potential GHG Benefits	Land Use/Land Cover Type
1	Forest Protection	~198 million tons of CO_2e (one-time avoided emissions)	Non-protected Forest
2	Multistrata Agroforestry	~5 million tons CO_2e /year (sequestration) minus the potential reduction for emissions from soil disturbance	Non-degraded Grassland
3	Perennial Staple Crops	~3.8 million tons CO_2e /year (sequestration)	Degraded Grassland
4	Tree Plantations (on degraded land)	~3.7 million tons CO_2e /year (sequestration)	Degraded Grassland

Note: Several Hawai‘i-specific factors were not included in Project Drawdown’s solution assumptions. It should be noted, however, that the *multistrata agroforestry* a solution has the potential to increase emissions through soil disturbance, if they are pursued in an area with high soil carbon stocks (such as areas with Andisol soils). Additionally, the potential emissions related to the need to ship timber to markets outside the state of Hawai‘i were not factored into Project Drawdown's model for the *tree plantations (on degraded land)* solution.

Highest Performers Based on Co-Benefits Alone

All of the fully analyzed solutions in this report scored high (green) or medium (yellow) providing some combination of co-benefits, including water quality, soil health, food security, biodiversity, human health, crop yield, reduced fuel use, reduced labor needs, and financial benefits to the land manager. The highest scoring solutions were the *silvopasture, conservation agriculture*, *regenerative annual cropping*, *tree intercropping*, *multistrata agroforestry*, and *forest protection* solutions. See Appendix C for full table.

Highest Performers Based on Limited Risks Alone

Nearly all of the fully analyzed solutions in this report presented some risks or potential unintended consequences. Generally, the risks and unintended consequences included invasive species potential, land competition, water competition, potential cultural impacts, lack of market signal, lack of necessary infrastructure, potential for greenhouse gas emissions increase, and risk of reduced yields. The solutions with the least amount of risk or potential for unintended consequences were the *forestry protection* and *coastal wetland protection* solutions. The solutions that presented the greatest number of risks or potential for unintended consequences were the *conservation agriculture, regenerative annual cropping*, *silvopasture*, and *tree plantations (on degraded land)* solutions. See Appendix D for full table.

Ranking of Solutions for Hawai‘i

Important information is lacking in Hawai‘i to allow for a ranking of these solutions with any kind of meaningful precision. Information about land degradation status, slope, soil type, climate, water availability, and land use history, as well as the potential plant species to be used in a given solution would greatly affect each solution's appropriateness and potential benefits in Hawai‘i. Therefore, the ranking of solutions provided below is not quantitative, rather it is a reflection of the relative strengths and weaknesses for Hawai‘i that were identified in this study.

Ranking	Solution	Land Use/Land Cover Type	Priority for Land Use/ Land Cover Type
1	Forest Protection	Forest (non-degraded)	A
2	Tree Intercropping	Degraded Cropland	A
3	Coastal Wetland Protection	Coastal Wetlands (non-degraded)	A
4	Perennial Staple Crops	Degraded Grassland	A
5	Tropical Forest Restoration	Degraded Forest	A
6	Urban Forests	Urban Forests	A
7	Multistrata Agroforestry	Grassland (non-degraded)	A
8	Regenerative Annual Cropping	Cropland (non-degraded)	A
9	Coastal Wetlands Restoration	Degraded Coastal Wetlands	A
10	Conservation Agriculture	Cropland (non-degraded)	B
11	Silvopasture	Grassland (non-degraded)	B
12	Managed Grazing	Grassland (non-degraded)	C
13	Tree Plantations (on degraded land)	Degraded Grassland	B

Hawai‘i Prioritization by Land Cover/Land Use Type

Cropland	Degraded Cropland	Grassland	Degraded Grassland	Forest	Degraded Forest	Developed/ Urban
1. Regenerative Annual Cropping	1. Tree Inter-cropping	1. Multistrata Agroforestry	1. Perennial Staple Crops	1. Forest Protection	1. Tropical Forest Restoration	1. Urban Forests
2. Conservation Agriculture		2. Silvopasture	2. Tree Plantations (on degraded land)	2. Coastal Wetland Protection	2. Coastal Wet-lands Restoration	
		3. Managed Grazing				

HAWAI‘I'S OPPORTUNITIES TO TAKE ACTION

As discussed in detail in this report, Hawai‘i lacks a lot of data that would allow for a more precise translation of Project Drawdown's solutions to Hawai‘i's natural and working lands and nearshore waters. Nevertheless, the broad review of these solutions for Hawai‘i provides a starting point and identifies opportunities for public and private land managers to help reduce greenhouse gases in the atmosphere while maximizing co-benefits and minimizing risks or unintended consequences for Hawai‘i's policy goals.

Support Site-Specific Decision Making

There are many areas of further research needed to most appropriately take advantage of these opportunities in Hawai‘i. These areas include a better understanding of the degradation status of cropland and grassland across the state and a better understanding of where Hawai‘i's major soil carbon sinks are located and how best to protect them. Information on the costs to implement some of these solutions in Hawai‘i will also provide a better understanding of their financial feasibility for specific landowners and land managers.

Support Sustainable Local Production and Local Consumption

As the most isolated archipelago on the planet, Hawai‘i faces unique challenges in achieving the potential benefits of the solutions explored in this study. Some of these challenges include preventing the introduction and spread of invasive species and diseases that threaten our native ecosystems while developing and supporting the locally produced inputs (e.g. animal feed, fertilizer, soil amendments, etc.), infrastructure, and markets that farmers and ranchers need to sell more of their products locally. Supporting farmers and ranchers to keep working lands in production and utilizing land management practices that provide greenhouse gas benefits and other co-benefits should be a priority for all consumers in Hawai‘i.

Leverage Unique Strengths

Hawai‘i also has unique advantages when considering opportunities to limit greenhouse gas emissions and increase sequestration. These advantages include the uniquely high occurrence of soils with great carbon sequestration potential (such as Andisols), as well as some areas with soil carbon stocks that are already high, and the large percentage of land across the islands that remain forested. Preserving these carbon sinks and further understanding when there are opportunities to enhance their health and ability to sequester carbon should be prioritized.

Emphasize the Role Everyone Needs to Play

The changes necessary to avoid the worst impacts of climate change reach far beyond the land sector – into every aspect of modern life, and all of these changes will be critical. This study suggests that there are many opportunities for Hawai‘i's land use and land management decisions to contribute to that effort with active support from its community of consumers, researchers, landowners, land managers, and public decision makers.

II. INTRODUCTION

According to the United Nations' Intergovernmental Panel on Climate Change (IPCC), the citizens, corporations, and governments of all nations of this shared planet have only ten years left to avoid the worst impacts predicted from the acceleration of climate change.[8] These extreme impacts include the complete loss of coral reefs and other ecosystems, extreme sea level rise, significant increases in drought, floods, and extreme heat, and poverty for hundreds of millions of people.[9]

Avoiding the most extreme effects of climate change will require drastically changing current behaviors to reduce the net human-caused emissions of greenhouse gases[10] by forty-five percent by 2030 and reach "net zero" emissions by 2050.[11] To reach "net zero," any greenhouse gas emissions that cannot be avoided must be balanced by removing carbon dioxide (CO_2) from the air. The IPCC makes clear that meeting these challenges will require "rapid and far-reaching" transitions in our global "energy, land, urban, infrastructure (including transport and buildings) and industrial systems."[12]

The land sector in particular provides opportunities to both reduce greenhouse gases released into the atmosphere (emissions) and remove CO_2 from the air and store it (sequestration). Decisions made at the global and local level about land use and land management have a significant role to play in changing the human behaviors that are accelerating climate change.

A. PROJECT PURPOSE

To explore these opportunities in Hawai'i's land sector, the Greenhouse Gas Sequestration Task Force issued a public Request for Quotes for a study to identify, analyze, evaluate, summarize, and compare key metrics for various greenhouse gas sequestration pathways specific to Hawai'i's natural and working lands and nearshore waters.

The Greenhouse Gas Sequestration Task Force (Task Force) was established within the State of Hawai'i Office of Planning as a permanent task force by Act 15, Session Law of Hawai'i (2018). The Task Force is charged, in part, with identifying land and marine use policies, agricultural policies, agroforestry policies, and mitigation options that would encourage agricultural and aquacultural practices and land use practices that promote and increase greenhouse gas sequestration, build healthy soils, and provide greenhouse gas benefits.

Conservation International (CI) was awarded the contract for this study. CI is a nonprofit organization founded in 1987 to help move societies toward a healthier, more sustainable development path that values nature's role in human wellbeing. CI's Hawai'i program was created in 2011 with a focus on ensuring that a healthy and abundant environment will continue to benefit Hawai'i and its people, now and into the future.

For this study, CI worked in collaboration with a directed study class from the William S. Richardson School of Law at the University of Hawai'i at Mānoa to synthesize existing literature, data, and information, identify significant data gaps, and develop broad comparisons of the greenhouse gas sequestration pathways provided by Hawai'i's natural and working lands and nearshore waters.

The analysis of each land use sector in this study uses existing and available information to compare each land use sector's potential for:

- greenhouse gas benefits and potential emissions;
- non-greenhouse gas co-benefits;
- risks and unintended consequences;
- potential monetary costs; and
- potential incentives and funding options.

B. METHODOLOGY

1. Project Drawdown

The Task Force framed the scope for this study in reference to grenhouse gas sequestration solutions defined by Project Drawdown. Project Drawdown is a nonprofit research organization and global coalition of scholars, scientists, entrepreneurs, and advocates that is mapping, measuring, modeling, and communicating about substantive solutions to global warming, with the goal of reaching drawdown.[13] Project Drawdown defines "drawdown" as "the point in time when the concentration of greenhouse gases in the Earth's atmosphere begins to decline on a year-to-year basis."[14]

The goal of Project Drawdown's research is to determine if the buildup of atmospheric carbon can be reversed within thirty years. Toward that goal, Project Drawdown evaluated more than 100 activities that can be acted on by individuals to contribute to this reversal.[15] Each of these activities, what Project Drawdown calls "solutions" were evaluated by Project Drawdown using the following criteria:

- "Is the solution currently available and scaling?
- Is it economically viable? (i.e. is there a business case?)
- Does it have the potential to reduce greenhouse

8 IPCC, *supra* note 1, at 4.
9 *Id.* at 7-9.
10 Referencing the IPCC, the Hawai'i Department of Health's inventory report of greenhouse gas emissions defines "greenhouse gases" as "gases that trap heat in the atmosphere by absorbing infrared radiation and thereby warming the planet. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)." ICF and the University of Hawaii Economic Research Organization, Hawaii Greenhouse Gas Emissions Report for 2015: Final Report at 1 (January 2019) (available at: https://health.hawaii.gov/cab/files/2019/02/2015-Inventory_Final-Report_January-2019-004-1.pdf. (last visited Mar. 17 2020) [hereinafter Hawaii Greenhouse Gas Emissions Report for 2015].
11 IPCC, *supra* note 1, at 12.
12 *Id.* at 15.
13 Frequently Asked Questions, *supra* note 6.
14 *Id.*
15 *Id.*

gases in the atmosphere, either through avoided emissions or sequestration, by at least fifty million tons of greenhouse gases globally over thirty years?
- Are there any negative results, such as pollution, reduced food security, land conversion, etc.? And if so, do the positive benefits outweigh the negatives?
- Do we have sufficient data to be able to model these technologies at global scale?"[16]

Based on each solution's performance against these criteria, Project Drawdown selected eighty solutions for full evaluation, modeling, and ranking.[17] These solutions were grouped into seven sectors for discussion: (1) Energy; (2) Food; (3) Women and Girls; (4) Buildings and Cities; (5) Land Use; (6) Transport; and (7) Materials.[18]

This desktop study for the Task Force focuses on Project Drawdown solutions from the Food and Land Use Sectors that have potential application in Hawai'i on lands currently used for agriculture, agroforestry, aquaculture, forestry, ranching, and urban forestry.

Food and Land Use Solutions from Project Drawdown Potentially Applicable to Hawai'i Lands

Food Sector Solutions	Land Use Sector Solutions
Silvopasture	Tropical Forests Restoration
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Perennial Biomass Production	Coastal Wetland Restoration
Nutrient Management	
Farm Irrigation Efficiency	
Biochar Production	

The twenty-one solutions reflected in the table above, as defined by Project Drawdown, provided a starting point for this study, to understand which activities they involve, which land types they are recommended for, and how they have been prioritized for action at the global scale.

Project Drawdown's analysis of each solution provided the total cost of implementing that solution at a global scale, which reflected the total amount needed to purchase, install, and operate anything required for that solution from 2020 to 2050.[19] By comparing this total cost to what Project Drawdown estimated was the typical cost of the practice being replaced, Project Drawdown provided what it determined to be the net costs or savings of that solution, if implemented on a global scale.[20] It is important to note that Project Drawdown did not consider any revenue that the might be generated from the carbon itself to reduce solution costs or savings (such as through the sale of voluntary or mandatory carbon offset credits, carbon tax-based incentives, or direct payments to landowners). The options available to generate revenue from carbon sequestration or emissions reduction will vary greatly from country to country; therefore Project Drawdown did not include this potential source of revenue in its global analysis of costs and savings.

2. Desktop Analysis

Using available Hawai'i data, research, and information, this desktop study reviews the potential for each of these twenty-one Project Drawdown solutions to:

- be adopted across the state of Hawai'i (i.e. available acres of recommended land type or use),
- increase greenhouse sequestration,
- reduce greenhouse gas emissions,
- generate co-benefits, and
- limit risks and unintended consequences.

The study also considers Hawai'i-specific factors that would likely impact the economic feasibility of each solution.

Specifically, the desktop research for this study took the following approach:

1. Analyzed Project Drawdown's solutions from the Land Use and Food Sectors that described current land covers and/or land uses for climate zones that are represented in Hawai'i;
2. Conducted online research for publicly available academic studies, journal articles, public agency reports, and nonprofit organization reports that described unique factors or circumstances that affect greenhouse gas sequestration rates or emissions reduction potential, co-benefits, and risks or unintended consequences in Hawai'i for the activities described in the selected Project Drawdown solutions;
3. Conducted online research for publicly available academic studies, journal articles, public agency reports, and nonprofit organization economic data and reports that described unique factors or circumstances in Hawai'i that would likely influence the po-

16 *Id.*
17 *Id.*
18 Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming 224-25 (Paul Hawken ed. 2017) [hereinafter Drawdown].

19 *Id.* at xiv.
20 Project Drawdown used a conservative approach that assumed costs on the high end associated with the adopting the solution and kept those costs relatively constant from 2020 to 2050. These are estimates derived from global data and fed into various projection models and only reflect the costs for thirty years of adoption. *Id.* at xiv.

tential costs per acre and/or potential net revenue per acre described in Project Drawdown solutions;

4. Analyzed the gathered research to rate each solution using a basic color scale (i.e. green=high, yellow=medium, or red=low) to reflect the solution's relative strength or weakness to contribute positively to greenhouse gas benefits, provide co-benefits, and limit risks or unintended consequences *(*Sufficient cost and savings data was not available for Hawai'i; therefore, the economic feasibility of each solution was not included in the ratings or ranking.);*
5. All analyzed solutions were then compared against each other and the highest rated solutions were identified for greenhouse gas benefits, co-benefits, and risks or unintended consequences;
6. All analyzed solutions were assigned a rank based on their relative ratings; and
7. Areas for further research were recommended.

The table below reflects the color rating that was used to reflect each solution's relative strength or weakness to contribute positively to greenhouse gas reduction, provide co-benefits, and limit risks and unintended consequences:

High	Medium	Low	
			Potential for Greenhouse Gas Benefits
			Potential for Co-Benefits
			Lack of Risks

III. HAWAI'I CONTEXT

To help understand the context within which Project Drawdown's solutions were considered for this desktop study, this section provides a brief overview of Hawai'i's climate, soils, and native biodiversity.

A. CLIMATE

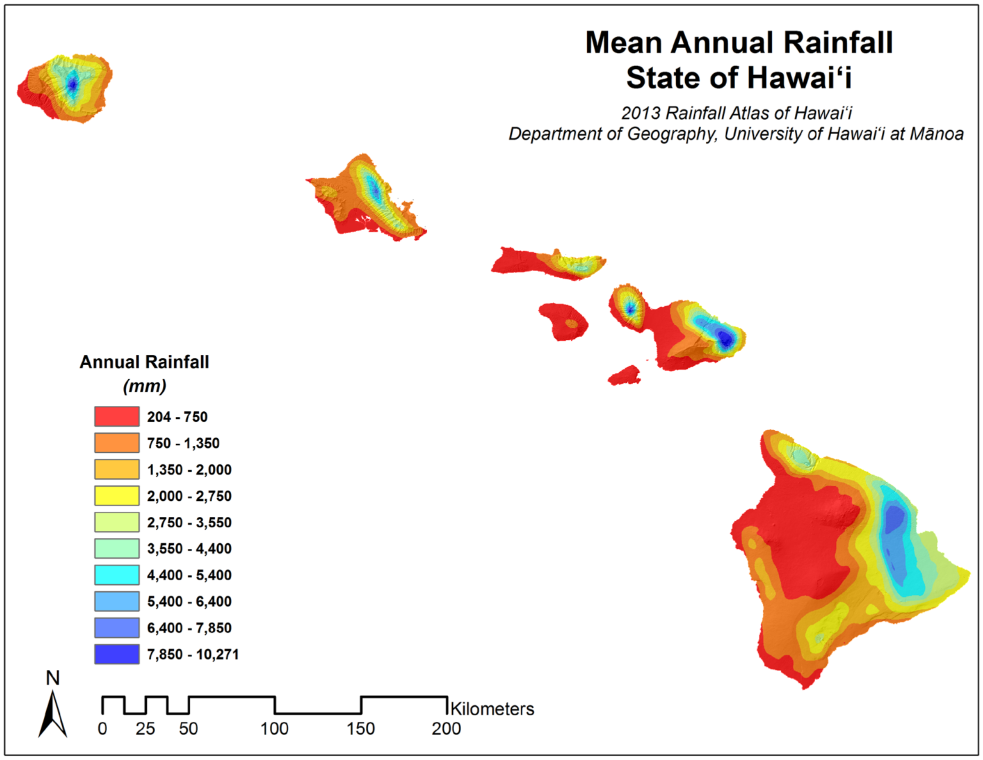
As described by the National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC), Hawai'i's climate is generally characterized by:

- a two-season year,
- mild and fairly uniform temperature conditions ev erywhere except at high elevations,
- striking, marked geographic differences in rainfall,
- generally humid conditions and high amounts of cloudiness except on the driest coasts and high elevations, and
- a general dominance of trade-wind flow especially at elevations below a few thousand feet.[21]

The NCDC further observes that Hawai'i is the only U.S. state that is completely surrounded by the ocean, and the only U.S. state within the tropics.[22] It is an archipelago that includes eight human-inhabited, widely spaced, and topographically diverse islands: Hawai'i; Maui, Moloka'i, Lāna'i, Kaho'olawe, O'ahu, Kaua'i, and Ni'ihau.[23] As estimated by the NCDC, the total area of these eight islands is 6,424 square miles, with Hawai'i Island being the biggest (4,021 square miles).[24] Important for the context of climate change concerns and discussions in Hawai'i, the NCDC points out that all Hawai'i islands are bordered by coral reef, and almost half of the area of the State of Hawai'i lies within five miles of the coast.[25]

The map below shows the distribution of the seven moisture zones across the main Hawaiian Islands.

21 National Climatic Data Center, Climate of Hawaii at 5, *available at* https://www.ncdc.noaa.gov/climatenormals/clim60/states/Clim_HI_01.pdf (last visited Mar. 17, 2020) [hereinafter Climate of Hawaii].
22 *Id.* at 1.
23 *Id.*
24 *Id.*
25 *Id.* at 1-2.



SOURCE: Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte. 2013. "Online Rainfall Atlas of Hawai'i." Bull. Amer. Meteor. Soc*. 94 313-316 doi: 10.1175/BAMS-D-11-00228.1*

B. SOILS

In discussions about climate change mitigation opportunities, the large contribution that soil can make is being increasingly recognized. Soil has been described as playing the following six key roles for ecosystems: "1) a medium for plant growth, 2) a system for water supply and purification, 3) a recycling system for nutrients and organic wastes, 4) a habitat for soil organisms, 5) a modifier of the atmosphere, and 6) an engineering medium."[26]

Research in Hawai'i has shown that the state is home to a diversity of soil types (ten of the twelve soil orders of the U.S. Department of Agriculture's classification system).[27] Of great importance to the topic of climate change mitigation in Hawai'i, research has shown that two of the soil orders found in Hawai'i (Histosols[28] and Andisols[29]) have an inherent potential to sequester large amounts of carbon.[30]

Additionally, these two soil orders make up about sixty-five percent of the soils found in Hawai'i.[31] As reflected in the map below, Andisols and Histosols are primarily concentrated on the islands of Maui and Hawai'i.[32] Detailed information about the soils found in specific parts of the state can be found through the Hawai'i Soil Atlas, an interactive, online tool developed by the University of Hawaii at Manoa, with support of the Hawai'i Agribusiness Development Corporation.[33]

26 Nyle C. Brady & Ray R Weil, The Nature and Properties of Soils. (14th ed. 2008); *see also* Hannah L. Hubanks, Jonathan L. Deenik, and Susan E. Crow, *Getting the Dirt on Soil Health and Management*, Reference Module in Earth Sys. & Envtl. Sci. 2 (2018) (providing a review of the important roles of soil, the changes in the soil health concept in recent history, and how soil health is being tested and applied to real-world issues).

27 J. Deenik & A.T. McClellan, *Soils of Hawai'i*, Soil & Crop Mgmt. 1-12, 1 (Sept. 2007), *available at:* https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-20.pdf (last visited Mar. 18, 2020). The ten soil orders are: Andisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols. Id.

28 Histosols are "soils that develop from organic materials and consist of more than 50 percent organic matter in the surface horizon." *Id.* at 3. "They are typically found in cool, moist environments that are so wet that they have anaerobic conditions in the soil profile." Id. They are found most extensively on Hawai'i Island. Id.

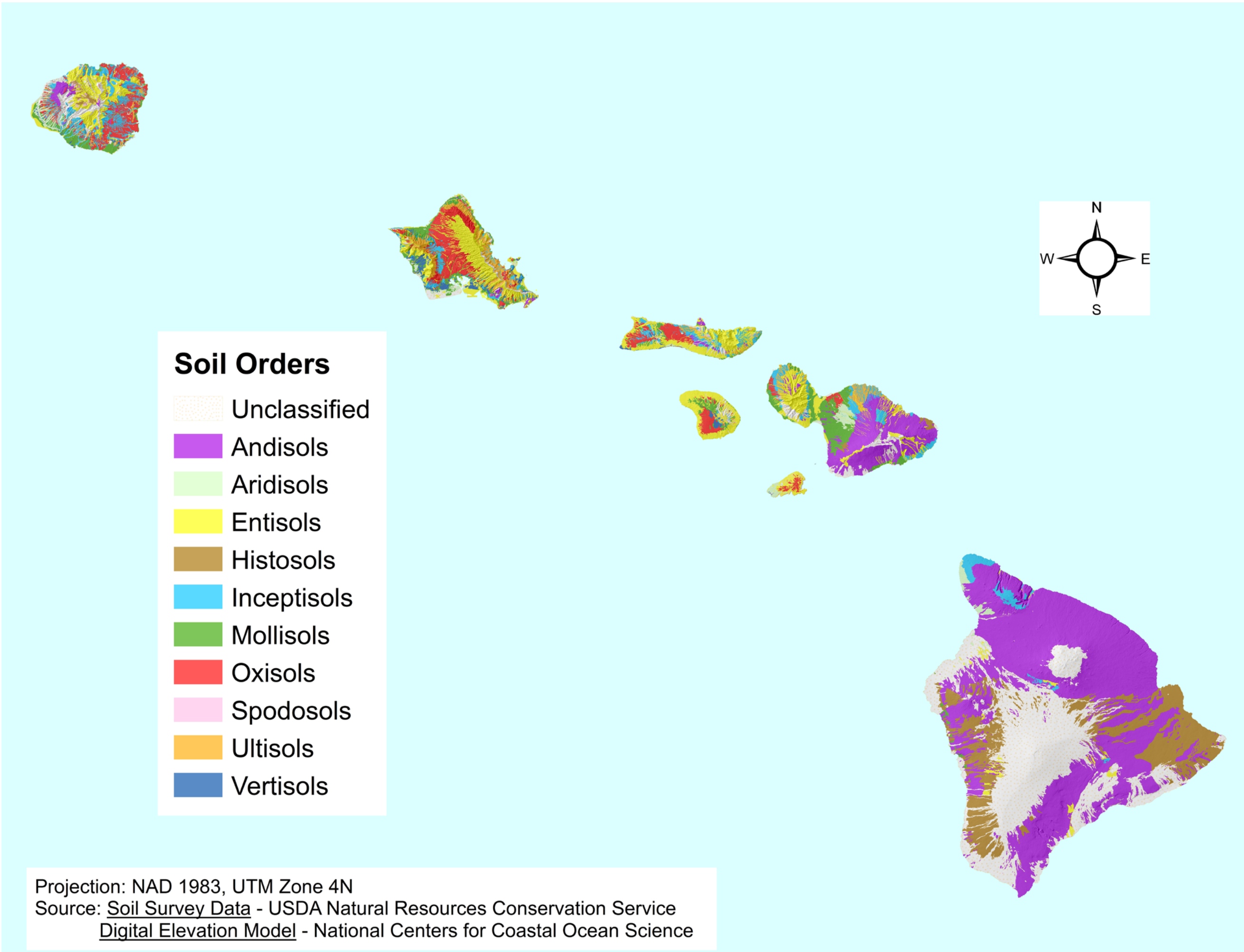
29 Andisols are volcanic ash-derived soils with a high mineral surface area and tremendous water-holding capacity. *Id.* at 2.

30 Laurie J. Osher, Pamela A. Matson, & Ronald Amundson, Effect of land use change on soil carbon in Hawaii, 65 Biogeochemistry 213 (2003) (acknowledging that Andisols store higher levels of carbon in a study that investigated the effect of land use changes from tropical forest to both sugarcane agriculture an dpasture on volcanic ash soils); R. A. Dahlgren, M. Saigusa, & F.C. Ugolini, *The Nature, Properties and Management of Volcanic Soils*, 82 Advances in Agronomy, 113-182 (2004).

31 Deenik & McClellan, *supra* note 27, at 3.

32 University of Hawai'i - College of Tropical Agriculture and Human Resources, Hawaii Soil Atlas, https://gis.ctahr.hawaii.edu/SoilAtlas#overview (last visited Mar. 17, 2020) [hereinafter Hawaii Soil Atlas].

33 *Id.*



SOURCE: Hawaii Soil Atlas, https://gis.ctahr.hawaii.edu/downloads/soilAtlas/SoilOrderSeries.jpg (last visited Mar. 17, 2020).

C. BIODIVERSITY

Re-emphasized in a recent assessment of the carbon balance in Hawaiʻi's ecosystems, the plant life of Hawaiʻi is unique to the world due in large part to the extreme isolation of the island archipelago.[34] Nearly ninety percent of Hawaiʻi's native plants are found nowhere else on the planet and many of them are listed as endangered or threatened.[35] In fact, Hawaiʻi contains forty-four percent of all the endangered and threatened plant species of the United States, despite making up less than one percent of the United States' land mass.[36] Only a few tree species were naturally established in Hawaiʻi, including the ʻŌhia which is the most abundant tree species in most native Hawaiian plant communities.[37]

The vegetation on the main Hawaiian Islands is influenced by a combination of moisture availability, temperature, and substrate type and age.[38] These factors determine the composition, structure, and distribution of plant species and communities across the archipelago.[39]

As acknowledged in the recent carbon balance assessment for Hawaiʻi's ecosystems, human changes to Hawaiʻi's original landscape, as well as impacts from introduced invasive plants and animals, have dramatically altered the composition and distribution of Hawaiʻi's plant communities, particularly in lower elevations.[40]

As reflected in the map below, more than sixteen percent of the main Hawaiian Islands has been heavily impacted by

34 James D. Jacobi, Jonathan P. Price, Lucas B. Fortini, Samuel M. Gon III, & Paul Berkowitz, *Chapter 2. Baseline Land Cover* in Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawaiʻi 9, 9 (Paul C. Selmants, Christian P. Giardina, James D. Jacobi, and Zhiliang Zhu, eds., 2017), *available at* https://pubs.usgs.gov/pp/1834/a/pp1834_chapter2.pdf (last visited Mar. 19, 2020).

35 State of Hawaii, Division of Forestry and Wildlife, Native Ecosystems Protection & Management, Rare Plant Program, https://dlnr.hawaii.gov/ecosystems/rare-plants/ (last visited Mar. 17, 2020).

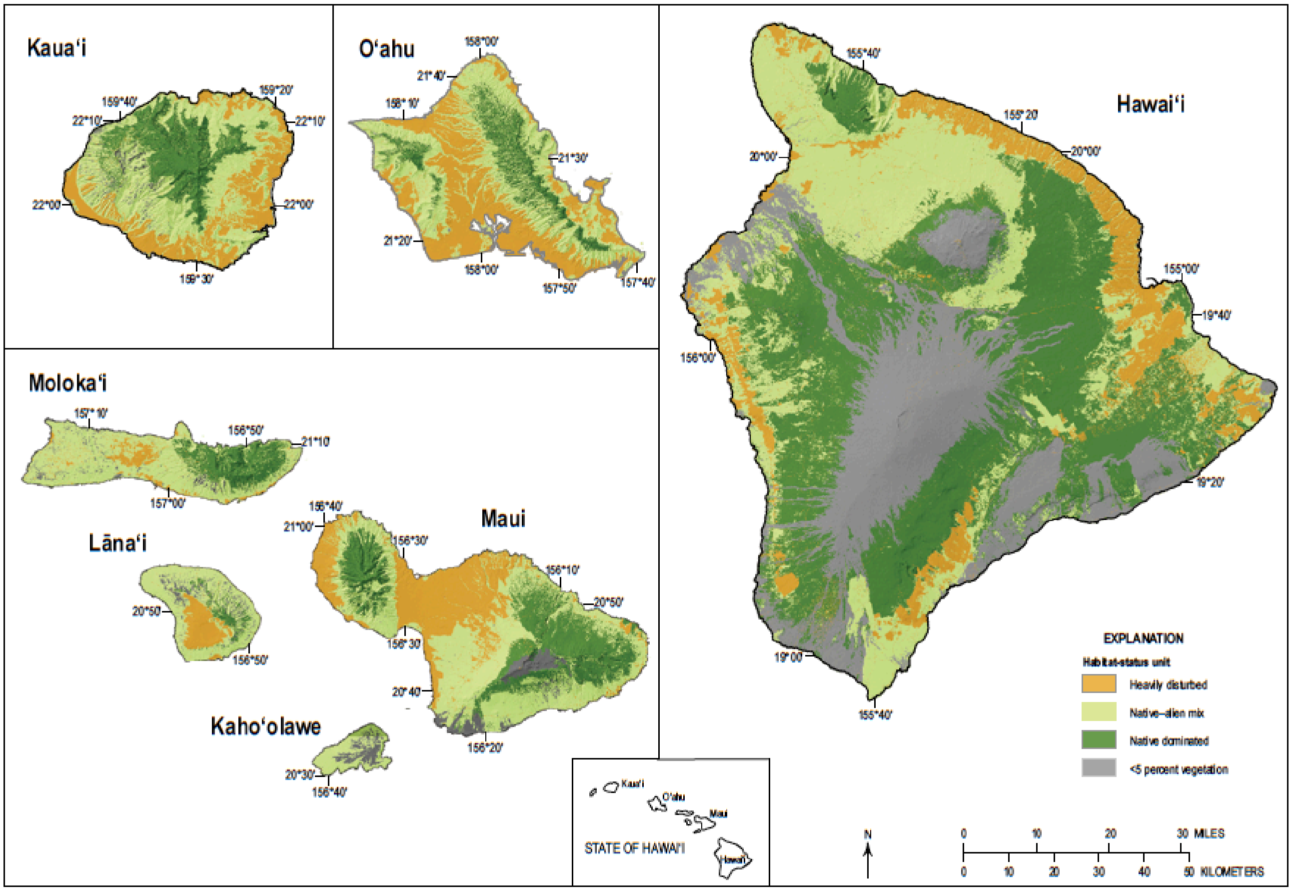
36 *Id.*

37 Jacobi, Price, Fortini, Gon, & Berkowitz, *supra* note 34 at 9.

38 *Id.* at 10; L.W. Pratt & S.M. Gon, III, *Terrestrial ecosystems*, in Atlas of Hawaiʻi (S.P. Juvik & J.O. Juvik, eds., 1998); J.P. Price, et al., *Mapping plant species ranges in the Hawaiian Islands—Developing a methodology and associated GIS layers*, U.S. Geological Survey Open-File Report 2012–1192, 1 appendix (species table), 1,158 maps (2012), *available at* http://pubs.usgs.gov/of/2012/1192/.

39 *Id.*

40 Jacobi, Price, Fortini, Gon, & Berkowitz, *supra* note 34, at 10; L.W. Cuddihy, & C.P. Stone, Alteration of native Hawaiian vegetation—Effects of humans, their activities and introductions (1990); F.R. Warshauer, *Alien species and threats to native ecology*, in Atlas of Hawaiʻi 146–149 (S.P. Juvik & J.O. Juvik, eds., 1998); Hawaiʻi's Invasive Species—A guide to invasive plants and animals in the Hawaiian Islands (G. W. Staples & R.H. Cowie, eds., 1st ed. 2001).



Source: BASELINE AND PROJECTED FUTURE CARBON STORAGE AND CARBON FLUXES IN ECOSYSTEMS OF HAWAI'I 9, 13 (Paul C. Selmants, Christian P. Giardina, James D. Jacobi, and Zhiliang Zhu, eds., 2017), available at: https://doi.org/10.3133/pp1834.

agriculture, urban development, and resort development.[41] Approximately thirty-one percent of the islands are still dominated by native vegetation, and thirty-six percent of the area has habitats that are somewhat disturbed, with a mix of native and alien plant species.[42]

IV. AGRICULTURE

A. OVERVIEW

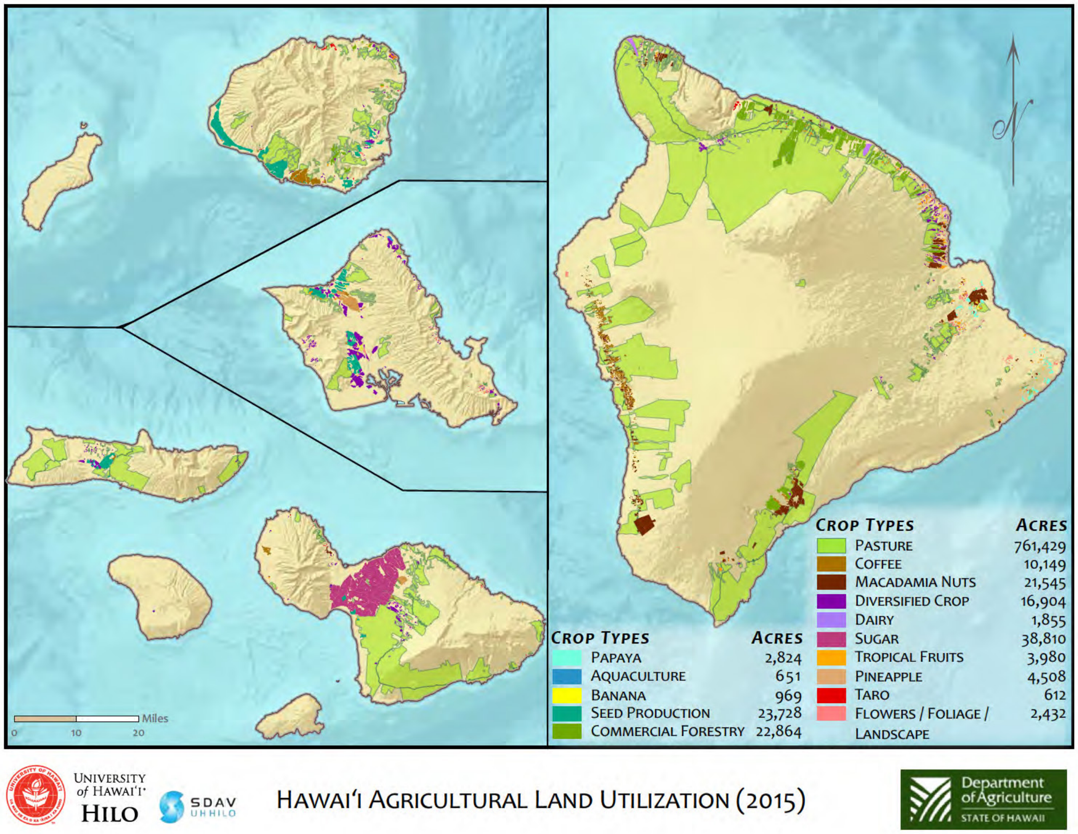
ATTRA, a Sustainable Agriculture Program developed and managed by the National Center for Appropriate Technology (NCAT) and funded by the United States Department of Agriculture (USDA), provides a helpful overview of the greenhouse gas emissions reduction and removal potential within the United States agriculture sector. Guidance from ATTRA notes that agriculture activities can serve as both sources and sinks for greenhouse gases.[43] For the agriculture sector, the primary sources of greenhouse gases are "the production of nitrogen-based fertilizers; the combustion of fossil fuels such as coal, gasoline, diesel fuel and natural gas; and waste management."[44] Additionally, the fermentation that takes place in the digestive systems of some livestock (i.e. ruminant animals like cows, sheep, or goats) also emits methane.[45]

The carbon sequestration potential in the agriculture sector relies on the capacity of agriculture lands to remove carbon dioxide from the atmosphere.[46] This potential for increased sequestration can be additional to carbon benefits provided by long-term storage of carbon in stable grasslands and healthy soil, which can act as carbon sinks.[47] Globally, soil serves as the largerrestrial sink for carbon.[48]

ATTRA's research reflects that greenhouse gas emissions from the agriculture sector in the United States account for a small percentage of overall emissions (eight percent), but those emissions have increased since 1990.[49] Although the percentage of overall emissions is small, agricultural produc-

41 Jacobi, Price, Fortini, Gon, & Berkowitz, *supra* note 34, at 13.
42 Id.
43 Jeff Schahczenski & Holly Hill, ATTRA: Agriculture, Climate Change and Carbon Sequestration 3 (2008) *available at* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_002437.pdf (last visited Mar. 18, 2020).
44 *Id.*
45 *Id.*
46 *Id.* at 5.
47 *Id.*
48 *Id.*
49 *Id.*; Congressional Budget Office, Policy Options for Reducing CO2 Emissions (2008), *available at* https://www.cbo.gov/sites/default/files/110th-congress-2007-2008/reports/02-12-carbon.pdf (last visited Mar. 18, 2020).

tion in the United States still generates more annual greenhouse gas emissions[50] than it captures, "despite the potential for this sector to sequester higher levels of carbon with management changes."[51] As noted by ATTRA, "[t]he ability of agriculture lands to store or sequester carbon depends on many factors, including climate, soil type, type of crop or vegetation cover, and management practices."[52]



Source: JEFFREY MELROSE, RYAN PERROY, & SYLVANA CARES, STATEWIDE AGRICULTURAL LAND USE BASELINE 2015, 21 (2016), available at http://hdoa.hawaii.gov/wp-content/uploads/2016/02/StateAgLandUseBaseline2015.pdf

A Statewide Agricultural Land Use Baseline for 2015 was prepared for the State of Hawai'i Department of Agriculture.[53] Above is a helpful overview map and table (on the next page) provided in the baseline study of the distribution of agriculture activities across the state of Hawai'i as of 2015.

B. CONSERVATION AGRICULTURE OR REGENERATIVE ANNUAL CROPPING SOLUTION

Project Drawdown's *conservation agriculture* solution and *regenerative annual cropping* solution are closely linked in Project Drawdown's modeling and analysis.[54] As a result, their separate definitions are provided here; however, the analysis for their application to Hawai'i are combined

1. Conservation Agriculture Definition

As defined by Project Drawdown, the *conservation agriculture* solution is "an annual crop production system that provides biosequestration via crop rotation, cover cropping, and reduced tillage."[55] This solution has three components: (1) minimal soil disturbance (no-till or reduced tillage), (2) permanent soil cover (cover crops), and (2) diversified crop rotations.[56] Project Drawdown considers this solution suitable to both mechanized and unmechanized contexts. Greenhouse gas benefits from this solution are anticipated through reduced emissions from tillage and increased soil carbon sequestration.[57]

50 "The U.S. agricultural production sector contributes more greenhouse gas emissions from methane (CH_4) and nitrous oxide (N_2O) than from carbon dioxide (CO_2)." Schahczenski & Hill, *supra* note 43, at 5.
51 *Id.*
52 *Id.*
53 Jeffrey Melrose, Ryan Perroy, & Sylvana Cares, Statewide Agricultural Land Use Baseline 2015 (2016), *available at* http://hdoa.hawaii.gov/wp-content/uploads/2016/02/StateAgLandUseBaseline2015.pdf (last visited Mar. 18, 2020).
54 Drawdown.org, Technical Summary: Conservation Agriculture, https://www.drawdown.org/solutions/conservation-agriculture/technical-summary (last visited Mar. 18, 2020) [hereinafter Technical Summary: Conservation Agriculture].
55 *Id.*
56 *Id.*
57 *Id.*

2015 Crop Summary by Acreage							
Crop Types	**Hawai'i**	**Kaua'i**	**Maui**	**Moloka'i**	**Lāna'i**	**O'ahu**	**State Total**
Aquaculture	165	183	-	28	-	274	*651*
Banana	536	26	62	-	-	345	*969*
Coffee	5,525	3,788	545	123	-	168	*10,149*
Commercial Forestry	21,061	1,743	33	-	-	26	*22,864*
Dairy	1,855	-	-	-	-	-	*1,855*
Diversified Crop	3,266	1,199	1,582	937	54	9,865	*16,904*
Flowers / Foliage / Landscape	1,612	165	134	26	10	484	*2,432*
Macadamia Nuts	21,359	-	186	-	-	-	*21,545*
Papaya	2,566	-	-	93	-	166	*2,824*
Pineapple	-	-	1,094	-	-	3,414	*4,508*
Seed Production	-	13,299	754	2,342	-	7,333	*23,728*
Sugar	-	-	38,810	-	-	-	*38,810*
Taro	61	443	54	2	-	51	*612*
Tropical Fruit	3,144	463	104	43	-	227	*3,980*
Crop Total:	***61,149***	***21,310***	***43,360***	***3,593***	***65***	***22,354***	**151,831**
Pasture	554,324	41,934	108,447	38,261	-	18,464	761,429
Total Agriculture	***615,473***	***63,244***	***151,808***	***41,854***	***65***	***40,818***	**913,261**

Source: JEFFREY MELROSE, RYAN PERROY, & SYLVANA CARES, STATEWIDE AGRICULTURAL LAND USE BASELINE 2015, 47 (2016), available at http://hdoa.hawaii.gov/wp-content/uploads/2016/02/StateAgLandUseBaseline2015.pdf

2. Regenerative Annual Cropping Definition

As defined by Project Drawdown, the *regenerative annual cropping* solution is "any annual cropping system that includes at least four of the following six practices:

- Compost application,
- Cover crops,
- Crop rotation,
- Green manures,
- No-till or reduced tillage, and/or
- Organic production."[58]

The *regenerative annual cropping* solution essentially adds any two of the following practices to the *conservation agriculture* solution: compost application, green manures, or organic production. According to Project Drawdown, under this solution, the *conservation agriculture* solution becomes more ecological.[59]

3. Potential Application to Hawai'i Lands

Project Drawdown considered the *conservation agriculture* solution to be a replacement for conventional annual cropping systems with tillage.[60] More specifically, Project Drawdown limited the application of this solution to cropland of minimal slope.[61] Project Drawdown considers the *conservation agriculture* solution to be bridge technology to the *regenerative annual cropping* solution, so their adoption scenarios are linked.[62] As a result, their application to Hawai'i lands is considered to be the same for this analysis. As of 2017, there were approximately 191,175 acres of cropland across the state of Hawai'i.[63] Information is not currently available to indicate how many of these acres use conventional annual cropping systems and have minimal slopes. If that data were available, it would provide a more detailed picture of where this solution might be considered for adoption in Hawai'i.

4. Potential Greenhouse Gas Benefits

a) Sequestration

Project Drawdown set the following sequestration rates for the *conservation agriculture* solution:[64]

Climate zone and moisture regime	Sequestration rate (tons of CO_2e)
Tropical humid	2.86 per hectare/yr (or 1.16 per acre/yr)
Temperate/boreal humid	1.39 per hectare/yr (or 0.56 per acre/yr)
Tropical semi-arid	2.24 per hectare/yr (or 0.91 per acre/yr)
Temperate/boreal semi-arid	0.92 per hectare/yr (or 0.37per acre/yr)

58 Drawdown.org, Technical Summary: Regenerative Annual Cropping, https://www.drawdown.org/solutions/regenerative-annual-cropping/technical-summary (last visited Mar. 18, 2020) [hereinafter Technical Summary: Regenerative Annual Cropping].
59 *Id*
60 Technical Summary: Conservation Agriculture, *supra* note 54.
61 *Id.*
62 *Id.*
63 National Agricultural Statistics Service, *Table 1. Historical Highlights: 2017 and Earlier Census Years, in* 2017 Census of Agriculture -State Data (2017), available at https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Hawaii/st15_1_0001_0001.pdf (last visited Mar. 18, 2020) [hereinafter *Table 1. Historical Highlights*].
64 Technical Summary: Conservation Agriculture, *supra* note 54. Project Drawdown provides all of its carbon sequestration rates in tons of carbon per year. To provide consistent units in this report, Project Drawdown's sequestration rates have been multiplied by 3.67 to convert them to tons of CO_2e per year.

Project Drawdown set the sequestration rates for the *regenerative annual cropping* solution using the upper boundary from the *conservation agriculture* solution model, since the *regenerative annual cropping* solution adds known sequestration practices to the three already practiced in the *conservation agriculture* solution.[65]

Project Drawdown set the following sequestration rates for the *regenerative annual cropping* solution:[66]

Climate zone and moisture regime	Sequestration rate (tons of CO_2e)
Tropical humid	4.4 per hectare/yr (or 1.78 per acre/yr)
Temperate/boreal humid	2.2 per hectare/yr (or 0.89 per acre/yr)
Tropical semi-arid	5.1 per hectare/yr (or 2.08 per acre/yr)
Temperate/boreal semi-arid	1.5 per hectare/yr (or 0.61 per acre/yr)

Areas in Hawaiʻi where the *conservation agriculture* or *regenerative annual cropping* solutions might be applied are likely to fall within the tropical humid or tropical semi-arid zones.

An additional factor to consider for Hawaiʻi is that two of Hawaiʻi's soil orders, Histosols and Andisols, have an inherent ability to sequester large amounts of carbon.[67] These soils make up sixty-five percent of soils in Hawaiʻi and are primarily concentrated on the islands of Maui and Hawaiʻi.[68] If these soils are found in the areas where the *conservation agriculture* solution or *regenerative annual cropping* solutions are pursued, the carbon sequestration rate per acre could be higher than the rate set by Project Drawdown for tropical humid and tropical semi-arid zones.

b) Emissions Reductions

According to Project Drawdown, greenhouse gas emissions reductions from the *conservation agriculture* and the *regenerative annual cropping* solutions would come from replacing current practices on cropland with practices that minimize soil disturbance (no tillage), maintain soil cover (by leaving crop residues after harvesting or growing cover crops) and manage crop rotation.[69] Using global data and analysis, Project Drawdown set the emissions reduction rate for both solutions at 0.23 tons of carbon dioxide equivalent (CO_2e)[70] per hectare per year (or approximately 0.09 tons of CO_2e per acre per year).[71]

In 2015, emissions from agricultural soils in Hawaiʻi were 0.56 million metric tons (MMT) CO_2e, accounting for fifty-one percent of Hawaiʻi's agriculture, forestry, and other land uses (AFOLU) sector emissions.[72] The model currently used to determine soil emissions for Hawaiʻi, however, is based on the continental U.S. and has limitations in its application to Hawaiʻi, including its small land area and high climate and soil variability.[73] There are efforts currently underway to develop methods and modeling tools specific to Hawaiʻi that would provide more accurate estimates of emissions for agricultural soils. Improved Hawaiʻi-specific modeling of these emissions would provide a better picture of Hawaiʻi's opportunities to reduce emissions in this category.

Another factor to consider for Hawaiʻi is that despite interest in local food production, Hawaiʻi's agricultural sector is still largely export oriented. Sugar, macadamias, coffee, commercial forestry and flowers, seed research, and other export crops accounted for over seventy-nine percent of the crops in land use in 2015.[74] Emissions related to exporting crops out of the state would limit the emissions reduction estimates for the *conservation agriculture* and *regenerative annual cropping* solutions provided by Project Drawdown.

5. Potential Co-Benefits

According to Project Drawdown, the *conservation agriculture* and *regenerative annual cropping* solutions make land more resilient to climate-related events such as long droughts and heavy downpours.[75] Reducing tillage also improves water conservation, reduces soil erosion, reduces fuel consumption, reduces compaction, increases planting and harvesting flexibility, reduces labor requirements, and improves soil tilth.[76] Reduced soil erosion can benefit streams and nearshore marine habitats, which also benefits the people who use them. Crop rotation and soil cover can also increase habitat for microorganisms and pollinators, such as insects and some native birds. Soil cover can also improve air quality by decreasing soil erosion from wind.

One Hawaiʻi agricultural extension agent reported the potential for proper crop rotation to break pest cycles that can become very costly.[77] Rotation between cash crops and cover crops can also increase soil organic matter.[78] Increased soil organic matter connected with *regenerative annual cropping* can also result in: vital microbes proliferating, plant roots going deeper, nutrient uptake improving, water

65 Technical Summary: Regenerative Annual Cropping, *supra* note 58.
66 *Id.*
67 Osher, Matson, & Amundson, supra note 30; Dahlgren, Saigusa, & Ugolini, *supra* note 30.
68 Deenik & McClellan, *supra* note 27, at 3; Hawaii Soil Atlas, *supra* note 32.
69 Technical Summary: Conservation Agriculture, *supra* note 54.
70 As explained in the Hawaii Greenhouse Gas Emissions Report for 2015, '[t]he amount of warming caused by each greenhouse gas depends on how effectively the gas traps heat and how long it stays in the atmosphere." Hawaii Greenhouse Gas Emissions Report for 2015, *supra* note 10 at 1. "The [IPCC] developed the Global Warming Potential (GWP) concept to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to the reference gas, CO_2. The relative contribution of each gas is shown in carbon dioxide equivalent (CO_2e)." *Id.;* IPCC, Good Practice Guidance for Land Use, Land-Use Change, and Forestry (J. Penman, et al., eds. 2004), *available at*: https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf (last visited Mar. 18, 2020).
71 Technical Summary: Conservation Agriculture, *supra* note 54.; Technical Summary: Regenerative Annual Cropping, *supra* note 58.
72 Hawaii Greenhouse Gas Emissions Report for 2015, *supra* note 10 at 49.
73 *Id.* at 50.
74 Melrose, Perroy, & Cares, supra note 53, at 4.
75 Technical Summary: Conservation Agriculture, *supra* note 54.
76 Schahczenski & Hill, *supra* note 43, at 12.
77 Glenn Teves, County Extension Agent, University of Hawaiʻi College of Tropical Agriculture and Human Resources, Cooperative Extension Service Molokai: Rotating your crop, Hawaiʻi Homegrown Food Network, *available at* https://www.hawaiihomegrown.net/talking-story/521-rotating-your-crop (last visited Mar. 18, 2020).
78 Research in Hawaiʻi showed a 14% increase in soil organic matter following seven years of consecutive rotation between cash crops and cover crops in a conservation tillage system. Josiah Marquez, Kelsey Mitsuda, & Koon-Hui Wang, Improving Conservation Tillage with Conservation Agriculture Practices (2016), *available at* https://gms.ctahr.hawaii.edu/gs/handler/getmedia.ashx?moid=2336&dt=3&g=12 (last visited Mar. 18, 2020).

retention increasing, and soil fertility compounding.[79]

6. Risks and Potential Unintended Consequences

Hawaiʻi has very limited no-till resources.[80] No-till agriculture[81] can have high equipment costs and a steep learning curve.[82] Most no-till equipment is built for very large farms, can cost $50,000 or more, and are generally not used by Hawaiʻi farmers who mostly operate on small farms.[83] In some cases, when transitioning from tillage to no-till practices, different pest species can arise, and the kinds of weeds and crop diseases can change.[84]

Switching to organic production (one option under the *regenerative annual cropping* solution) can be costly, mainly due to weed control needs.[85] In Hawaiʻi, use of compost could be limited by the availability of on-island composting facilities that supply quantities large enough for farming at scale.[86]

7. Economic Feasibility

Under Project Drawdown's analysis, the *conservation agriculture* solution and the *regenerative annual cropping* solution would require an initial investment to transition from conventional annual crop production systems, but an annual net profit would be expected that would be higher than the annual net profit expected from the conventional systems.

Using global data and modeling, Project Drawdown estimated the following related to adopting the *conservation agriculture* or the *regenerative annual cropping* solutions on cropland currently using conventional annual crop production systems:[87]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Crop Yield Gains
$355.05 per hectare (or approximately $143.68 per acre)	$530.39 per hectare/yr (or approximately $214.64 per acre/yr)	$474.21 per hectare/yr (or approximately $152.56-$191.91 per acre/yr)	6% (conservation agriculture) -1.02% (regenerative annual cropping)

Project Drawdown's cost estimates above are likely a fraction of the costs required to adopt these practices in Hawaiʻi. A 2012 study conducted in Hawaiʻi found that, in general, Hawaiʻi farmers faced higher costs for labor, electricity, fertilizer, land, and transportation than their U.S. mainland and Japanese market competitors.[88] This resulted in much of the food consumed in Hawaiʻi being produced out of the state, mostly on the U.S. mainland.[89] Intense import competition squeezed profit margins for Hawaiʻi farms and reduced local production.[90]

Labor was found to be the largest factor input for Hawaiʻi farms in that 2012 study, and its overall share was significantly higher than on U.S. Mainland farms in the same sector.[91] Hawaiʻi was also found to have a greater percentage of labor-intensive fruit/tree-nut and vegetable/melon farms.[92]

Hawaiʻi's smaller farm scale (on average, less than half the size of the average U.S. Mainland farm) was found to further aggravate the cost disadvantages.[93] Small farmers would likely need to take part of their limited land out of production to grow a cover crop, which would also require a sacrifice of cash crop revenue.[94] That may not be financially feasible for many small farmers in Hawaiʻi.[95] Since the *regenerative annual cropping* solution anticipates the adoption of one to three more practices than the *conservation agriculture* solution, the costs to Hawaiʻi farmers would likely be even higher.

Another Hawaiʻi-specific factor to consider is that any costs associated with equipment, supplies, or specialized labor that would need to be shipped in from out-of-state or shipped between islands would likely involve additional costs for Hawaiʻi farmers than was estimated by Project Drawdown.

8. Overall Ratings

Conservation Agriculture

High	Medium	Low	
			Potential for Greenhouse Gas Benefits
			Potential for Co-Benefits
			Lack of Risks

79 Technical Summary: Regenerative Annual Cropping, *supra* note 58.

80 E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center, to Aarin Gross, Conservation International Hawaiʻi Program (Dec. 9, 2019, 9:36am HST) (on file with author) [herein after E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center].

81 In the U.S., no-till agriculture fits under the broader U.S. Department of Agriculture definition of "conservation tillage," which includes "any method that retains enough of the previous crop residues such that at least 30 percent of the soil surface is covered after planting." David R. Huggins & John P. Reganold, *No-Till: the Quiet Revolution*, Scientific Am. Inc. 73, 70-77 (July 2008), available at https://www.ars.usda.gov/ARSUserFiles/20902500/DavidHuggins/NoTill.pdf (last visited Mar. 18, 2020).

82 *Id.* at 75.

83 E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center, *supra* note 80. In 2017, the largest number of farms in Hawaiʻi were between 1 and 9 acres (4,868 farms) followed by farms between 10 and 49 acres (1,693 farms). National Agricultural Statistics Service, *Table 9. Land in Farms, Harvested Cropland, and Irrigated Land by Size of Farm: 2017 and 2012, in* 2017 Census of Agriculture - State Data (2017), *available at* https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Hawaii/st15_1_0009_0010.pdf (last visited Mar. 18, 2020) [hereinafter *Table 9. Land in Farms, Harvested Cropland, and Irrigated Land by Size of Farm*].

84 Huggins & Reganold, *supra* note 81, at 75. There is a perception by some that no-till agriculture requires more chemical inputs (e.g. fertilizer, pesticides, herbicides, etc.) than conventional tillage practices. Theodor Friedrich & Amir Kassam, *No-Till Farming and the Environment: Do No-Till Systems Require More Chemicals?*, Outlooks on Pest Mgmt., 54, 53-57 (August 2012).

85 E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center, *supra* note 80.

86 *Id.*

87 Technical Summary: Conservation Agriculture, *supra* note 54; Technical Summary: Regenerative Annual Cropping, *supra* note 58.

88 "For Hawaiʻi farmers who face imports from a much larger, cost-efficient agricultural producer, the competitive challenges are steep." Shawn Arita, Emiko Naomasa, & PingSun Leung, *Comparison of Cost Structure and Economic Performance of Hawaiʻi and U.S. Mainland Farms,* CTAHR, Economic Issues, 1, 1-20 (2012), available at *https://www.ctahr.hawaii.edu/oc/freepubs/pdf/EI-21.pdf* (last visited Mar. 18, 2020).

89 Id.

90 *Id.*

91 *Id.* at 6.

92 *Id.* at 8.

93 *Id.* at 1.

94 E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center, *supra* note 80.

95 *Id.*

Regenerative Annual Cropping

High	Medium	Low	
	■		Potential for Greenhouse Gas Benefits
■			Potential for Co-Benefits
		■	Lack of Risks

Further Research Needed:

- Data and maps that reflect conventional annual crop production system use on croplands of limited slopes in Hawai'i;
- Models specific to Hawai'i for estimating changes in soil organic carbon;[96]
- Understanding of how climate change impacts, such as continued warming, might affect microbial communities and soil organic carbon pools;[97]
- Research into small-scale, no-till equipment and the potential for public and private investment opportunities to support adoption of that technology; and
- Cost information on implementation of *conservation agriculture* or *regenerative annual cropping* practices in Hawai'i.

C. ADD-ON SOLUTIONS

The two solutions covered below in this section, *nutrient management* and *farm irrigation efficiency,* are solutions that may bring additional greenhouse gas benefits when combined with another Project Drawdown solution (in this case, *regenerative annual cropping* or *conservation agriculture*). This section covers the highlights of these two add-on solutions.

1. Nutrient Management Solution Definition

Project Drawdown defines the *nutrient management* solution as "fertilizer application practices that use right source, right rate, right time, and right placement principles."[98]

Project Drawdown notes that the application of nitrogen fertilizers to the soil can lead to emissions of nitrous oxide, when fertilizer that is not used by plants is used by denitrifying bacteria that release nitrous oxide as a metabolic byproduct.[99] Additionally, producing fertilizer is an energy-intensive process that creates high amounts of carbon dioxide emissions, so reducing fertilizer use can also reduce the emissions associated with its production.[100]

Project Drawdown's *nutrient management* solution replaces conventional fertilizer use on cropland.[101] Using global data and analysis, Project Drawdown estimated the emissions reduction potential for this solution using the following rates: [102]

Source of Reduction	Rate of Emissions Reduction
Reduced emissions from carbon dioxide	0.49 tons of CO_2e per hectare per year (or 0.20 tons of $CO_2$2e per acre per year)
Reduced emissions from nitrous oxide	0.44 tons of CO_2e per hectare per year (or 0.18 tons of CO_2e per acre per year)

According to Project Drawdown, implementation of this nutrient management solution would require farmers to reduce their fertilizer inputs rather than undertake a new practice or install a new technology.[103] Project Drawdown suggests that education, assistance, incentives, and regulation could accelerate the adoption of this solution; however, ultimately concludes that the true solution to nutrient management would be rotational regenerative land practices that could eliminate most, if not all, of the need for synthetic nitrogen.[104]

In 2017, there were 191,175 acres of cropland across the state in Hawai'i.[105] It's unclear from available data how many of those acres would benefit from the *nutrient management* solution.

There are several Hawai'i-specific factors that would likely influence the adoption of the *nutrient management* solution. First, managing nitrogen excess is important to protect drinking water supplies in Hawai'i.[106] Most of the drinking water in Hawai'i comes from groundwater that is fed by rainfall and collected in underground aquifers that sit above the saline ocean water.[107] These aquifers are not shared among the islands and are finite.[108] Avoiding contamination of these limited drinking water supplies is critical for communities across the state.

Second, overapplication of nutrients can become potential runoff into streams and nearshore marine ecosystems. A factor to consider is that some of Hawai'i's soils (such as Oxisols, Ultisols, and Andisols) hold some chemicals, such as phosphorous, strongly against plant uptake. [109] This means large amounts of fertilizer are often applied before the chemicals can become available to the plants.[110] Adjust-

96 Jennifer W. Harden, et al., *Networking our science to characterize the state, vulnerabilities, and management opportunities of soil organic matter*, Global Change Biology, Oct. 05: e705-e718 (2017), *available at* https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13896 (last visited Mar. 18, 2020).
97 *Id.*
98 Drawdown.org, Technical Summary: Nutrient Management, *https://www.drawdown.org/solutions/nutrient-management/technical-summary* (last visited Mar. 18, 2020) [hereinafter Technical Summary: Nutrient Management]. Project Drawdown considers these principles to be important "for both countries where fertilizer consumption is high and nitrogen use efficiency is low (e.g., United States, China) as well as in countries where substantial increases in nutrient inputs on cropland is needed (Sub-Saharan Africa). *Id.*
99 *Id.*
100 *Id.*
101 *Id.*
102 Drawdown.org, Nutrient Management, *https://www.drawdown.org/solutions/nutrient-management* (last visited Mar. 18, 2020) [hereinafter Overview: Nutrient Management].
103 *Id.*
104 *Id.*
105 *Table 1. Historical Highlights, supra* note 63.
106 J. A. Silva, C. I. Evensen, R. L. Bowen, R. Kirby, G. Y. Tsuji, & R. S. Yost, Managing Fertilizer Nutrients to Protect the Environment and Human Health, in Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture, 10, 7-22 (2000), available at *https://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm1.pdf* (last visited Mar. 18, 2020).
107 *Id.*
108 *Id.*
109 *Id.*
110 *Id.* at 10-11.

ing the pH levels of the soil can affect how tightly these chemicals are held, but raising the pH in these soils can also release nitrate that has already been applied and potentially have negative effects on groundwater and other environmental consequences.[111] This dynamic would need to be closely monitored and managed to achieve the greatest nutrient management efficiency for these soils.

A third consideration is that reducing fertilizer use would also reduce the greenhouse gas emissions related to shipping the fertilizer into Hawai'i. Using recyclable waste materials (such as chicken manure, compost from food waste, fish waste, or tree trimmings) could be explored to help reduce the need to import fertilizers.[112]

The final consideration is that there may currently be a lack of research and extension to farmers or incentive for farmers to adopt this solution in Hawai'i.[113]

2. Farm Irrigation Efficiency Solution

Project Drawdown defines the *farm irrigation efficiency* solution as "a set of energy-efficient irrigation practices that increase crop yields while reducing emissions."[114] These practices include drip and sprinkler methods, irrigation scheduling and deficit irrigation for variable water application, and sensors to monitor soil moisture and control irrigation systems automatically.[115] Rainwater and runoff can also be captured and reused to reduce total water consumption.[116] All of these technologies are aimed at making water application more exact, so the amount delivered matches the amount crops need to thrive.[117]

According to Project Drawdown, "because pumping and distributing water requires large quantities of energy, irrigation is a source of carbon emissions."[118] This solution replaces conventional irrigation on irrigated cropland.[119] Project Drawdown estimates that employing improved farmland irrigation practices across the agricultural sector can bring water and greenhouse gas savings as high as twenty-five percent and forty percent under sprinkler and drip methods, respectively, compared with conventional irrigation methods.[120]

Project Drawdown also acknowledges that "both drip and sprinkler irrigation systems require infrastructure and upkeep, which can be expensive, sometimes prohibitively so."[121] Using global data and modeling, Project Drawdown estimated that if no irrigation system is present on the land, there would be necessary first costs of $671.37 per hectare (or approximately $271.69 per acre) prior to adopting the *farm irrigation efficiency* solution.[122] Following those costs, the costs below reflect what Project Drawdown estimated would be required to adopt and operate the *farm irrigation efficiency* solution in comparison to conventional irrigation practices:[123]

First Costs to Adopt Solution	Operational Cost with Solution	Operational Cost with Current Practice	Crop Yield Gains
$1,575.86 per hectare (or $637.73 per acre)	$151.02 per hectare (or $61.12 per acre)	$274.04 per hectare (or $110.90 per acre)	Not addressed

In 2017, Hawai'i had 25,402 acres of irrigated cropland across the state.[124] More than seventy percent of the farms with irrigated land were less than nine acres in size.[125] Reducing the overall amount of water that crops need to thrive can be particularly important in Hawai'i where many areas of the state have limited water access and many competing uses. Additionally, Hawai'i farmers face some of the highest electricity costs in the U.S.[126] This *farm irrigation efficiency* solution could reduce the electricity costs associated with irrigation.

Being an island economy, however, Hawai'i farmers face a maritime transportation cost disadvantage.[127] As with other solutions discussed in this report, materials, equipment, or technology used in the *farm irrigation efficiency* solution will likely be more costly for Hawai'i farmers, if it must be shipped in from out of the state.

D. SOLUTIONS THAT REQUIRE MORE INFORMATION

Project Drawdown provides two solutions related to rice cultivation (*improved rice production*[128] and *system of rice intensification*[129]). Hawai'i does not currently have commercial rice cultivation, so these solutions are not discussed or analyzed in this report. It is worth noting, however, that Hawai'i does cultivate wetland taro, which is one of Hawai'i's most iconic

111 *Id.* at 14.
112 Hazel Parcon, Shawn Arita, Matthew Loke, & PingSun Leung, *A Comparison of Agricultural Input Prices: Hawai'i vs. Its Major Export Competitors*, CTAHR, Economic Issues 12-16, 1-23 (October 2011).
113 E-mail from Jayme Barton, Hawai'i Agriculture Research Center, *supra* note 80.
114 Drawdown.org, Technical Summary: Farm Irrigation Efficiency, https://www.drawdown.org/solutions/farm-irrigation-efficiency/technical-summary (last visited Mar. 19, 2020) [hereinafter Technical Summary: Farm Irrigation Efficiency].
115 Drawdown.org, Farm Irrigation Efficiency, https://www.drawdown.org/solutions/farm-irrigation-efficiency (last visited Mar. 19, 2020) [hereinafter Overview: Farm Irrigation Efficiency].
116 *Id.*
117 *Id.*
118 *Id.* Project Drawdown's meta-analysis of Food and Agriculture Organization (FAO) data found that conventional irrigation requires 2.3 terawatt-hours per million hectares per year, while improved irrigation uses 1.5 terawatt-hours per million hectares per year. Technical Summary: Farm Irrigation Efficiency, *supra* note 114.
119 Technical Summary: Farm Irrigation Efficiency, *supra* note 114.
120 Technical Summary: Farm Irrigation Efficiency, *supra* note 114.
121 Overview: Farm Irrigation Efficiency, *supra* note 115.
122 Technical Summary: Farm Irrigation Efficiency, *supra* note 114.
123 *Id.*
124 National Agricultural Statistics Service, *Table 71. Summary by Size of Farm: 2017*, *in* 2017 Census of Agriculture - State Data (2017), *available at* https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Hawaii/st15_1_0071_0071.pdf (last visited Mar. 19, 2020) [herein after *Table 71. Summary by Size of Farm*].
125 *Table 9. Land in Farms, Harvested Cropland, and Irrigated Land by Size of Farm*, *supra* note 83.
126 Arita, Naomasa, & Leung, *supra* note 88, at 1.
127 Parcon, Arita, Loke, & Leung, *supra* note 112, at 10.
128 Drawdown.org, Improved Rice Production, https://www.drawdown.org/solutions/improved-rice-production (last visited Mar. 19, 2020).
129 Drawdown.org, System of Rice Intensification, https://www.drawdown.org/solutions/system-of-rice-intensification (last visited Mar. 19, 2020).

crops and is deeply connected to Native Hawaiian culture.[130] Wetland taro fields are essentially man-made wetlands that may be worth exploring for greenhouse gas benefits. In 2015, there were 610 acres of wetland taro across the state with most of those acres concentrated on the island of Kauaʻi.[131] Research into whether there are practices that might increase the greenhouse gas benefits and co-benefits provided by wetland taro cultivation may be helpful, as taro cultivation could play an increasing role in food security for Hawaiʻi. At this time, Project Drawdown does not provide solutions similar enough to wetland taro to include an analysis in this report.

This section briefly discuss two more agriculture solutions (*abandoned farmland restoration*[132] and *biochar production*[133]), as defined by Project Drawdown, that are worth noting for their potential greenhouse gas benefits or co-benefits, but for which sufficient information is currently lacking in Hawaiʻi to fully consider their potential application, risks, or economic feasibility.

1. Abandoned Farmland Restoration Solution

Project Drawdown defines the *abandoned farmland restoration* solution as "a set of processes for restoring degraded, abandoned land to productivity and biosequestration."[134] This solution replaces the conventional practice of abandoning degraded grassland.[135] Project Drawdown's model assumed that abandoned farmland would be represented by currently degraded grassland.[136]

Globally, Project Drawdown estimated 950 million to 1.1 billion hectares (2.3 billion to 2.7 billion acres) of deserted farmland around the world.[137] The loss of agricultural productivity on these lands threatens food security.[138] According to Project Drawdown, these lands have also lost substantial carbon from soil and biomass.[139]

Project Drawdown assumed that the process required for the *abandoned farmland restoration* solution takes one year, after which the land would return to production.[140] Once restored, Project Drawdown assumed that the land would become part of the *regenerative annual cropping* solution, since most of the farmland restoration measures are based on improving soil health through organic inputs.[141]

Project Drawdown's analysis found that restoring abandoned farmland to productivity sequesters carbon.[142] Project Drawdown set the carbon sequestration rate for the *abandoned farmland restoration* solution at 4.8 tons of CO_2e per hectare per year (or 1.9 tons of CO_2e per acre per year).[143]

Project Drawdown also concluded that in some parts of the world restoring abandoned farmland can substantially reduce emissions from avoided deforestation.[144]

It is unclear how much abandoned farmland or degraded grassland currently exists across the state of Hawaiʻi. Hawaiʻi has experienced a major transition in its agricultural lands in recent decades, with a change from 1980 with 350,830 acres in cropland and 1.1 million acres in pasture use to only 151,830 acres in crop use and 761,430 acres in pasture by 2015.[145]

Restoring abandoned farmland could contribute to food security and lower emissions from importing food into Hawaiʻi. Additionally, restoring abandoned farmland could reduce the potential to spread invasive species. Abandoned agricultural land in Hawaiʻi is often taken over by invasive species, which can pose threats to the water table and human health (such as with Albizia trees), increased competition with native species, and increased fire risk from invasive grasses.[146]

A 2011 study conducted in Hawaiʻi observed that "[g]iven its relative scarcity of land, Hawaiʻi has high real estate values that make agricultural land a prime target for conversion to urban use and, subsequently, highly lucrative property development."[147] An acre of Hawaiʻi agricultural real estate had been found to be approximately four times more valuable than agricultural land in the continental United States.[148] A 2015 study for the Department of Agriculture found that the increasing value of Hawaiʻi's real estate has a significant impact on farmers' ability to affordably acquire farmland.[149] As recently observed by a former Hawaiʻi lawmaker, once the land is acquired, farmers also need a steady market for their products, access to farm-worker housing options, low-cost and long-term land leases, and affordable water.[150]

One Hawaiʻi-specific risk in restoring abandoned farmland is the potential increase of greenhouse gas emissions caused by soil disturbance. If the land being restored has soils that

130 Melrose, Perroy, & Cares, *supra* note 53, at 31.
131 *Id.*
132 Drawdown.org, Abandoned Farmland Restoration, https://www.drawdown.org/solutions/abandoned-farmland-restoration (last visited Mar. 19, 2020) [hereinafter Overview: Abandoned Farmland Restoration].
133 Drawdown.org, Biochar Production, https://www.drawdown.org/solutions/biochar-production (last visited Mar. 19, 2020) [hereinafter Overview: Biochar Production].
134 Drawdown.org, Technical Summary: Abandoned Farmland Restoration, https://www.drawdown.org/solutions/abandoned-farmland-restoration/technical-summary (last visited Mar. 19, 2020) [hereinafter Technical Summary: Abandoned Farmland Restoration].
135 *Id.*
136 *Id.*
137 Overview: Abandoned Farmland Restoration, *supra* note 132.
138 *Id.*
139 *Id.*
140 Technical Summary: Abandoned Farmland Restoration, *supra* note 134.
141 *Id.*
142 *Id.*
143 *Id.*
144 *Id.*
145 Melrose, Perroy, & Cares, *supra* note 53, at 4.
146 E-mail from Jayme Barton, Hawaiʻi Agriculture Research Center, *supra* note 80.
147 Parcon, Arita, Loke, & Leung, *supra* note 112, at 8.
148 *Id.*; Arita, Naomasa, & Leung, *supra* note 88 at 1.
149 Melrose, Perroy, & Cares, *supra* note 53, at 6.
150 Gary Hooser, Op-Ed., *Food/farm policy, Hawaii style*, The Garden Island, Nov. 20, 2019, *available at* https://www.thegardenisland.com/2019/11/20/opinion/food-farm-policy-hawaii-style/ (last visited Mar. 20, 2020).

have high soil carbon stocks, there is a risk that disturbing the soil (to plant crops) could emit more carbon than the *abandoned farmland restoration* solution could sequester.

2. Biochar Production Solution

Project Drawdown defines the *biochar production* solution as "a biosequestration process for converting biomass to long-lived charcoal (and energy) which can be used as a soil amendment."[151] As defined by Project Drawdown, this solution provides an alternative to disposing unused biomass through burning or decomposition.[152]

Biochar for use as a soil amendment is created by "heating organic material under conditions of limited or no oxygen."[153] According to Project Drawdown, biochar production stabilizes photosynthetic carbon by reducing emissions that would occur if the organic material were decomposed or disposed of conventionally.[154]

Biochar can create changes in the chemical, physical, and microbial community structure and function of soil that some studies have found can decrease emissions of greenhouse gases, though other studies have found a lack of effect or increases in soil emissions.[155] Other researchers have reported that biochar may have the ability to increase the total carbon storage capacity of soils, in some cases.[156]

Soils generally have a maximum carbon-holding capacity or "carbon saturation" point where carbon gains into the soil are offset by carbon lost to the atmosphere through carbon dioxide emissions.[157] Some research suggests that soils amended with biochar may not be subject to this carbon saturation point.[158]

The effects of biochar application is likely to vary greatly over climate, soil types, and agricultural land-use practices, but there is some indication that it may have much greater impacts on disturbed, degraded, or highly weathered soils.[159] Research in Hawai'i has found a more pronounced influence of biochar in the highly weathered, low fertility Oxisol soils.[160]

Biochar application can also involve risks. The interaction of biochar with soil microbial communities and the long-term fate, stability and toxicity in soil is still being researched.[161] Depending on the moisture content of the feedstock, production of biochar can release more energy than it consumes.[162] If tillage is required to incorporate biochar into the soil, it can be counterproductive to a goal of overall soil carbon sequestration.[163] In some cases, biochar may make soils too alkaline, which may cause nutrient deficiencies and decreased plant growth.[164] Depending on the feedstock used and method of biochar production, biochar application may introduce harmful substances or toxins into the soils.[165] It is important to understand what biochar will likely do when applied to the soil, because it is very stable and nearly impossible to remove from the soil once incorporated.[166]

Project Drawdown's *biochar production* solution does not replace a current agricultural practice but is an alternative to disposing unused biomass by burning it or letting it decompose.[167] The limit for the production of biochar for this solution is the availability of a biomass feedstock.[168]

Using global data and modeling, Project Drawdown assumed that a maximum of 50% of crop biomass that is currently burned would be available for biochar production, with the remainder used in other solutions, including the *conservation agriculture* solution.[169] According to Project Drawdown, the carbon benefits of biochar were found to be much higher than leaving crop residues on the fields.[170] However, Project Drawdown assumed that feedstock would not be produced specifically to support the *biochar production* solution.[171]

Project Drawdown estimated avoided emissions from the *biochar production* solution of 0.95 tons of CO_2e per ton of feedstock. This figure reflects the amount of CO_2e sequestered in the form of biochar, which would otherwise have been emitted if the feedstock had been burned or decom-

151 Drawdown.org, Technical Summary: Biochar Production, *https://www.drawdown.org/solutions/biochar-production/technical-summary* (last visited Mar. 20, 2020) [hereinafter Technical Summary: Biochar Production].
152 *Id.*
153 Josiah Hunt, Michael DuPonte, Dwight Sato, & Andrew Kawabata, *The Basics of Biochar: A Natural Soil Amendment*, CTAHR, Soil and Crop Management 1, 1-6 (Dec. 2010), *available at* https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-30.pdf (last visited Mar. 20, 2020).
154 Technical Summary: Biochar Production, *supra* note 151.
155 Lauren M. Deem & Susan E Crow, *Biochar, in* Reference Module in Earth Systems and Environmental Sciences 2, 1-5 (2017), available at https://soilandcarbon.files.wordpress.com/2017/12/deem-and-crow-2017_biochar.pdf (last visited Mar. 20, 2020).
156 David A. Laird, USDA National Soil Tilth Laboratory, Biochar Farms, Farm Blog, available at http://biocharfarms.org/farming/ (last visited Mar. 20, 2020).
157 Catherine E. Steward, Keith Paustian, Richard T. Conant, Alain F. Plante, & Johan Six, *Soil carbon saturation: concept, evidence, and evaluation*, 86 Biogeochemistry 19-31 (2007).
158 Keith Paustian, Eric Larson, Jeffrey Kent, Ernie Marx, & Amy Swan, Soil C Sequestration as a Biological Negative Emission Strategy, 241 Frontiers in Climate 5-6, 1-11 (Oct. 2019).
159 Laird, *supra* note 156; Johannes Lehmann & Marco Rondon, *Bio-Char Soil Management on Highly Weathered Soils in the Humid Tropics, in* Biological Approaches to Sustainable Soil Systems, 525, 517-530 (2006).
160 Yu, Julian, Lauren M. Deem, Susan E. Crow, Jonathan L. Deenik, & C. Ryan Penton, *Biochar application influences microbial assemblage complexity and composition due to soil and bioenergy crop type interactions*, Soil Biology & Biochemistry 97-107 (Feb. 2018). A greenhouse experiment in Hawai'i also showed that a low-volatility biochar made from macadamia nutshells supplemented with fertilizer outperformed fertilizer alone by sixty percent. David J. Tenenbaum, *Biochar: Carbon Mitigation from the Ground Up*, 117 Environmental Health Perspectives A72 (Feb. 2009), *available at* https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.117-a70 (last visited Mar. 20, 2020).
161 Zakaria M. Solaiman & Hossain M. Anawar, *Application of Biochars for Soil Constraints: Challenges and Solutions*, Pedosphere 631-638 (2015) *available at* https://www.researchgate.net/profile/Zakaria_Solaiman/publication/281237938_Application_of_Biochars_for_Soil_Constraints_Challenges_and_Solutions/links/5bec2a54299bf1124fd1ddf8/Application-of-Biochars-for-Soil-Constraints-Challenges-and-Solutions.pdf (last visited Mar. 20, 2020).
162 "A sustainable model of biochar production primarily uses waste biomass, such as greenwaste from municipal landscaping, forestry, or agriculture." Hunt, DuPonte, Sato, & Kawabata, supra note 153, at 2.
163 Laird, *supra* note 156.
164 Hunt, DuPonte, Sato, & Kawabata, *supra* note 153, at 3.
165 Laird, *supra* note 156.
166 Deem & Crow, *supra* note 155, at 3.
167 Technical Summary: Biochar Production, *supra* note 151.
168 *Id.*
169 *Id.*
170 *Id.*
171 *Id.*

posed.[172] While it is possible to reduce greenhouse gas emissions by adding biochar to the soil, careful selection of biochar type and rate of application in a range of soils is essential.[173] Project Drawdown determined that data was insufficient to effectively model the impacts of soil sequestration from biochar application to soil at the global level.[174] However, Project Drawdown's analysis did include an eighteen percent yield gain assumption for biochar-amended soils.[175]

In 2015, sugarcane was the only major crop in Hawai‘i for which crop residues were regularly burned.[176] The last sugar mill in Hawai‘i closed in 2016, and sugar cane is no longer produced commercially at a large scale in the Hawai‘i. As a result, the *biochar production* solution, as defined and modeled by Project Drawdown, would have limited application in Hawai‘i, since crop residues are no longer being burned (removing the anticipated feedstock for biochar production).

More research would be needed to determine if it would be beneficial to make other crop residues in Hawai‘i available for biochar production. At least one Hawai‘i island-based company is currently producing biochar commercially in Hawai‘i, using macadamia nut shells as feedstock.[177] It is not clear if it is financially feasible for Hawai‘i farmers to purchase locally produced biochar for farm-scale applications.

Knowledge gaps about biochar still exist, including the longevity of biochar in field conditions and its long-term impacts.[178] Exact recommended quantities of biochar for specific crops, specific soil types, and specific climates are not currently available.[179] It might be worth exploring how to support research in this area, as well as the broader potential for local businesses to use existing waste streams to produce biochar for on-island use.

V. RANCHING

A. OVERVIEW

Research evaluating the opportunities and vulnerabilities presented by soil organic matter has suggested that rangelands may represent untapped potential for soil organic carbon sequestration, because they occur across a wide range of conditions, cover approximately forty percent of the Earth's ice-free land area, and store approximately thirty percent of the land's soil organic carbon pool.[180] Unfortunately, poor management practices have resulted in degradation of the soil organic carbon stocks in many of the planet's grazing lands .[181] These stocks can be degraded through erosion, compaction, and overgrazing and can be improved through changes in grazing, irrigation, plant species management, and fertilizer practices.[182]

As of 2015, grasslands in Hawai‘i were estimated to be a net carbon source to the atmosphere.[183] The rangelands that support Hawai‘i's livestock industry are primarily found at higher elevations, mostly on Hawai‘i and Maui.[184] The livestock raised across the state of Hawai‘i, include cattle, dairy cows, goats, sheep, horses, poultry and pigs. [185] Generally, all but the poultry and pigs are raised in open pasture.[186]

A 2018 study of Hawai‘i's cattle management practices noted that cattle production in Hawai‘i is very different from the rest of the U.S. because of its climate, culture, and unique ecosystems.[187] Based on 2017 statistics, Hawai's beef industry was the second highest ranking agricultural commodity in the state's economy.[188]

As accounted in the "Statewide Agricultural Land Use Baseline 2015" report, from the 1800s through the 1970s, "virtually all cattle in Hawai‘i were grazed, harvested, and consumed in the islands." [189] Locally grown field corn supplemented imported feed, and there were feed lots and slaughterhouses on multiple islands to process the meat. [190] In the 1980s, increased operating costs (primarily global feed corn prices) led many cattle ranchers to ship their calves to the mainland to be finished on grain and processed on the mainland rather than shipping feed into Hawai‘i and slaughtering the cattle locally. [191]

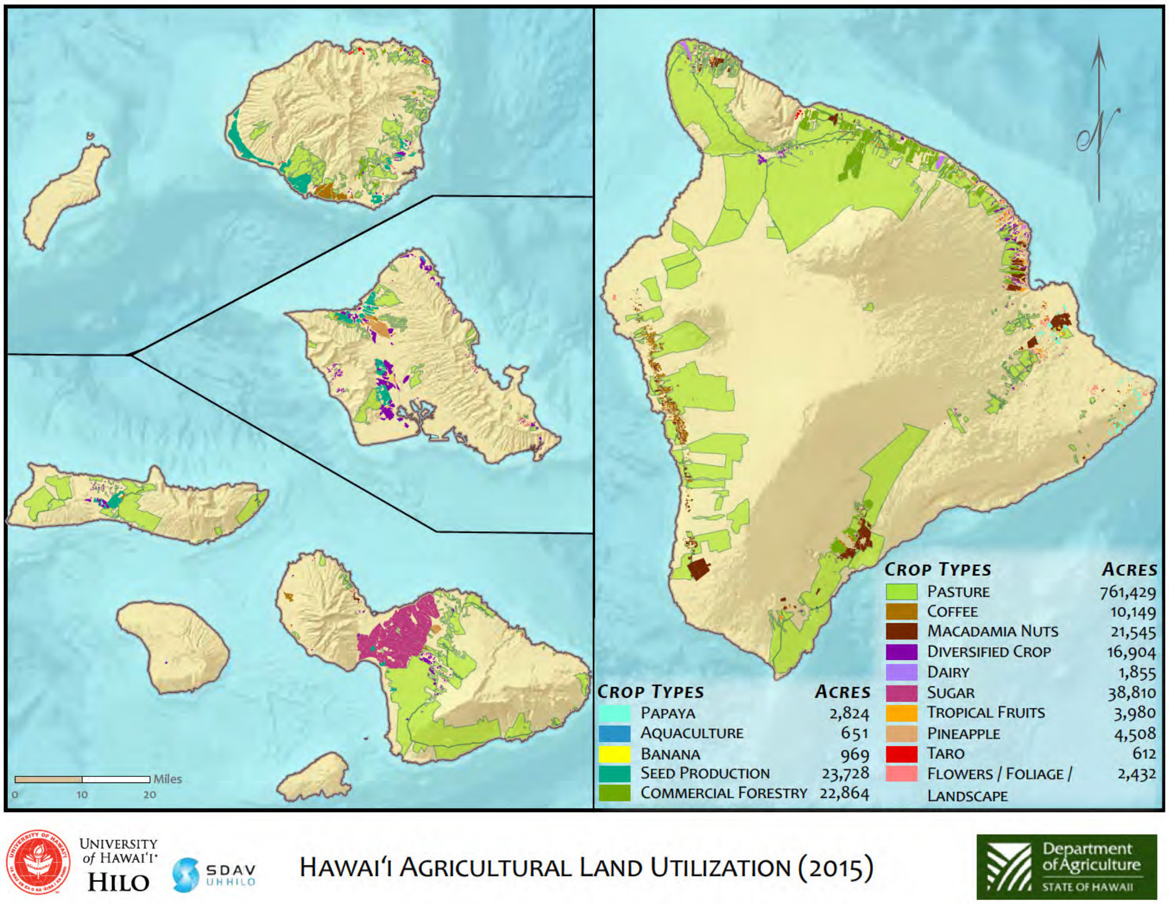
By 2015, the majority of Hawai‘i's marketed cattle were being shipped to the West Coast of the U.S. and Canada.[192] At that time, there were certified cattle slaughterhouses on Hawai‘i island, Kaua‘i, Maui, Moloka‘i, and O‘ahu, but all of the operations were "small by mainland standards and rela-

172 Id.
173 Solaiman & Anawar, *supra* note 161, at 636.
174 Technical Summary: Biochar Production, *supra* note 151.
175 *Id.*
176 The greenhouse gas emissions from other major crops from the field burning of crop residues were assumed to be zero. Hawaii Greenhouse Gas Emissions Report for 2015, *supra* note 10 at 129.
177 Pacific Biochar.com, Mac Nut Biochar, https://pacificbiochar.com/products/mac-nut-biochar-2/ (last visited Mar. 20, 2020).
178 Deem & Crow, *supra* note 155, at 2.
179 Laird, *supra* note 156.
180 Harden, et al., *supra* note 96, at e710. "The global potential for rangeland [carbon] sequestration has been estimated to range from 0.3 to as much as 1.6 Pg CO_2-eq year^{-1}." *Id.*; K. Paustian, J. Lehmann, S. Ogle, D. Reay, G.P. Robertson, & P. Smith, *Climate smart soils,* 532 Nature, 49–57 (2016).
181 Harden, et al., *supra* note 96, at e710.
182 *Id.* at e711.
183 Paul C. Selmants, Christian P. Giardina, Sinan Sousan, David E. Knapp, Heather L. Kimball, Todd J. Hawkbaker, Alvaro Moreno, Jami Seirer, Steve W. Running, Tomoaki Miura, Rafael Bergstrom, R. Flint Hughes, Creighton M. Litton, & Gregory P. Asner, *Chapter 6. Baseline Carbon Storage and Carbon Fluxes in Terrestrial Ecosystems of Hawai‘i* in Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawai‘i 9, 9 (Paul C. Selmants, Christian P. Giardina, James D. Jacobi, and Zhiliang Zhu, eds., 2017), *available at* https://pubs.usgs.gov/pp/1834/a/pp1834_chapter6.pdf (last visited Mar. 23, 2020).
184 Climate of Hawaii, *supra* note 21, at 16.
185 Melrose, Perroy, & Cares, *supra* note 53, at 35.
186 *Id.*
187 Senorpe Assem-Hiablie, C. Alan Rotz, J. Dale Sandlin, M'Randa R. Sandlin, & Robert C. Stout, *Management characteristics of beef cattle production in Hawai‘i*, The Professional Animal Scientist 167, 167-176 (April 2018) *available at* https://www.sciencedirect.com/science/article/pii/S1080744618300299 (last visited Mar 30, 2020).
188 *Id.* at 167.
189 Melrose, Perroy, & Cares, *supra* note 53, at 35.
190 *Id.* at 35-36.
191 *Id.* at 36.
192 *Id.*

tively expensive to operate."[193] As of 2019, less than eight percent of the beef consumed in Hawai'i was local.[194] An increasing number of Hawai'i ranchers are interested in keeping their animals and selling the meat to a growing local grass-fed beef market. Opportunities to provide necessary processing infrastructure and reduce feed, shipping, and other operating costs may make producing beef for local markets feasible for more Hawai'i ranchers.[195] Distribution of pasture lands across the state as of 2015 are reflected in the map below:

2. Potential Application to Hawai'i Lands

According to Project Drawdown, the *silvopasture* solution replaces conventional livestock grazing on pasture and rangeland.[197] Project Drawdown limited the adoption of the *silvopasture* solution to non-degraded grassland with minimal or moderate slopes.[198] Project Drawdown identified the *silvopasture* solution as the highest priority for these kinds of lands.[199] To support tree growth, Project Drawdown targeted grassland for the application of this solution that was not too dry.[200]



Source: JEFFREY MELROSE, RYAN PERROY, & SYLVANA CARES, STATEWIDE AGRICULTURAL LAND USE BASELINE 2015, 37 (2016), available at http://hdoa.hawaii.gov/wp-content/uploads/2016/02/StateAgLandUseBaseline2015.pdf

B. SILVOPASTURE SOLUTION

1. Definition

Project Drawdown defines the *silvopasture* solution as "the addition of trees to pastures for increased productivity and biosequestration."[196]

Project Drawdown's analysis assumed that the majority of grassland modeled at the global level would likely be too dry to support tree growth.[201] A 2017 assessment by the U.S. Forest Service suggested, however, that the much of the pasturelands and rangelands in Hawai'i could be restored to

193 *Id.*
194 Nate Eaton, *VanderSloot rescues jobs, gives ranchers $1.5 million in "game-changing" move for Hawaii's cattle industry,* EastIdahoNews.com (Oct. 9, 2019) *available at* https://www.eastidahonews.com/2019/10/vandersloot-rescues-jobs-gives-ranches-1-5-million-in-game-changing-move-to-save-hawaiis-cattle-industry/ (last visited on Mar. 30, 2020). One local cattle company has suggested that 80,000 calves (or ninety-five percent) are still leaving Hawai'i by plane or boat. Hawaii Agricultural Foundation, Kunoa Cattle Company, *https://www.hawaiiagfoundation.org/local-inside-csa/farms/kunoa-cattle-company/* (last visited Mar. 30, 2020); Andrew Gomes, *Local beef production to grow with new company Hawaii Meats*, West Hawaii Today (Sept. 17 2019) available at https://www.westhawaiitoday.com/2019/09/17/hawaii-news/local-beef-production-to-grow-with-new-company-hawaii-meats/ (last visited Mar. 30, 2020).
195 A 2018 study noted that "[p]resently, most calves are exported to the mainland for finishing due to lack of available finishing pasture and no other destocking options." Assem-Hiablie, Rotz, Sandlin, Sandlin, & Stout, *supra* note 187, at 167.
196 Drawdown.org, Technical Summary: Silvopasture, https://www.drawdown.org/solutions/silvopasture/technical-summary (last visited Mar. 30, 2020) [hereinafter Technical Summary: Silvopasture].
197 *Id.*
198 *Id.*
199 *Id.*
200 *Id.*
201 *Id.*

forest or partial forest cover with silvopastoral techniques.[202]

In 2017, there were 761,816 acres of permanent pasture and rangeland[203] across the state of Hawaiʻi.[204] The vast majority of these acres are found on Hawaiʻi Island followed by Maui.[205] Data is not currently available to indicate how many of these acres are non-degraded grassland with minimal or moderate slopes. If that data were available, it would provide a more detailed picture of potential applicability of this solution in Hawaiʻi.

3. Potential Greenhouse Gas Benefits

a) Sequestration

Project Drawdown sets the sequestration rate of the silvopasture solution at 9.9 tons of CO_2e per hectare per year (or approximately 4 tons of CO_2e per acre per year).[206] According to Project Drawdown, "[r]esearch suggests that *silvopasture* systems can store significant amounts of carbon in both soils and tree biomass, while maintaining or increasing productivity and providing additional benefits."[207] Project Drawdown found the *silvopasture* solution to have substantially higher greenhouse gas mitigation impact than the *managed grazing* solution.[208]

As discussed with the *conservation agriculture* and *regenerative annual cropping* solutions, if Histosol or Andisol soils are found on the sites where the *silvopasture* solution is pursued in Hawaiʻi, the carbon sequestration rate per acre could be higher than the rate set by Project Drawdown. However, there is also a possibility that, depending on the pastureland location, disturbing the soil to plant trees could release more stored soil carbon than might be recaptured by the trees being planted.[209] Any pursuit of the *silvopasture* solution would need to keep this in mind.

b) Emissions Reductions

Project Drawdown's global modeling assumed that emissions of the greenhouse gases methane and nitrous oxide would continue under the *silvopasture* solution, but would be more than offset by carbon sequestration, at least until soil carbon saturation was achieved.[210] In its analysis, however, Project Drawdown assumed that emissions would not change with the adoption of the *silvopasture* solution.[211]

As mentioned above, depending on the soil and land use history, planting trees in a grassland in Hawaiʻi that has high amounts of stored soil carbon could result in emissions that exceed the sequestration potential of the *silvopasture* solution. [212] As a result, the potential for high amounts of stored soil carbon in an area should be well-understood before pursuing the *silvopasture* solution in Hawaiʻi.

Additionally, as mentioned in the overview for this section, the majority of Hawaiʻi's marketed cattle are currently being sent out of the state (by plane or by boat).[213] The emissions associated with this practice would not be captured in Project Drawdown's analysis of the *silvopasture* solution, including its conclusion that sequestration would more than offset the greenhouse gases generated by adoption of the *silvopasture* solution.

4. Potential Co-Benefits

According to Project Drawdown, under the *silvopasture* solution, livestock, trees, and additional forestry products (e.g. nuts, fruit, and mushrooms), can generate income on different time horizons.[214] Project Drawdown suggests that the *silvopasture* solution can improve the health and productivity of the land and animals and increase meat and dairy yields.[215] Project Drawdown also suggests that the *silvopasture* solution can help farmers and their livestock adapt to erratic weather and increased drought.[216]

According to guidance from the USDA's National Agroforestry Center, trees in silvopasture systems can provide habitat for wildlife species including pollinators.[217] Additionally, silvopasture systems can conserve soil humidity, reduce wind, improve water quality, and reduce soil erosion.[218] The National Agroforestry Center also suggests that silvopasture trees can recycle "nutrients from deeper layers of soil for use by plants and microorganisms nearer the soil surface and in the case of nitrogen fixing species, add nitrogen to the system."[219]

Silvopastoral systems in Pacific Island agroforestry systems have been found to provide additional benefits: reduced economic risk (from production of multiple products); enhanced tree growth from reduced grass competition and fire

202 J.B. Friday, Kathleen Friday, & Craig Elevitch, *Appendix A: Regional summaries: Hawaii and the U.S.-Affiliated Pacific Islands* in Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions 150, 147-153 (Michele M. Schoeneberger, Gary Bentrup, Toral Patel-Weynand, eds., 2017) *available at* https://www.fs.usda.gov/treesearch/pubs/55775 (last visited Mar. 30, 2020).
203 This excludes pastured woodland.
204 National Agricultural Statistics Service, *Table 8. Income from Farm-Related Sources: 2017 and 2012, in* 2017 Census of Agriculture - State Data (2017), *available at* https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Hawaii/st15_1_0007_0008.pdf (last visited Mar. 30, 2020) [hereinafter *Table 8. Income from Farm-Related Sources*].
205 Melrose, Perroy, & Cares, *supra* note 53, at 37.
206 Technical Summary: Silvopasture, *supra* note 196.
207 *Id.*
208 *Id.*
209 At least one case study in Hawaiʻi suggests that disturbing volcanic soils in certain rangelands to plant trees could release more stored soil carbon than might be recaptured by the planted trees. Susan E. Crow, Mataia Reeves, Scott Turn, Shintaro Taniguchi, Olivia S. Schubert, & Nicholas Koch, *Carbon balance implications of land use change from pasture to managedeucalyptus forest in Hawaiʻi*, Carbon Management 7, 1-11 (2016) *available at* https://soilandcarbon.files.wordpress.com/2017/12/crow-et-al-2016_carbon-balance-implications-of-land-use-change-from-pasture-to-managed-eucalyptus-forest-in-hawaii.pdf (last visited Mar. 30, 2020).
210 Technical Summary: Silvopasture, *supra* note 196.
211 *Id.*
212 Crow, Reeves, Turn, Taniguchi, Schubert, & Koch, *supra* note 209, at 7.
213 Melrose, Perroy, & Cares, *supra* note 53, at 36; Assem-Hiablie, Rotz, Sandlin, Sandlin, & Stout, *supra* note 187; Eaton, *supra* note 194; Hawaii Agricultural Foundation, *supra* note 194.
214 Drawdown.org, Silvopasture, https://www.drawdown.org/solutions/silvopasture (last visited Mar. 30, 2020) [hereinafter Overview: Silvopasture].
215 *Id.*
216 *Id.*
217 National Agroforestry Center, Agroforestry: Working Trees for Islands (Jan. 2015) *available at* https://www.fs.usda.gov/nac/assets/documents/workingtrees/brochures/Working_Trees_Islands.pdf (last visited Mar. 30, 2020).
218 *Id.*
219 *Id.*

risk; and reduced use of herbicides.[220] Silvopastoral systems can also have fewer issues with dust, odors, noise, heard disease, and water pollution when compared with concentrated livestock operations.[221]

5. Risks and Potential Unintended Consequences

Project Drawdown suggests that the *silvopasture* solution often runs counter to farming norms and can be costly and slow to implement.[222] A recent review of silvopastoral systems observed that "[d]esigning and maintaining productive silvopastoral systems adapted to each local context can be challenging."[223] As observed by some practitioners, managing livestock among trees can be more intensive.[224] According to the USDA National Agroforestry Center, "[r]otational grazing is a key management activity when using silvopasture in order to minimize damage to trees."[225] In silvopasture systems, newly planted tree seedlings may need to be fenced to protect them from browsing by livestock.[226]

In Hawai'i, adoption of silvopasture may be particularly difficult, as many of the trees well-suited to silvopasture may not survive. Informal discussions with some Hawai'i ranchers suggest that ranchers may anticipate needing to take pastures out of production for at least ten years (or completely) to get the trees established.[227] Depending on the tree used and the climate, there is also a potential for non-native trees negatively impacting groundwater aquifer recharge. There is also a risk that adoption of silvopasture could negatively impact food security (temporarily or permanently), if a portion of grazing lands need to be taken out of production to plant the trees.

Managing land for tree crops is also a long-term investment that may not match all ranchers' land tenure or lease terms.[228] Additionally, in arid and semi-arid areas or areas that have experienced extended periods of drought, forage produced under established trees may not be enough to sustain an economically viable livestock production operation.[229]

6. Economic Feasibility

Using global data and modeling, Project Drawdown estimated the following related to adopting the *silvopasture* solution on non-degraded grassland with minimal or moderate slopes:[230]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$1180.65 per hectare (or $477.79 per acre)	$840.25 per hectare/yr (or $340.04 per acre/yr)	$154.12 per hectare/yr (or $62.37 per acre/yr)	11.1%

The financial costs estimated by Project Drawdown for this solution are likely much lower than they would be in Hawai'i. The yield benefits are also questionable for Hawai'i, given the feasibility issues discussed above regarding anticipated productivity loss required to establish trees in existing grazing pastures. Tree establishment in those conditions will take intensive management and care to survive, including fencing which is very costly.

Hawai'i ranchers also experience high costs, limited time, and limited access to slaughter facilities.[231] High electricity costs and variable access to water on pastureland in Hawai'i would affect the net profit estimates. Additionally, Hawai'i cattle ranchers that ship calves to the mainland for finishing and processing would face costs that would not be captured in Project Drawdown's net profit estimates.

7. Overall Rating

Silvopasture **Solution**

High	Medium	Low	
■ (green)			Potential for Greenhouse Gas Benefits
■ (green)			Potential for Co-Benefits
		■ (red)	Lack of Risks

Further Research Needed:

- Data and maps that reflect conventional livestock grazing on non-degraded grassland;
- Data and maps that reflect non-degraded grassland with minimal or moderate slopes and sufficient rainfall to permit tree growth;
- Cost information on implementation of *silvopasture* practices specific to Hawai'i; and
- Opportunities to support and incentivize processing livestock locally.

220 Craig R. Elevitch & Kim M. Wilkinson, *Introduction to Integrating Trees Into Pacific Island Farm Systems*, in Agroforestry Guides for Pacific Islands 123-148 (Craig R. Elevitch & Kim M. Wilkinson eds., 2000).
221 Dep't of Natural Resources & Envtl. Mgmt. CTAHR, Toward Sustainable Agriculture: A Guide for Hawai'i's Farmers 49 (Jody Smith & Samir A. El-Swaify eds. 2006) *available at* https://www.sare.org/Learning-Center/SARE-Project-Products/Western-SARE-Project-Products/A-Guide-for-Hawai-i-s-Farmers (last visited Mar. 30, 2020).
222 Overview: Silvopasture, *supra* note 214.
223 Shibu Jose & Jeanne Dollinger, *Silvopasture: a sustainable livestock production system*, 93 Agroforestry Systems 7, 1-9 (2019) *available at* https://link.springer.com/article/10.1007/s10457-019-00366-8 (last visited Mar. 31, 2020).
224 Stephanie Hanes, *From chickens to chestnuts: Where farmers work the old-fashioned way*, The Christian Science Monitor (Nov. 14, 2019) available at https://www.csmonitor.com/Environment/2019/1114/From-chickens-to-chestnuts-Where-farmers-work-the-old-fashioned-way (last visited Mar. 31, 2020).
225 National Agroforestry Center, Silvopasture, https://www.fs.usda.gov/nac/practices/silvopasture.php (last visited Mar. 31, 2020).
226 Jose & Dollinger, *supra* note 223 at 6.
227 E-mail from Jayme Barton, Hawai'i Agriculture Research Center, *supra* note 80.
228 Hanes, *supra* note 224.
229 Jose & Dollinger, *supra* note 223 at 3.
230 Technical Summary: Silvopasture, *supra* note 196.
231 In 2015, there were two certified cattle slaughterhouses on Hawaii Island, three on Kauai, one each on Maui, Molokai, and Oahu. All of these operations are small by mainland standards and relatively expensive to operate. Melrose, Perroy, & Cares, *supra* note 53, at 36.

C. MANAGED GRAZING SOLUTION

1. Definition

Project Drawdown defines the *managed grazing* solution as "a set of practices that sequester carbon in grassland soils by adjusting stocking rates, timing, and intensity of grazing."[232]

Project Drawdown identified the following three managed-grazing techniques that it suggests can "improve soil health, carbon sequestration, water retention, and forage productivity:

1. *Improved continuous grazing*, which "adjusts standard grazing practices and decreases the number of animals per acre[;]"
2. *Rotational grazing*, which "moves livestock to fresh paddocks or pastures, allowing those already grazed to recover[;]" and
3. *Adaptive multi-paddock grazing*, which "shifts animals through smaller paddocks in quick succession, after which the land is given time to recover."[233]

2. Potential Application to Hawai'i Lands

Project Drawdown's *managed grazing* solution replaces conventional grazing on grasslands, including both pastures and rangelands.[234] Adoption of the *managed grazing* solution was Project Drawdown's second-highest priority for non-degraded grasslands.[235]

In 2017, there were 761,816 acres of permanent pasture and rangeland[236] across the state of Hawai'i.[237] The vast majority of these acres are found on Hawai'i Island followed by Maui.[238] Data is not currently available to indicate how many of these acres are non-degraded grassland. If that data were available, it would provide a more detailed picture of potential applicability of this solution in Hawai'i.

3. Potential Greenhouse Gas Benefits

a) Sequestration

Project Drawdown suggests that the *managed grazing* solution can "enhance net carbon sequestration and other modes of soil and vegetation quality on grazing lands."[239] Project Drawdown set the following sequestration rates for the *managed grazing* solution:[240]

Climate zone and moisture regime	Sequestration rate (tons of CO_2e)
Tropical humid	2.46 per hectare/yr (or 1.0 per acre/yr)
Temperate/boreal humid	1.76 per hectare/yr (or 0.71per acre/yr)
Tropical semi-arid	2.35 per hectare/yr (or 0.95 per acre/yr)
Temperate/boreal semi-arid	2.31 per hectare/yr (or 0.93 per acre/yr)

A 2017 life cycle analysis of a U.S. mainland ranch found net greenhouse gas benefits from adaptive grazing management.[241] As discussed previously with the *silvopasture* solution, if Histosol or Andisol soils are found on the sites where the *managed grazing* solution is pursued in Hawai'i, the carbon sequestration rate per acre may be much higher than the rate set by Project Drawdown. Unlike the *silvopasture* solution, the risk of negatively impacting high soil carbon stocks by planting trees would not be a concern with the *managed grazing* solution.

b) Emissions Reductions

Project Drawdown notes that improved grazing does not address all the methane emissions generated by cattle, sheep, or goats, which "ferment cellulose in their digestive systems and break it down with methane-emitting microbes."[242] Project Drawdown's analysis made the conservative assumption that greenhouse gas emissions "do not change with conversion from conventional to managed grazing."[243]

As discussed in the *silvopasture* solution section of this report, the emissions associated with the practice of sending Hawai'i cattle to the U.S. mainland for finishing and processing would not be captured in Project Drawdown's emissions reductions analysis of the *managed grazing* solution.

4. Potential Co-Benefits

In addition to greenhouse gas benefits, Project Drawdown suggests that the *managed grazing* solution can improve soil health, water retention, and forage productivity.[244] A 2007 analysis of the pasture land leases in Hawai'i observed that properly managed grazing can be effectively used to reduce wildfire fuels, control weeds and shrubs, manage wildlife habitat, improve range or pasture, and protect native and endangered species and ecosystems.[245] Practitioner observations suggest that in some cases managed grazing can also decrease the impacts of invasive spe-

232 Drawdown.org, Technical Summary: Managed Grazing, https://www.drawdown.org/solutions/managed-grazing/technical-summary (last visited Mar. 31, 2020) [hereinafter Technical Summary: Managed Grazing].
233 Drawdown.org, Technical Summary: Managed Grazing, https://www.drawdown.org/solutions/managed-grazing/technical-summary (last visited Mar. 31, 2020) [hereinafter Technical Summary: Managed Grazing]
234 Technical Summary: Managed Grazing, *supra* note 232.
235 *Id.*
236 This excludes pastured woodland.
237 Table 8. Income from Farm-Related Sources, supra note 204.
238 Melrose, Perroy, & Cares, *supra* note 53, at 37.
239 Technical Summary: Managed Grazing, *supra* note 232.
240 *Id.*
241 White Oak Pastures, Building Soil with Animal Impact: White Oak Pastures, https://www.whiteoakpastures.com/meet-us/environmental-sustainability/ (last visited Mar. 31, 2020); Mariko Thorbecke & Jon Dettling, Quantis, Carbon Footprint Evaluation of Regenerative Grazing at White Oak Pastures (Feb. 25, 2019) *available at* https://blog.whiteoakpastures.com/hubfs/WOP-LCA-Quantis-2019.pdf (last visited Mar. 31, 2020).
242 Overview: Managed Grazing, *supra* note 233.
243 Technical Summary: Managed Grazing, *supra* note 232.
244 Overview: Managed Grazing, *supra* note 233.
245 Mark Thorne, Linda J. Cox, & Matthew H. Stevenson, *Calculating Minimum Grazing Lease Rates for Hawai'i*, CTAHR, Pasture and Range Management 1, 1-7 (June 2007) *available at* https://www.ctahr.hawaii.edu/oc/freepubs/pdf/PRM-3.pdf (last visited Mar. 31, 2020).

cies, and in some cases, help reestablish native species.[246]

5. Risks and Potential Unintended Consequences

Hawai'i has a history of escaped livestock (e.g. pigs, cattle, sheep, goats, etc.) becoming feral and damaging native forests and other vegetation.[247] Depending on the livestock used and location of the grazing area, adopting the *managed grazing* solution on lands in Hawai'i that are not currently grazed could increase the risk of escaped livestock affecting sensitive ecosystems.

Managed grazing practices can be more labor intensive than traditional livestock grazing practices, so they can involve higher labor costs. If labor is limited or expensive in certain areas, adopting managed grazing practices may not be feasible for ranchers in those areas.

Additionally, short lease terms may disincentivize the *managed grazing* solution. Month-to-month grazing leases can be common in Hawai'i.[248] As observed by the 2007 pasture land lease analysis, "[s]hort-term leases do not provide incentives for sound grazing management decisions by the grazer, because the lease can be terminated at any time."[249]

6. Economic Feasibility

Under Project Drawdown's analysis, the *managed grazing* solution would require less initial financial investment than the *silvopasture* solution to transition from conventional livestock grazing practices. The annual net profit expected from the *managed grazing* solution is less than what Project Drawdown estimated for the *silvopasture* solution, but it is still higher than the annual net profit expected from conventional grazing practices. The estimated yield gains are also higher under the *managed grazing* solution.

Using global data and modeling, Project Drawdown estimated the following related to adopting the *managed grazing* solution on non-degraded grassland: [250]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$75.01 per hectare (or $30.36 per acre)	$342.20 per hectare/yr (or $138.48 per acre/yr)	$154.12 per hectare/yr (or $62.37 per acre/yr)	21.4%

Again, the costs to implement this solution are likely much higher in Hawai'i than Project Drawdown estimated based on its global analysis. As discussed earlier in this report, Hawai'i ranchers experience high costs (particularly fencing costs) and limited time and access to slaughter facilities.[251] High electricity costs and water costs, as well as variable access to water on grassland in Hawai'i would affect the net profit estimates. Additionally, Hawai'i cattle ranchers that ship calves to the mainland for finishing and processing would face additional costs that would not be captured in Project Drawdown's net profit estimates. Since labor costs in Hawai'i are higher than the rest of the U.S.,[252] adopting managed grazing practices may involve a higher labor expense for Hawai'i ranchers than was captured in Project Drawdown's net profit estimates. For Hawai'i ranchers that cannot rely on pasture forage alone, they may face high feed and shipping costs to bring feed in from out of the state.[253] In 2016, shipping feed in from the U.S. mainland often doubled the total price of feed. [254] At that time, feed contributed fifty to seventy percent of the total cost of raising livestock in Hawai'i. [255]

7. Overall Rating

Managed Grazing **Solution**

High	Medium	Low	
	■		Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
	■		Lack of Risks

Further Research Needed:

- Data and maps that reflect conventional grazing practices on non-degraded grassland and pasturelands that would be suitable for forage-finished beef production across Hawai'i;
- Cost information on implementation of the *managed grazing* practices in Hawai'i;
- Modeling of climate change scenarios and effects on temperature and precipitation patterns and their associated impacts on pasture ecology and productivity;
- Feasibility of growing local livestock feeds that might replace currently imported feeds; and
- Incentives that might compensate ranchers for maintaining and preserving high soil carbon stocks in Hawai'i grasslands.

VI. AGROFORESTRY

A. OVERVIEW

According to the USDA, agroforestry is a land management system that intentionally integrates trees and shrubs into

246 E-mail from Jayme Barton, Hawai'i Agriculture Research Center, *supra* note 80.
247 David G. Smith, DLNR, Division of Forestry and Wildlife, Hawai'i Forest Action Plan 2016 (December 31, 2016) *available at* https://dlnr.hawaii.gov/forestry/files/2013/09/Hawaii-Forest-Action-Plan-2016-FINAL.pdf (last visited Mar. 31, 2020).
248 Thorne, Cox, & Stevenson, *supra* note 245, at 3.
249 *Id.*
250 Technical Summary: Managed Grazing, *supra* note 232.
251 Melrose, Perroy, & Cares, *supra* note 53, at 36.
252 Arita, Naomasa, & Leung, *supra* note 88, at 6.
253 Noelle Fujii-Oride, *The Need for Feed*, Hawaii Business Magazine (Nov. 14 2016) *available at* https://www.hawaiibusiness.com/the-need-for-feed/ (last visited Mar. 31, 2020).
254 *Id.*
255 *Id.*

crop and livestock production systems.[256] A 2017 assessment by the USDA of the use of agroforestry for mitigation and adaptation services found that agroforestry can be an important land use approach in a comprehensive greenhouse gas mitigation strategy.[257] The assessment found that agroforestry sequesters carbon in biomass and soils and reduces greenhouse emissions on agricultural lands, in part by avoiding emissions from energy and fuel use.[258]

According to the USDA's Agroforestry Strategic Framework for 2019-2024, the five most common categories of agroforestry practiced in the United States are:

- windbreaks (for fields, farmsteads, and livestock),
- riparian forest buffers (along waterways),
- silvopasture systems (with trees, livestock, and forages),
- forest farming (with edible, herbal/botanical, medicinal, and decorative products grown under managed forest cover), and
- alley cropping (with annual crops and high-value trees and shrubs).[259]

Various forms of agroforestry have been part of traditional practices in the Pacific Islands for thousands of years.[260] Agroforestry practices can be implemented in a variety of ways depending on site conditions, crop selection, farmer choices, and economic and ecological risks.[261] The USDA suggests that, depending on the practices involved, agroforestry can also protect valuable topsoil, livestock, crops and wildlife; increase productivity of agricultural and horticultural crops; diversify local economies; improve water quality; reduce energy and chemical inputs; increase water-use efficiency by plants and animals; and enhance biodiversity and landscape diversity.[262]

This section includes three Project Drawdown solutions that fall within the agroforestry sector: *multistrata agroforestry*, *tree intercropping*, and *perennial staple crops*. The definition of each approach is provided separately; however, given that these solutions share many commonalities, the analysis for their application to Hawai'i are combined.

B. DEFINITIONS

1. Multistrata Agroforestry Solution

Project Drawdown defines the *multistrata agroforestry* solution as "a perennial cropping system featuring multiple layers of trees and other perennial crops, with high biosequestration impacts."[263]

At the global level, Project Drawdown observes that the combination of plants used in multistrata agroforestry "varies by region and culture, but the spectrum includes macadamia and coconut, black pepper and cardamom, pineapple and banana, shade-grown coffee and cacao, as well as rubber and timber."[264] Project Drawdown also includes home gardens in the *multistrata agroforestry* approach.[265]

2. Tree Intercropping Solution

Project Drawdown defines the *tree intercropping* solution as "a suite of agroforestry systems that deliberately grow trees together with annual crops in a given area at the same time."[266]

According to Project Drawdown, the arrangement of trees and crops for the *tree intercropping* solution can vary with topography, culture, climate, and crop value.[267] This solution encompasses different types of practices, including using "trees to support annual crop production (e.g. intercropping nitrogen-fixing trees, as in evergreen agriculture) or as protective systems against erosion, flooding, or wind damage (e.g. hedgerows, riparian buggers, and windbreaks)."[268] Trees may also serve as crops themselves, such as with "strip intercropping of annual crops with timber or fruit trees."[269]

3. Perennial Staple Crops Solution

Project Drawdown defines the *perennial staple crops* solution as "the production of trees and other perennial crops for staple protein, fats, and starch."[270]

Project Drawdown observes that, globally, "the dominant agricultural crops are annual—planted, harvested, and replanted every year."[271] By contrast, perennials are crops that "come back year after year, with similar yield and higher rates of carbon sequestration."[272] According to Project Draw-

256 U.S. Department of Agriculture, Forest Service, Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions v (Michele M. Schoenberger, Gary Bentrup, & Toral Patel-Weynand eds., 2017) *available at* https://www.fs.fed.us/research/publications/gtr/gtr_wo96.pdf (last visited Mar. 31, 2020).
257 *Id.*at vii.
258 *Id.*
259 U.S. Department of Agriculture, Agroforestry Strategic Framework: Fiscal Years 2019-2024 3 (January 2019) *available at* https://www.usda.gov/sites/default/files/documents/usda-agroforestry-strategic-framework.pdf (last visited Mar. 31, 2020).
260 Craig R. Elevitch & Kim M. Wilkinson, *Information Resources for Pacific Island Agroforestry*, in Agroforestry Guides for Pacific Islands 3, 3-22 (Craig R. Elevitch & Kim M. Wilkinson eds., 2000).
261 Craig Elevitch, Garien Behling, Michael Constantinides, & James B. Friday, *Grower's Guide to Pacific Island Agroforestry Systems, Information Resources, and Public Assistance Programs*, in Food-Producing Agroforestry Landscapes of the Pacific 5 (2014) *available at* http://oahurcd.org/wp-content/uploads/2016/04/Growers_Guide_Pacific_Agroforestry_Elevitch_etal.pdf (last visited Mar. 31, 2020).
262 U.S. Department of Agriculture, *supra* note 259, at 3.
263 Drawdown.org, Technical Summary: Multistrata Agroforestry, https://www.drawdown.org/solutions/multistrata-agroforestry (last visited Mar. 31, 2020) [hereinafter Technical Summary: Multistrata Agroforestry].
264 Drawdown.org, Multistrata Agroforestry, https://www.drawdown.org/solutions/multistrata-agroforestry (last visited Mar. 31, 2020) [hereinafter Overview: Multistrata Agroforestry].
265 *Id.*
266 Drawdown.org, Technical Summary: Tree Intercropping, https://www.drawdown.org/solutions/tree-intercropping/technical-summary (last visited Mar. 31, 2020) [hereinafter Technical Summary: Tree Intercropping].
267 Drawdown.org, Tree Intercropping, https://www.drawdown.org/solutions/tree-intercropping (last visited Mar. 31, 2020) [hereinafter Overview: Tree Intercropping].
268 Technical Summary: Tree Intercropping, *supra* note 266.
269 *Id.*
270 Drawdown.org, Technical Summary: Perennial Staple Crops, https://drawdown.org/solutions/perennial-staple-crops/technical-summary (last visited Mar. 31, 2020) [hereinafter Technical Summary: Perennial Staple Crops].
271 Drawdown.org, Perennial Staple Crops, https://drawdown.org/solutions/perennial-staple-crops (last visited Mar. 31, 2020) [hereinafter Overview: Perennial Staple Crops].
272 *Id.*

down, "staple foods from trees include starchy fruits such as bananas and breadfruit, oil-rich fruits such as avocado, and nuts such as coconut and Brazil."[273]

C. POTENTIAL APPLICATION TO HAWAIʻI LANDS

1. Grassland

Project Drawdown's *multistrata agroforestry* solution replaces grazing on non-degraded tropical humid grassland.[274] Project Drawdown concluded that, at the global scale, adoption of the *multistrata agroforestry* solution was the fifth priority for non-degraded grasslands.[275]

Project Drawdown's *perennial staple crops* solution replaces conventional annual crop production in humid and semi-arid tropics in grasslands and croplands.[276] At the global level, Project Drawdown determined that adoption of the *perennial staple crops* solution was the second-highest priority for degraded grassland and the sixth-highest priority for degraded cropland.[277]

In 2017, there were 761,816 acres of permanent pasture and rangeland[278] across the state of Hawaiʻi.[279] Information on the degradation status of these grasslands is not currently available.

2. Degraded cropland

Project Drawdown's *tree intercropping* solution replaces conventional annual crop production on degraded cropland.[280] At the global scale, Project Drawdown identified the *tree intercropping* solution as its top priority for degraded cropland.[281]

As of 2017, there were 191,175 acres of cropland across the state of Hawaiʻi.[282] Data is not currently available to indicate how many of these acres currently use conventional annual cropping systems and are degraded. If that data were available, it would provide a more detailed picture of potential applicability of this solution in Hawaiʻi.

D. POTENTIAL GREENHOUSE GAS BENEFITS

a) Sequestration

The amounts and duration of carbon sequestration and reduction in greenhouse emissions are influenced by the local growing environment, design specifics, and management activities, making agroforestry a complex but flexible greenhouse gas mitigation option.[283]

Project Drawdown set the following carbon sequestration rates for the agroforestry solutions:

Agroforestry Solution	Sequestration rate (tons of CO_2e)
Multistrata Agroforestry	16.3 per hectare/yr (or 6.6 per acre/yr) [284]
Tree Intercropping	6.2 per hectare/yr (or 2.5 per acre/yr)[285]
Perennial Staple Crops	12.3 per hectare/yr (or 5.0 per acre/yr)[286]

b) Emissions Reductions

Project Drawdown does not address potential emissions reductions involved with adopting the *multistrata agroforestry*, *tree intercropping*, or *perennial staple crops* solutions. The *multistrata agroforestry* solution may provide opportunities to reduce greenhouse gas emissions through improved soil health and reduced fire risk, if the current use of degraded grasslands is further degrading the soil and increasing the fire risk through spread of invasive alien grasses. Emissions reduction opportunities may be limited, however, by increased emissions related to soil disturbance (particularly on grasslands with high soil carbon stocks), fertilizer use, decomposition of organic matter, and fuel use (for transportation to market and other needs).

If the *tree intercropping* solution reduces the need for off-farm inputs, such as purchased mulch, soil amendments, or fertilizer, it may reduce emissions related to the production and transportation of those inputs (into the state as well as within the state).

One critical assumption that Project Drawdown makes about the *perennial staple crops* solution is that it would only be adopted on grassland and cropland, with no forest clearing involved.[287] In many places around the world, forest is being cleared for staple tree crops like avocado and oil palm.[288] According to Project Drawdown, if forest (particularly peatland) is cleared for the *tropical staple tree* solution, net greenhouse gas emissions will result, regardless of how much carbon is sequestered by adopting the solution.[289]

273 *Id.*
274 Technical Summary: Multistrata Agroforestry, *supra* note 263.
275 *Id.*
276 Technical Summary: Perennial Staple Crops, *supra* note 270.
277 *Id.*
278 This excludes pastured woodland.
279 Table 8. Income from Farm-Related Sources, supra note 204.
280 Technical Summary: Tree Intercropping, *supra* note 266.
281 *Id.*
282 National Agricultural Statistics Service, *State Profile: Hawaii, in* 2017 Census of Agriculture - State Data (2017), *available at* https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Hawaii/cp99015.pdf (last visited Mar. 31, 2020) [hereinafter *State Profile: Hawaii]*. Only 4,899 of those acres were used to produce corn for grain, 165 acres were used to produce soybeans, and 149 acres were used to produce potatoes. *Table 71. Summary by Size of Farm, supra* note 124.
283 Elevitch, Behling, Constantinides, & Friday, *supra* note 261, at 5.
284 Technical Summary: Multistrata Agroforestry, *supra* note 263.
285 This rate assumed tree intercropping with tillage-based annual cropping. According to Project Drawdown, if tree intercropping were combined with climate-friendly practices like the *conservation agriculture* or *regenerative agriculture* solutions, it is possible that the sequestration rates might be higher than either practice alone. Technical Summary: Tree Intercropping, *supra* note 266.
286 Project Drawdown's analysis assumed that all carbon sequestered through the *perennial staple crops* solution would be re-emitted to the atmosphere at the end of an orchard or plantation's useful life, which was set at 37.5 years. Technical Summary: Perennial Staple Crops, *supra* note 270.
287 *Id.*
288 *Id.*
289 *Id.*

If the *perennial staple crops* solution replaced any of the demand for imported corn, wheat, potato, and soybean products, Hawai'i would likely benefit from emissions reductions related to the importation of these products from out-of-state.

E. POTENTIAL CO-BENEFITS

According to Project Drawdown, these agroforestry solutions share a lot of the same co-benefits, including: providing food, preventing erosion and flooding, recharging groundwater, restoring degraded land and soils, and supporting biodiversity by providing habitat between fragmented ecosystems.

Additionally, guidance provided by breadfruit agroforestry practitioners and researchers working in the Pacific suggests that practices in the *multistrata agroforestry* solution can: increase crop yields (by reducing water evaporation and transpiration from plants, buffering from drastic weather shifts, reducing wind damage, suppressing invasive weeds, and improving soils); create habitat for beneficial species (which may reduce losses from pests and diseases); and improve community self-sufficiency (by increasing resilience to weather extremes and increasing local food and nutrition security.[290]

Practices in the *tree intercropping* solution have the potential to: reduce land degradation from wind, erosion, salt spray, and pesticide drift;[291] improve crop quality and yield;[292] reduce the need for off-farm inputs (such as purchased mulch and nitrogen fertilizers);[293] diversify yields;[294] make more efficient use of land (through the use of marginal land); rehabilitate degraded land; and increase efficiency.[295]

Practices in the *perennial staple crops* solution have the potential to: provide yields equivalent to or better than their annual staple crop competitors;[296] grow on steep slopes in a wide range of soils; provide stable habitat for pollinators, birds, and other species;[297] and use lower inputs of fuel, fertilizer, and pesticides.[298]

F. RISKS AND POTENTIAL UNINTENDED CONSEQUENCES

These agroforestry solutions share a lot of the same challenges, including: the potential for exotic species to be used which may pose unknown or unintended consequences in Hawai'i;[299] likely need for increased human (rather than mechanized) labor; need for longer-term access to land in order to benefit from longer-term returns from trees; need to manage for multiple products and/or environmental services, which can be dynamic and more complex;[300] and the need to manage potential competition for water and nutrients.[301]

The expanded adoption of the *multistrata agroforestry* solution may be limited by the lack of available or affordable labor, and it may be more financially feasible for subsistence food production than for commercial. Adoption of this solution would also need to guard against trees escaping and becoming problem weeds in native forests. The same properties that make multipurpose trees useful on farms—for example, the ability to grow rapidly, fix nitrogen, or reproduce quickly—also make them likely to become invasive.[302]

For the *tree intercropping* solution, appropriate species selection, spacing, and management practices are necessary to maximize positive interactions between trees and crops and minimize negative interactions.[303] Negative interactions come from competition for water or nutrients.[304] There may also be some loss in crop production, which may be compensated for by other benefits from the trees.[305] Mixed cropping systems often involve some trade-offs in production, so careful advanced planning is important to minimize risks and maximize benefits.[306]

Products from the *perennial staple crops* solution could be more labor intensive to produce than annuals, require a longer period between planting and harvest, face limited market opportunities, and require more knowledge and technology to implement. Some staple tree or perennial products may also have a shorter shelf-life. Consumers may need education, outreach, or incentives to transition their tastes and expectations away from imported annual staple crop products and toward Hawai'i-grown tropical staple tree products

290 Craig R. Elevitch & Diane Ragone, Breadfruit Agroforestry Guide: Planning and implementation of regenerative organic methods 6 (2018) *available at* https://ntbg.org/wp-content/uploads/2020/02/breadfruit_agroforestry_guide_web_edition.pdf (last visited Apr. 1, 2020).
291 Elevitch & Wilkinson, *supra* note 260, at 123.
292 A 2016 study showed that coffee-macadamia intercropping resulted in higher profitably than monocropped coffee. Marcos J. Perdona & Rogerio P. Soratto, *Arabica Coffee–Macadamia Intercropping: A Suitable Macadamia Cultivar to Allow Mechanization Practices and Maximize Profitability,* 108 Agronomy Journal 2301-2312 (2016).
293 Monkeypod is a nitrogen-fixing tree that is commonly used in Hawai'i for shade in coffee farms below 1,500 ft elevation. Travis Idol, *Ecosystem Services from Trees in Coffee Agroecosystems*, Hanai 'Ai/The Food Provider (March-May 2012) *available at* https://pdfs.semanticscholar.org/41cb/bb941089b960343d2fdf77a71537c41c5dc5.pdf (last visited Apr. 1, 2020).
Koa is a native nitrogen fixer that can be grown with coffee at higher elevations (above 2,000 feet). There are also many traditional tropical nitrogen fixers that are found in Hawai'i, but less widely used (such as *Gliricidia sepium* and *Inga edulis*). *Id.*
294 Elevitch & Wilkinson, *supra* note 260, at 123.
295 *Id.*
296 Technical Summary: Tree Intercropping, *supra* note 266.
297 *Id.*
298 *Id.*
299 Risks and unintended consequences would likely be avoided if any efforts to expand multistrata agroforestry were based firmly on the many time-tested agroforestry species that already exist in the Pacific Islands, strengthened, where appropriate with properly evaluated introduced trees and technologies. Randolph R. Thaman, Craig R. Elevitch, & Kim M. Wilkinson, *Multipurpose Trees for Agroforestry in the Pacific Islands,* Agroforestry Guides for Pacific Islands 26, 23-70 (2000).
300 Appropriate species selection, spacing, and management practices are necessary to maximize positive interactions between trees and crops and minimize negative interactions. Elevitch & Wilkinson, *supra* note 260, at 124.
301 *Id.*
302 Dep't of Natural Resources & Envtl. Mgmt. CTAHR, *supra* note 221, at 47-48.
303 Elevitch & Wilkinson, *supra* note 260, at 124.
304 *Id.*
305 *Id.*
306 *Id.*

G. ECONOMIC FEASIBILITY

These agroforestry solutions tend to have higher initial investment requirements than many of the other solutions considered in this report. Two out of the three, however, also provide much higher estimated net profits than the assumed current land use practice, based on global data and modeling.

Project Drawdown estimated the following related to adopting the *multistrata agroforestry* solution on degraded grassland in humid tropical climates:[307]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$1,335.70 per hectare (or $540.54 per acre)	$1,799.40 per hectare/yr (or $728.19 per acre/yr)	$154.12 per hectare/yr (or $62.37 per acre/yr)	N/A[308]

Project Drawdown estimated the following related to using the *tree intercropping* solution to replace conventional annual crop production on temperate and tropical degraded cropland.[309]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$988.12 per hectare (or $399.88 per acre)	$639.02 per hectare/yr (or $258.60 per acre/yr)	$492.81 per hectare/yr (or $199.43 per acre/yr)	N/A

Project Drawdown estimated the following related to using the *perennial staple crops* solution to replace conventional annual crop production in humid and semi-arid tropics:[310]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$1,298.40 per hectare (or approximately $525.44 per acre)	$1,025.98 per hectare per year (or approximately $415.20 per acre per year)	$154.12 per hectare per year (or approximately $62.37 per acre per year)	2.4 times greater[311]

Factors that would likely affect the net profit estimates of all of these agroforestry solutions, if adopted in Hawai‘i, are the higher costs of land, labor, production, and shipping. Higher transportation costs between islands would also apply if products on all the islands needed to access larger markets concentrated on O‘ahu.

All these agroforestry solutions may offer opportunities for diversified income that could spread the market risk across multiple products and mitigate risks from weather and economic forces. In Hawai‘i, additional income opportunities may be developing for the waste streams of agroforestry systems. For example, local research has been exploring the potential uses for the forty percent of papaya grown in Hawai‘i that does not go to market because of flaws.[312] This waste papaya was being researched by Hawai‘i Pacific University's Oceanic Institute as a potential feedstock for fungal proteins that could be used as feed for shrimp and fish operations.[313] As mentioned in the Agriculture section of this report, one company is also using macadamia nut shells to produce biochar as a soil amendment.[314]

There has also been a resurgence of breadfruit consumption in Hawai‘i, but actual commercial crop production is still early.[315] There are efforts to produce new, more stable products from breadfruit (like flour) that could help encourage future plantings.[316] There are also networks and cooperatives that focus on encouraging greater utilization of breadfruit locally.[317]

Diversification with tree crops can also provide supplemental business opportunities, such as the kind of agro- or ecotourism that can already be seen on some Hawai‘i coffee farms.

H. OVERALL RATINGS

Multistrata Agroforestry **Solution**

High	Medium	Low	
			Potential for Greenhouse Gas Benefits
			Potential for Co-Benefits
			Lack of Risks

Tree Intercropping **Solution**

High	Medium	Low	
			Potential for Greenhouse Gas Benefits
			Potential for Co-Benefits
			Lack of Risks

Perennial Staple Crops **Solution**

High	Medium	Low	

307 Technical Summary: Multistrata Agroforestry, *supra* note 263.
308 Project Drawdown assumed yields "to be equal to the business-as-usual annual cropping, due to the great variation in crops and cropping systems." *Id.*
309 Technical Summary: Tree Intercropping, *supra* note 266.
310 Technical Summary: Perennial Staple Crops, *supra* note 270.
311 Project Drawdown determined that the "weighted average yield of perennial staple crops is 2.4 times greater than that of annual staples, based on analysis of date from 7 perennials and 15 annuals." *Id.*
312 Fujii-Oride, *supra* note 253.
313 *Id.*
314 Pacific Biochar.com, *supra* note 177.
315 Melrose, Perroy, & Cares, *supra* note 53, at 30.
316 *Id.*
317 For example, https://eatbreadfruit.com/pages/about-the-co-op and https://hawaiihomegrown.net/breadfruit (last visited Apr. 1, 2020).

			Potential for Greenhouse Gas Benefits
			Potential for Co-Benefits
			Lack of Risks

Further Research Needed:

- Data and maps that reflect degraded status of grasslands in humid areas in Hawai'i;
- Data and maps that reflect conventional annual crop production system use on degraded grassland in humid and semi-arid areas in Hawai'i;
- Data and maps that reflect conventional annual crop production system use on degraded cropland in Hawai'i;
- Cost information on implementation of *multistrata agroforestry*, *tree intercropping*, and *perennial staple crops* practices in Hawai'i;
- Carbon sequestration rates for trees frequently used in Hawai'i for these practices (e.g. avocado, banana, breadfruit, and coconut);
- Market potential for substituting imported annual crop products with local agroforestry products; and
- Market potential for new products from agroforestry system waste streams.

VII. FORESTRY

A. OVERVIEW

The U.S. Geological Service published a key assessment in 2017 of carbon storage and flux across the Hawaiian Islands.[318] The assessment provided critical baseline data and projections of how carbon will be cycled and stored in Hawai'i's terrestrial ecosystems as we move into the future.[319] The assessment acknowledged the significant role that forest ecosystems have to play, noting that "[g]lobally, forest ecosystems contain nearly [forty-five] percent of all carbon stored in terrestrial ecosystems and account for nearly [fifty] percent of all carbon sequestered by ecosystems."[320]

According to Project Drawdown, global emissions from tropical deforestation and forest degradation are 5.1 to 8.4 gigatons of CO_2e per year or fourteen to twenty-one percent of global human-caused emissions.[321] The IPCC has concluded that reserving and enhancing the carbon stocks that already exist in forests has immediate and important climate benefits.[322] Generally, forest ecosystems cannot continue sequestering carbon indefinitely.[323] As plants mature or as carbon reservoirs reach saturation, the amount of CO_2 they can remove every year declines toward zero.[324] Peatlands and coastal wetlands provide an exception to that general rule, as they do not reach carbon saturation and can continue sequestering carbon in soil organic matter for centuries.[325] All forest ecosystems share potential vulnerability to land use change pressures and other human-influenced impacts, as well as unknown future impacts from climate change.[326]

B. FOREST PROTECTION SOLUTION

Project Drawdown provides five solutions focused on protecting existing ecosystems: *coastal wetland protection* solution; *forest protection* solution, *indigenous people's forest tenure* solution, *peatland protection and rewetting* solution, and *grassland protection* solution. The *coastal wetland protection* solution is addressed in detail in the Marine Environment section of this report. Since the *grassland protection* solution protects "natural, ungrazed grasslands," it does not appear to be broadly applicable in Hawai'i; therefore, it is not analyzed further.[327]

As defined by Project Drawdown, the *indigenous people's forest tenure* solution is "providing indigenous communities with secure legal tenure rights to their traditional forest land."[328] This solution replaces non-degraded forest without such tenure.[329]

Accurately describing the Native Hawaiian people's landscape of legal rights to their traditional forest land requires a complex legal analysis that is beyond the scope of this limited study. Therefore, this solution is not analyzed separately. Some aspects of Project Drawdown's analysis of the *indigenous people's forest tenure* solution are similar to the *forest protection* solution,[330] which will be analyzed in this section.

318 Paul C. Selmants, Christian P. Giardina, James D. Jacobi, Lucas B. Fortini, R. Flint Hughes, Todd J. Hawbaker, Richard A. MacKenzie, Benjamin M. Sleeter, & Zhiliang Zhu, *Executive Summary – Baseline & Projected Future Carbon Storage and Carbon Fluxes in Ecosystems of Hawai'i* in Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawai'i 1, 1-2 (Paul C. Selmants, Christian P. Giardina, James D. Jacobi, & Zhiliang Zhu, eds., 2017), *available at* https://pubs.usgs.gov/pp/1834/a/pp1834_executive_summary.pdf (last visited Apr. 1, 2020).

319 *Id.*

320 Todd J. Hawbaker, Clay Trauernicht, Stephen M. Howard, Creighton M. Litton, Christian P. Giardina, James D. Jacobi, Lucas B. Fortini, R. Flint Hughes, Paul C. Selmants, & Zhiliang Zhu, *Chapter 5. Wildland Fires and Greenhouse as Emissions in Hawai'i* in Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawai'i 57, 57-73 (Paul C. Selmants, Christian P. Giardina, James D. Jacobi, & Zhiliang Zhu, eds., 2017), *available at* https://pubs.usgs.gov/pp/1834/a/pp1834_chapter5.pdf (last visited Apr. 1, 2020).

321 Drawdown.org, Technical Summary: Forest Protection, https://www.drawdown.org/solutions/forest-protection/technical-summary (last visited Apr. 1, 2020) [hereinafter Technical Summary: Forest Protection].

322 IPCC, Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems 191 (P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, eds., 2019) *available at* https://www.ipcc.ch/srccl/ (last visited Apr. 1, 2020).

323 *Id.* at 18.

324 *Id.*

325 *Id.;* Drawdown.org, Technical Summary: Peatland Protection & Rewetting, https://www.drawdown.org/solutions/peatland-protection-and-rewetting/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Peatland]; Drawdown.org, Technical Summary: Coastal Wetland Protection, https://www.drawdown.org/solutions/coastal-wetland-protection/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Coastal Wetland Protection]

326 IPCC, Climate Change and Land *supra* note 322, at 79.

327 Project Drawdown defines the *grassland protection* solution as "the legal protection of natural, ungrazed grasslands from future grazing and/or conversion to annual cropland, perennial cropland, biomass or bioenergy crops." Drawdown.org, Technical Summary: Grassland Protection, https://www.drawdown.org/solutions/grassland-protection/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Grassland Protection].

328 Drawdown.org, Technical Summary: Indigenous Peoples' Forest Tenure, https://www.drawdown.org/solutions/indigenous-peoples-forest-tenure/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Indigenous Peoples' Forest Tenure].

329 *Id.*

330 Project Drawdown states that the indigenous peoples' forest tenure solution "can be seen as a form of productive forest protection, given sustainable management and utilization of forest products." *Id.* Project Drawdown uses the same avoided emissions rate for both this and the forest protection solutions (i.e. 281.1 tons of CO_2e/hectare or 113.76 tons of CO_2e/acre). Technical Summary: Forest

As defined by Project Drawdown, the *peatland protection and rewetting* solution is "the protection of carbon-rich peatlands, leading to reduced degradation rates and the safeguarding of carbon sinks as well as restoration (largely through rewetting) and protection of the currently degraded peatlands."[331] According to Project Drawdown peatlands are a hugely important stock of soil organic carbon at the global level – holding thirty percent of all soil carbon despite covering only three percent of the global land area (twice the carbon stock of all forest biomass).[332] Additionally, as mentioned above, unlike most terrestrial ecosystems, peatlands do not reach carbon saturation and can continue sequestering carbon in soil organic matter for centuries.[333] Project Drawdown concluded that it is "extremely important to prevent any further degradation of peatlands as well as to develop sustainable restoration plans for already degraded peatlands."[334]

It is unclear how many acres of peatlands exist across the state of Hawai'i or how many of those acres may already be located on protected public or private lands. Detailed information about the extent and status of peatlands in Hawai'i is needed to understand the potential application of this solution. As a result, the *peatland protection and rewetting* solution will not be analyzed separately here.

1. Definition

As defined by Project Drawdown, the *forest protection* solution is "the legal protection of forest lands, leading to reduced deforestation rates and the safeguarding of carbon sinks."[335]

2. Potential Application to Hawai'i Lands

The *forest protection* solution replaces non-protected, non-degraded forest land.[336] Project Drawdown assumed that the *forest protection* solution would primarily be implemented by government and non-government organizations rather than by private individuals or entities.[337]

According to Hawai'i's Division of Forestry and Wildlife, as of 2016 Hawai'i's forests covered approximately 1.7 million acres (forty-one percent) of total land area and approximately sixty percent is considered productive healthy forest.[338] Hawai'i's forests, particularly those in the Conservation District,[339] where most forests remain, are not threatened by logging or clearing, but by biological threats, such as hooved animals, invasive plants, and fire. As a result, unlike Project Drawdown, Hawai'i's watershed protection goals are not legal protection. For the purpose of this desktop study, however, we will use Hawai'i's priority watersheds to estimate the potential for application of Project Drawdown's *forest protection* solution in Hawai'i.

Approximately twenty percent of land area in the Hawaiian Islands (843,000 acres) is identified as priority watersheds.[340] As of 2018, Hawai'i had 140,000 acres of native watershed under high-level protection.[341] The difference between these two figures (i.e. 703,000 acres) would represent the area of potential application of the Project Drawdown *forest protection* solution.

3. Potential Greenhouse Gas Benefits

a) Sequestration

Project Drawdown does not address the sequestration rate of the *forest protection* solution.[342]

b) Emissions Reductions

Using global data and analysis, Project Drawdown sets the one-time emissions from deforestation at 281.1 tons of CO_2e per hectare (or 113.76 tons of CO_2e per acre).[343] These are the emissions that Project Drawdown estimates the *forest protection* solution would avoid if implemented.

In Hawai'i, although forests cover only thirty-six percent of the land, forest carbon accounts for the largest carbon sink for the state.[344] Forest carbon and urban trees are also projected to sequester more carbon between 2020-2025, due to expected increases in forest and urban areas.[345]

The emissions reduction potential of the *forest protection* solution in Hawai'i would be affected by the occurrence of wildfires. In 2015, emissions from forest fires in Hawai'i

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Protection, *supra* note 321; Indigenous Peoples' Forest Tenure, *supra* note 328. However, Project Drawdown considers the *indigenous people's forest tenure* solution to have additional social benefits, better sustainability, and provide management advantages for remote forest areas in hard climatic conditions. Indigenous Peoples' Forest Tenure, *supra* note 328.

331 Technical Summary: Peatland, *supra* note 325.

332 *Id.*

333 *Id.*

334 *Id.*

335 Technical Summary: Forest Protection, *supra* note 321.

336 *Id.*

337 *Id.*

338 Smith, *supra* note 247, at 268.

339 In Hawai'i, the overall framework of land use management was established by the State Land Use Law (Hawai'i Revised Statutes Chapter 205) in 1961. This framework classifies all lands in the State of Hawai'i into one of four land use districts:

1. Conservation,
2. Agricultural,
3. Rural, and
4. Urban.

State of Hawai'i Land Use Commission, About the LUC, https://luc.hawaii.gov/about/ (last visited Apr. 2, 2020). "Conservation lands are comprised primarily of lands in existing forest and water reserve zones and include areas necessary for protecting watersheds and water sources, scenic and historic areas, parks, wilderness, open space, recreational areas, habitats of endemic plants, fish and wildlife, and all submerged lands seaward of the shoreline. The Conservation District also includes lands subject to flooding and soil erosion." State of Hawai'i Land Use Commission, State Land Use Districts, https://luc.hawaii.gov/about/state-land-use-districts/ (last visited Apr. 2, 2020).

340 State of Hawai'i Dashboard, Agriculture & Environment: Watershed Area https://dashboard.hawaii.gov/en/stat/goals/ygf4-8dm6/pmmn-ftbu/3jyf-25ch (last visited Apr. 2, 2020).

341 *Id.*

342 Technical Summary: Forest Protection, *supra* note 321.

343 *Id.*

344 Hawbaker, Trauernicht, Howard, Litton, Giardina, Jacobi, Fortini, Hughes, Selmants, & Zhu, *supra* note 320, at 64. This methodology does not consider potential changes in sequestration rates due to the age of the forest ecosystem and forest management practices. *Id.* at 57. Live-biomass carbon storage in native forests was estimated as 32 TgC, which was 51 percent of all carbon stored as live biomass (63 TgC), followed by invaded forests (21 TgC) and alien tree plantations (6 TgC). Selmants, Giardina, Jacobi, Fortini, Hughes, Hawbaker, MacKenzie, Sleeter, & Zhu, *supra* note 318, at 1.

345 Hawaii Greenhouse Gas Emissions Report for 2015, *supra* note 10 at 72.

were 0.11 MMT CO_2e.[346] Wildland fires can change the land cover type, for example converting forest to grassland, leading to long-term and substantial impacts on the carbon cycle.[347] This type of possible impact is important in Hawai'i, where new wildland fire cycles have become established by invasive nonnative grasses.[348] Additionally the nonnative grasses that replace forested areas after fires, have a much lower capacity to store carbon.[349]

4. Potential Co-Benefits

According to Project Drawdown, the ***forest protection*** solution can provide co-benefits such as biodiversity protection, non-timber products, erosion control, pollination, ecotourism, and other ecosystem services like conserving water quality and quantity.[350]

According to the State of Hawai'i's Division of Forestry and Wildlife, forests in Hawai'i slow the movement of water from steep mountainsides through streams to maximize aquifer recharge and prevent flooding during heavy rains that can cause topsoil erosion and sedimentation.[351] Forests also keep fine sediment from smothering coastal coral reefs.[352] Forest protection in Hawai'i provides a consistent water supply that meets domestic, agricultural, industrial, and tourism needs.[353] Forests also provide other ecosystem services like drought mitigation, preservation of cultural heritage and local values and knowledge, livelihood support, air pollution removal, recreation opportunities, and preservation of unique native species.[354]

Hawai'i's native habitats and wildlife are important to residents and visitors and serve as the backbone of Hawai'i's multi-billion-dollar tourism industry.[355] In 2012, the Department of Land and Natural Resources estimated that the forests on the mountains of O'ahu alone had a net present value of $14 billion, based on their ability to provide water quality and recharge, climate control, biodiversity, and cultural, aesthetic, recreational, and commercial values to Hawai'i's visitors and residents.[356]

Forests also provide non-timber forest products, including animal products, edible medicinal plants, berries, seeds, and oils.[357] According to the State of Hawai'i's Division of Forestry and Wildlife, non-timber forest products are often important to rural communities, "for household subsistence, maintenance of cultural and familial traditions, spiritual fulfillment, medicine and healing, and a source of income."[358] In Hawai'i, common non-timber forest products include flowers and leaves for lei making and handicrafts, wild fruits and edible plants, game animals and water.[359]

5. Risks and Potential Unintended Consequences

Unlike most mainland areas, much of Hawai'i's unique native biodiversity is in restricted or remote, high-elevation forests where access is difficult to impossible, and opportunities to see them are limited.[360] As a result, many Hawai'i residents have little connection to, or knowledge of, the biodiversity that is unique to Hawai'i, so there is little demand from the public to provide the funding necessary to protect it.[361]

Hawai'i residents that do have a connection to the high-elevation forests often rely on the forest for non-timber forest products for household subsistence (particularly game animals) and for the maintenance of cultural and family traditions. Depending on how forested lands are protected, there can be a risk of negatively impacting indigenous or local community access and generating opposition to forest protection efforts.
Both indifference and overt opposition can be risks to the successful protection of forested land. Forest protection efforts in Hawai'i require education and outreach that is inclusive and sensitive to the concerns of Hawai'i's native people and the diverse community make-up of each island. This can require a significant amount of time and resources.

Additionally, there is a risk that increases in temperatures at higher elevations, where most native forests exist, could make forests more vulnerable to damage by invasive species.[362] An increase in storm frequency attributable to climate change may also increase forest disturbance, facilitating the spread and establishment of invasive species and making forest protection efforts more difficult and more costly.[363]

6. Economic Feasibility

Project Drawdown assumed that any costs for the *forest protection* solution (such as carbon payments or payment for ecosystem services) would be borne by a government or non-governmental entity.[364] Project Drawdown's land-based solutions only modeled costs that were incurred at the landowner or manager level; therefore, Project Drawdown provides no estimated costs for the *forest protection* solu-

346 *Id.* at 50.
347 Hawbaker, Trauernicht, Howard, Litton, Giardina, Jacobi, Fortini, Hughes, Selmants, & Zhu, *supra* note 320, at 58.
348 *Id.*
349 *Id.*
350 Drawdown.org, Forest Protection, https://www.drawdown.org/solutions/forest-protection (last visited Apr. 2, 2020) [hereinafter Overview: Forest Protection].
351 Smith, *supra* note 247, at 44.
352 *Id.*
353 *Id.*
354 *Id.*
355 *Id.* at 209.
356 Hawai'i DLNR, Wai 4, 1-16 (2012) available at https://dlnr.hawaii.gov/wp-content/uploads/2013/02/WAI-2012021.pdf (last visited Apr. 2, 2020).
357 Smith, *supra* note 247, at 262.
358 *Id.*
359 *Id.*
360 *Id.* at 204.
361 *Id.*
362 *Id.* at 84.
363 *Id.*
364 Technical Summary: Forest Protection, *supra* note 321.

tion.[365]

In Hawai‘i, the primary costs associated with forest protection efforts (public or private) are related to feral, hooved animals (e.g. pigs, goats, sheep, deer, and cattle) and invasive plants.[366] Without fencing (which can be very costly), feral animals trample, browse, and destroy vulnerable vegetation and turn up the ground leaving it bare and exposed, increasing erosion and allowing non-native species to germinate and thrive.[367] Invasive plants cause a loss of habitat for native plants and animals.[368] Introduced insect pests and plant diseases are also a threat and occur in all areas of the state, including forests, urban areas, and agricultural areas.[369] One example is a fungal pathogen (*Ceratocystis fimbriata*), often referred to as Rapid ‘Ōhia Death (ROD).[370] In 2016, ROD was only found on Hawai‘i Island but was identified as a threat that could to wipe out ‘ōhi‘a trees, Hawai‘i's most widespread and ecologically important tree species, which provides critical habitat to rare, threatened, and endangered birds.[371] Since then, ROD has also been detected on the islands of Kaua‘i, Maui, and O‘ahu.[372]
The numbers of non-native species established in Hawai‘i is increasing with new pathways of introduction (e.g. Internet mail order) and an economy with continued dependence on imports.[373] Global and local climate change also has the potential to extend the ranges of Hawai‘i's established invasive species to higher elevations.[374]

Hawai‘i has developed a unique capacity to meet the challenges of forest protection. As of 2016, eleven watershed partnerships were active on five islands across the State.[375] Watershed partnerships are voluntary alliances of both public and private landowners committed to the common value of protecting forested watersheds for water recharge, conservation, and other ecosystem services through collaborative management.[376] These partnerships involve over seventy-one public and private landowners and partners and twenty-four public agencies that cover more than 2.2 million acres of land in the state.[377] According to the State of Hawai‘i's Division of Forestry and Wildlife, the watershed partnerships have led to “results-oriented protection and restoration of forested watersheds through fencing and ungulate removal, invasive species control, native outplantings, and outreach and education involving schools and communities.”[378]

Hawai‘i also has a number of community-based forest management projects that focus on socially and culturally important forest resources. These projects are also public-private partnerships that have formed to protect native dry forests, which are one of the most threatened ecosystems in Hawai‘i.[379]

7. Overall Rating

***Forest Protection* Solution**

High	Medium	Low	
■			Potential for Greenhouse Gas Benefits
■			Potential for Co-Benefits
■			Lack of Risks

Further research:

- Data and maps that reflect the location and protection status of peatlands in Hawai‘i;
- Further research into the age of Hawai‘i forests, improved forest management practices, and their emissions reduction potential;
- Refined models of predicted effects of climate change at a spatial scale appropriate for Hawai‘i;
- Support for research on the effects of climate change on forest carbon pools;
- Increased research and monitoring of biological forest threats, such as Rapid ‘Ōhia Death; and
- Increased monitoring and survey of invasive species populations.

C. TROPICAL FOREST RESTORATION SOLUTION

In addition to the *peatland protection and rewetting* solution discussed previously, Project Drawdown provides three additional ecosystem restoration solutions: the *temperate forest restoration* solution,[380] the *tropical forest restoration* solution, and the *coastal wetland restoration* solution. Forests in Hawai‘i occur in a wide range of elevations, moisture levels, and temperatures; however by latitude Hawai‘i falls within the tropics. Therefore, only Project Drawdown's *tropical forest restoration* solution will be analyzed here. The *coastal wetland restoration* solution is discussed in detail in the Marine Environment section of this report.

1. Definition

Project Drawdown defines the *tropical forest restoration* solution as “the restoration and protection of tropical climate

365 *Id.*
366 Smith, *supra* note 247, at 76.
367 *Id.*
368 *Id.*
369 *Id.* at 78.
370 *Id.*
371 *Id.*
372 CTAHR, Current Distribution of Rapid ‘Ōhi‘a Death, https://cms.ctahr.hawaii.edu/rod/THE-DISEASE/DISTRIBUTION (last visited Apr. 2, 2020).
373 Smith, *supra* note 247, at 83.
374 *Id.* at 84.
375 *Id.* at 54.
376 *Id.* at 53.
377 *Id.* at 54.
378 *Id.*
379 *Id.* at 264.
380 Drawdown.org, Technical Summary: Temperate Forest Restoration, https://www.drawdown.org/solutions/temperate-forest-restoration/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Temperate Forest Restoration].

forests."[381] This solution is Project Drawdown's highest priority for degraded tropical forest land.[382]

2. Potential Application to Hawai'i Lands

The *tropical forest restoration* solution replaces degraded tropical forest, and it assumes that any forest regrowth will be legally protected so that it will not be cleared or degraded again.[383]

If this solution were applied according to Project Drawdown's highest priority for it, it would be applied to degraded forest. There are approximately 532,760 acres of mixed and alien forest across the state which can be used to estimate the application potential for the *tropical forest restoration* solution in Hawai'i.[384]

3. Potential Greenhouse Gas Benefits

a) Sequestration

At a global level, tropical forests tend to sequester more carbon than other ecosystems despite the fact that they cover only twelve percent of the ice-free terrestrial surface area.[385] Using global data, Project Drawdown set the sequestration rate for the *tropical forest restoration* solution at 16.1 tons of CO_2e per hectare per year (or 6.5 tons of CO_2e per acre per year). Data on soil carbon sequestration for this solution was unavailable for that analysis.[386] In Hawai'i, studies have indicated that reforestation of abandoned sugarcane land can be more effective in soil carbon increase and stabilization, than when that land is converted to pasture.[387]

b) Emissions Reductions

Project Drawdown's analysis does not address potential emissions reductions associated with the *tropical forest restoration* solution. As with the *forest protection* solution discussed above, any emissions reduction potential in Hawai'i would be affected by the occurrence of wildfires.

4. Potential Co-Benefits

According to the IPCC, forest restoration can increase terrestrial carbon stocks in deforested or degraded landscapes, while increasing resiliency of forests to climate change, enhancing connectivity between forest areas, and aiding in conservation of biodiversity hotspots.[388] The *tropical forest restoration* solution shares many of the co-benefits provided by the *forest protection* solution, including biodiversity protection, non-timber products, erosion control, pollination, ecotourism, and conservation of water quality and quantity.

5. Risks and Potential Unintended Consequences

The *tropical forest restoration* solution shares the same risks discussed in the *forest protection* solution section. Additionally, introduced pests and diseases could impact the ability to successfully incorporate some native trees into reforestation efforts. For example, according to the State of Hawai'i's Division of Forestry and Wildlife, "the statewide occurrence of *koa* wilt in native forests, plantations, and nurseries limits the use of this ecologically and economically important species for ecosystem restoration and commercial reforestation efforts."[389] There is also a risk that a reforestation effort could require well-maintained fencing to be successful (which can be costly to install, as well as maintain, particularly in remote areas).[390]

6. Economic Feasibility

According to Project Drawdown, the specific mechanics of forest restoration can vary.[391] Under the simplest scenario, a non-forest use (e.g. growing crops or grazing) is stopped in the restoration area and native forest comes back to the area on its own.[392] Protective measures may be needed to keep back pressures on the new forest growth, such as fire, erosion, or grazing.[393] Other types of forest restoration are more intensive, requiring "cultivating and planting native seedlings and removing invasives to accelerate natural ecological processes."[394]

Project Drawdown used the less intensive natural regeneration of forests on degraded lands to model the *tropical forest restoration* solution.[395] As with the *forest protection* solution, Project Drawdown assumed that any costs to implement the *tropical forest restoration* solution would be paid by government entities or non-governmental organizations and therefore were not modeled.[396]

Unlike the approach modeled by Project Drawdown, in Hawai'i, native forest restoration requires the more intensive approach. For that reason, even if Project Drawdown had modeled the costs for this solution, the costs in Hawai'i would likely be much higher. Area-based invasive species management is an integral component of native forest restoration in Hawai'i.[397] Native forest restoration in Hawai'i requires fencing out harmful ungulate species and sup-

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381 Drawdown.org, Technical Summary: Tropical Forest Restoration, https://www.drawdown.org/solutions/tropical-forest-restoration/technical-summary (last visited Apr. 2, 2020) [hereinafter Technical Summary: Tropical Forest Restoration].
382 *Id.*
383 *Id.*
384 Jacobi, Price, Fortini, Gon, & Berkowitz, *supra* note 34, at 17.
385 Hawbaker, Trauernicht, Howard, Litton, Giardina, Jacobi, Fortini, Hughes, Selmants, & Zhu, supra note 320, at 57.
386 Technical Summary: Tropical Forest Restoration, *supra* note 381.
387 Yiqing Li & Bruce M. Mathews, Effect of conversion of sugarcane plantation to forest and pasture on soil carbon in Hawaii in 335 Plant & Soil 245-253 (2010).
388 IPCC, Climate Change and Land, *supra* note 322, at 571.
389 Smith, *supra* note 247, at 251.
390 *Id.* at 89.
391 Drawdown.org, Tropical Forest Restoration, https://www.drawdown.org/solutions/tropical-forest-restoration (last visited Mar. 30, 2020) [hereinafter Overview: Tropical Forest Restoration].
392 *Id.*
393 *Id.*
394 *Id.*
395 Technical Summary: Tropical Forest Restoration, *supra* note 381.
396 *Id.*
397 Smith, *supra* note 247, at 73.

pressing invasive plants.[398] Outplanting native plants or conducting scarification (to release the native plant seedbank) can also be used to suppress invasive plants.[399] Forest restoration efforts in Hawaiʻi "need to be site-specific based on climate, historical use, and other physical factors."[400]

Also highlighted by the State of Hawaiʻi's Division of Forestry and Wildlife is that forest restoration in Hawaiʻi also involves "the genetic preservation of species threatened by a pest or disease."[401] Forest health conditions on private and public land must also be monitored, often using "ground surveys, transect monitoring, helicopter surveys, road surveys, photo points, and remote sensing for gathering data."[402] Invasive species management efforts in remote and challenging terrains add to the cost of forest restoration. Public education and outreach efforts to help contain invasive species and prevent future introductions also add to the costs.[403]

As discussed in the *forest protection* solution section, Hawaiʻi has developed public-private watershed partnerships to meet the unique challenges of forest restoration in Hawaiʻi. Additionally, to help mitigate the high costs of forest restoration in Hawaiʻi some public and private landowners are exploring the potential for reforestation projects to generate carbon offset credits for sale in voluntary or compliance markets outside of Hawaiʻi.[404] The potential to develop a voluntary or compliance market for carbon offset credits within the state has also been explored in recent years.[405] A detailed report prepared for the State Office of Planning on the potential feasibility of developing a carbon offset program for Hawaiʻi was finalized at the end of 2019.[406]

7. Overall Rating

***Tropical Forest Restoration* Solution**

High	Medium	Low	
■			Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
	■		Lack of Risks

Further Research Needed:

- Research and development of existing and new technologies to support detection, mapping, and monitoring of invasive species;
- More information on plants that are entering the state and potentially posing an invasive species threat; and
- Financial impact comparison of Hawaiʻi reforestation projects designed for different carbon offset credit markets -- existing and anticipated (e.g. voluntary, compliance, out-of-state, in-state, etc.).

D. TREE PLANTATIONS (ON DEGRADED LAND) SOLUTION

1. Definition

Project Drawdown defines the *tree plantations (on degraded land)* solution as "the cultivation of trees for timber or other biomass uses on degraded land."[407] Unlike the *tropical forest restoration* solution above, the general purpose of this solution is to plants trees where trees did not exist before with the intention of eventually cutting them down and using them for a specific purpose.[408] The practices in this solution are often referred to as "afforestation."

2. Potential Application to Hawaiʻi Lands

The *tree plantations (on degraded land)* solution replaces annual cropping on active cropland, and other uses on degraded grasslands, cropland, and forest.[409] Globally, Project Drawdown determined that the *tree plantations (on degraded land)* solution was the second-highest priority for degraded grassland.[410]

If this solution were applied according to Project Drawdown's highest priority for it, it would be applied to degraded grassland. In 2017, there were 761,816 acres of permanent pasture and rangeland[411] across the state of Hawaiʻi.[412] Information on the degradation status of these grasslands is not currently available.

In Hawaiʻi, as of 2015, the largest commercial tree planting was on approximately 17,000 acres on Hawaiʻi Island.[413] These lands and others were planted in eucalyptus varieties to produce wood fiber and biomass for energy production.[414] Project Drawdown did not include biomass for energy production as one of the uses modeled in its *tree plantations (on degraded land)* solution. Therefore, that potential use of

398 *Id.* at 89.
399 *Id.*
400 *Id.*
401 *Id.*
402 *Id.*
403 *Id.* at 90.
404 One reforestation project (in the Hāmākua District of the Big Island) is actively selling voluntary carbon credits in Hawaiʻi. *Id.* at 263. A pilot project in the Kona Hema forest on Hawaiʻi Island will launch in 2020. Janis L. Magin, Hawaiʻi companies invest in local carbon offset project, Pacific Business News (Sept. 23, 2019) *available at* https://www.bizjournals.com/pacific/news/2019/09/23/hawaii-companies-invest-in-local-carbon-offset.html (last visited Apr. 6, 2020). The State of Hawaii's Division of Forestry and Wildlife has also been developing a forest carbon project on Maui. State of Hawaiʻi Division of Forestry & Wildlife, Kahikinui/Nakula Forest Carbon Project, https://dlnr.hawaii.gov/forestry/frs/initiatives/forestcarbon/kahikinui-nakula-forest-carbon-project/ (last visited Apr. 6, 2020).
405 State of Hawaii Office of Planning, Carbon Offset Program Feasibility, https://planning.hawaii.gov/sustainability/carbon-offset-program/ (last visited Apr. 6, 2020).
406 A copy of the full report is available from the Office of Planning website. *Id.*

407 Drawdown.org, Technical Summary: Tree Plantations on Degraded Land, https://www.drawdown.org/solutions/nutrient-management/technical-summary (last visited Apr. 6, 2020) [hereinafter Technical Summary: Tree Plantations on Degraded Land].
408 *Id.*
409 Drawdown.org, Tree Plantations on Degraded Land, https://www.drawdown.org/solutions/tree-plantations-on-degraded-land (last visited Apr. 16, 2020) [hereinafter Overview: Tree Plantations on Degraded Land].
410 Technical Summary: Tree Plantations on Degraded Land, *supra* note 407.
411 This excludes pastured woodland.
412 Table 8. Income from Farm-Related Sources, supra note 204.
413 Melrose, Perroy, & Cares, *supra* note 53, at 25.
414 Melrose, Perroy, & Cares, *supra* note 53, at 25.

tree plantation products will not be included in this discussion of the *tree plantations (on degraded land)* solution.

3. Potential Greenhouse Gas Benefits

a) Sequestration

According to Project Drawdown, tree plantations on degraded land have been "widely promoted as a land-based [climate change] mitigation strategy due in part to its high sequestration rates."[415] Climate mitigation through the *tree plantations (on degraded land)* solution is achieved through "biosequestration in soils, biomass, and timber."[416] Project Drawdown set the sequestration rate for the *tree plantations (on degraded land)* solution at 12.1 tons of CO_2e per hectare per year (or 4.9 tons of CO_2e per acre per year).[417] Project Drawdown's analysis assumed that all sequestered carbon would be re-emitted when the trees are harvested, except for the carbon stored in the timber.[418] The analysis assumed the average lifespan of a tree plantation on degraded land plantation would be twenty-six years.[419]

In Hawai'i, tree plantations currently exist on both public and private lands throughout the state, but they have no large scale local market for their products.[420] As a result, some timber from these plantations is being harvested and sent to foreign markets. If timber from Hawai'i tree plantations must be shipped to foreign markets to be financially feasible, the sequestration benefits anticipated by Project Drawdown for the *tree plantations (on degraded land)* solution will be significantly reduced for Hawai'i.

b) Emissions Reductions

The *tree plantations (on degraded land)* solution aims to reduce emissions from deforestation by providing an alternative source of timber, however Project Drawdown did not model that impact.[421] Project Drawdown also did not model the impacts of timber replacing emissions-intensive carbon and steel in construction.[422]

Since Hawai'i does not currently have a large-scale, local timber market, any emissions reductions anticipated from providing an alternative source of timber would not likely apply at this time.

4. Potential Co-Benefits

According to Project Drawdown, depending on the method and species used, the *tree plantations (on degraded land)* solution can provide co-benefits that include "supporting biodiversity, addressing human needs for firewood, food, and medicine, and providing ecosystem services, such as flood and drought protection."[423] Afforestation also has the potential to provide building material and restore degraded lands.[424] In Hawai'i, where native tree species are used to replace non-native grasses, afforestation may reduce fire hazard. Afforestation projects that plant native trees can also increase the availability of native wood products while reducing pressure on intact or restored native forest land.[425]

5. Risks and Potential Unintended Consequences

According to Project Drawdown, tree plantations can be controversial because they have often been "created with purely economic motives and without consideration for the long-term well-being of the land, environment, or surrounding communities."[426] As discussed with other solutions in this report, Hawai'i would be particularly vulnerable if non-native species used in tree plantations became invasive. The intentional cultivation of invasive species could negatively impact the *forest protection* and *tropical forest restoration* solutions discussed earlier in this report by making them more difficult and more costly.

A significant challenge for the *tree plantations (on degraded land)* solution in Hawai'i is that there is currently no local sustainable commercial timber industry.[427] Hawai'i timber products that must be exported will likely lose many of the greenhouse gas benefits anticipated from Project Drawdown's *tree plantations (on degraded land)* solution.

6. Economic Feasibility

Using global data and modeling, Project Drawdown estimated the following costs related pursuing the *tree plantations (on degraded land)* solution: [428]

First Costs to Adopt Solution	Net Profit with Solution	Net Profit with Current Practice	Yield Gains
$668.57 per hectare (or $270.56 per acre)	$593.96 per hectare/yr (or $240.37 per acre/yr)	$37.84 per hectare/yr (or $15.31 per acre/yr)	Not applicable

Costs to implement the *tree plantations (on degraded land)* solution in Hawai'i (by public or private landowners) are likely much higher than Project Drawdown's estimates.[429] As discussed in earlier sections of this report, any costs associated with equipment, supplies, or specialized labor that would need to be shipped in from out-of-state or shipped

415 Technical Summary: Tree Plantations on Degraded Land, *supra* note 407.
416 *Id.*
417 Project Drawdown used a single sequestration rate across all climates. *Id.*
418 *Id.*
419 *Id.*
420 Smith, *supra* note 247, at 248.
421 Technical Summary: Tree Plantations on Degraded Land, *supra* note 407.
422 *Id.*
423 Overview: Tree Plantations on Degraded Land *supra* note 409.
424 Technical Summary: Tree Plantations on Degraded Land, *supra* note 407.
425 Smith, *supra* note 247, at 249.
426 Overview: Tree Plantations on Degraded Land *supra* note 409.
427 Smith, *supra* note 247, at 248.
428 Technical Summary: Tree Plantations on Degraded Land, *supra* note 407.
429 A 2000 farm forestry guide estimated that a typical farm forest in the Hawaiian Islands would cost between $1,000 and $2,500/acre to establish, with a further $1,500 to $3,500 per acre for silvicultural work and maintenance during the life of the farm forest. Craig R. Elevitch & Kim M. Wilkinson, *Economics of Farm Forestry: Financial Evaluation for Landowners,* in Agroforestry Guides for Pacific Islands #7 (2000) available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.199.3456&rep=rep1&type=pdf (last visited Apr. 6, 2020).

between islands would likely involve higher costs for Hawai‘i than was estimated by Project Drawdown. Factors that would likely affect the net profit estimates in Hawai‘i are the higher costs of land, labor, production, and shipping. Higher transportation costs between islands would also apply if products on all the islands needed to access larger markets concentrated on O‘ahu.

7. Overall Rating

***Tree Plantations (on degraded land)* Solution**

High	Medium	Low	
■			Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
		■	Lack of Risks

Further research needed:

- Potential feasibility of developing a local sustainable timber industry in Hawai‘i.

E. SOLUTIONS THAT REQUIRE MORE INFORMATION

This section includes two solutions that are worth noting for their potential greenhouse gas benefits, but for which sufficient information is currently lacking in Hawai‘i to understand their potential application or risks: *bamboo production* solution and *perennial biomass production* solution.

1. Bamboo Production

Project Drawdown defines the *bamboo production* solution as “the large-scale cultivation of bamboo for timber or other biomass uses on degraded land, which sequesters carbon in soils, biomass and long-lived bamboo products.”[430]

According to Project Drawdown, bamboo (a woody member of grass family) grows “in a wide range of environmental conditions, and sequesters carbon at a rate greater than or equal to that of many tree species.”[431] Project Drawdown notes that some of the benefits of bamboo are that it “matures much faster than trees and does not require replanting” and there are over 1,500 documented uses for bamboo, including building materials, paper, furniture, food, fodder and charcoal.[432] Project Drawdown also acknowledges, however, that there are concerns about the invasive potential of bamboo.[433]

It is not clear from Project Drawdown’s analysis whether the species of bamboo that might be utilized for timber or biomass products might pose an invasive or otherwise environmentally degrading risk for Hawai‘i. In Hawai‘i, bamboo is generally considered to be highly invasive. It can increase issues with erosion, as well as compete with native forest when it escapes from cultivated lands. Any attempt to explore cultivation of bamboo should be done with great caution.

If a non-invasive variety is confirmed to be a low-risk in Hawai‘i, it is not clear if Hawai‘i has the infrastructure or local market in place to utilize bamboo timber or biomass.[434] It is also not clear if local production of bamboo would be financially feasible, given the likely high competition from producers outside of Hawai‘i who can produce bamboo products at a much lower cost. Given this lack of information, the *bamboo production* solution is not analyzed further here.

2. Perennial Biomass Production

Project Drawdown defines the *perennial biomass production* solution as “the use of perennial grasses and coppiced woody plants for bioenergy feedstock, instead of annual crops like corn.”[435] This solution replaces grazing or annual cropping.[436]

Project Drawdown’s *perennial biomass production* solution is intended to replace annual crops that are currently being grown for bioenergy feedstock.[437] In Hawai‘i, it is not clear if annual crops are currently being grown for bioenergy feedstock. Given this lack of information, the *perennial biomass production* solution is not analyzed further here.

VIII. URBAN FORESTS

A. OVERVIEW

Trees in urban areas (i.e., urban forests) also sequester carbon from the atmosphere.[438] According to the IPCC, over half the world’s population lives in towns and cities, and that proportion is predicted to increase to approximately seventy percent by the middle of the century.[439] According to the U.S. Forest Service, in the contiguous United States, “urban trees store over 708 million tons of carbon (approximately 12.6% of annual carbon dioxide emissions in the U.S.) and

430 Drawdown.org, Technical Summary: Bamboo Production, https://drawdown.org/solutions/bamboo-production/technical-summary (last visited Apr. 7, 2020) [hereinafter Technical Summary: Bamboo Production].
431 *Id.*
432 *Id.*
433 Drawdown.org, Bamboo Production, https://www.drawdown.org/solutions/silvopasture (last visited Apr. 7, 2020) [hereinafter Overview: Bamboo Production].
434 There is at least one commercial producer of bamboo on Maui; however, it is not clear if there is a local market for commercial bamboo timber products. See https://www.whisperingwindsbamboo.com/
435 Project Drawdown’s analysis focused on two types of perennial energy crops: herbaceous crops (mostly giant grasses, such as switchgrass, fountain grass, and silvergrass) and short rotation coppice (where aboveground biomass of re-sprouting woody crops—such as poplar, willow, eucalyptus, and locust—is harvested mechanically on a 2-3 year rotation). Drawdown.org, Technical Summary: Perennial Biomass Production, https://drawdown.org/solutions/perennial-biomass-production/technical-summary (last visited Apr. 7, 2020) [hereinafter Technical Summary: Perennial Biomass Production].
436 *Id.*
437 *Id.*
438 David J. Nowak, Eric J. Greenfield, Robert E. Hoehn, & Elizabeth Lapoint, *Carbon storage & sequestration by trees in urban & community areas of the United States*, 178 Environmental Pollution 229, 229-236 (2013) *available at* https://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_nowak_001.pdf (last visited Apr. 7, 2020).
439 IPCC, Climate Change and Land, *supra* note 322, at 391.

capture an additional 28.2 million tons [per year]."[440]

At the time of this report, Project Drawdown did not provide solutions related to urban forests; therefore, this section does not use a Project Drawdown solution as the starting point to consider the potential application, greenhouse gas benefits, co-benefits, or trade-offs for urban forestry practices.

B. DEFINITION

The U.S. Forest Service provides a definition for the term "urban forest" as "all trees within a densely populated area, including trees in parks, on streetways, and on private property."[441] The composition, health, age, extent, and costs of urban forests vary considerably.[442]

C. POTENTIAL APPLICATION TO HAWAI'I LANDS

According to the U.S. Census Bureau, urbanized areas are defined as containing 50,000 people or more. [443] As of 2010, the urban areas in Hawai'i represented approximately six percent of the total land area.[444] By 2015, the percentage of urban land area had grown to 6.3 percent (or approximately 1,032 square kilometers of land).[445]

There are three urbanized areas in the State of Hawai'i, and two of them are located in the City and County of Honolulu, on the island of O'ahu.[446] Since the largest percentage of urbanized areas in Hawai'i occur on O'ahu, the *urban forests* discussion of this report will rely heavily on information available for urban trees on O'ahu. As a result, information for urban trees on other islands may not align or be fully represented in this discussion. When more information about urban trees on other islands becomes available, a more complete discussion of the potential benefits of urban forests across the state will be possible.

An analysis prepared for the City and County of Honolulu in 2007 estimated that the City and County's Division of Urban Forestry was responsible for about 235,800 trees, "of which approximately [sixty percent] (~142,000) were along streets and [forty percent] were in parks (~94,000).[447] These trees included at least 213 species, with the rainbow shower tree, pink tecoma, and coconut palm being the most predominant species.[448] At the time of the 2007 report, young trees were dominant in Honolulu's urban forest.[449] Honolulu's street tree stocking level was determined to be at thirty-five percent in 2007, and it was determined that Honolulu had room for as many as 265,000 additional urban trees. [450]

D. POTENTIAL GREENHOUSE GAS BENEFITS

According to the 2007 analysis prepared for the City & County of Honolulu, the two primary ways that urban forests can reduce atmospheric carbon dioxide are: 1) directly sequestering carbon dioxide as woody and foliar biomass as the trees grow, and 2) trees near buildings reducing emissions associated with electric power production and consumption of natural gas.[451]

1. Sequestration

In 2007, Honolulu's urban trees reduced atmospheric CO_2 by a net of 3,340 tons per year[452] Monkeypod trees had the largest cumulative effect in Honolulu, providing 12.2% of the benefit. In 2015, it was determined that urban trees had sequestered 0.40 MMT CO_2e, which accounted for eleven percent of the statewide carbon sinks.[453]

2. Emissions Reductions

In 2007, the estimated emissions reductions (due to energy savings) of the urban trees in Honolulu were 1,796 tons of CO_2e per year.[454] According to the 2007 analysis prepared for the City & County of Honolulu, avoided emissions are important in Honolulu because oil accounts for most of the fuel used in power plants that generate electricity for O'ahu.[455] Additionally, the analysis observed that shading by urban trees can reduce the need for air conditioning and result in reduced use of oil for electricity generation.[456] Monkeypod trees were found to account for only 3.1% of the urban trees in Honolulu; however, because of their age and great size, they provided 10.6% of the energy savings provided by all the urban trees in Honolulu.[457] According to the U.S. Forest Service, shading from urban trees can also extend the life of street pavement by as much as ten years, which also

440 Hannah Safford, Elizabeth Larry, E. Gregory McPherson, David J. Nowak, & Lynne M. Westphal, Urban Forests & Climate Change, https://www.fs.usda.gov/ccrc/topics/urban-forests-and-climate-change (last visited Apr. 7, 2020).

441 *Id.*
442 *Id.*
443 Hawai'i State Data Center, Urban and Rural Areas in the State of Hawaii, by County: 2010 (Sept. 2013) *available at* http://files.hawaii.gov/dbedt/census/Census_2010/Other/2010urban_rural_report.pdf (last visited Apr. 7, 2020).
444 Hawaii Greenhouse Gas Emissions Report for 2015, *supra* note 10 at 54.
445 Jacobi, Price, Fortini, Gon, & Berkowitz, *supra* note 34, at 16 (Table 2.3).
446 Hawai'i State Data Center, *supra* note 443.
447 Kelaine E. Vargas, E. Gregory McPherson, James R. Simpson, Paula J. Peper, Shelley L. Gardner, & Qingfu Xiao, City of Honolulu, Hawai'i Municipal Forest Resource Analysis 1-2, 1-71 (Nov. 2007) *available at* https://static1.squarespace.com/static/59af5d3cd7bdce7aa5c3e11f/t/5bd9f1a01ae6cfe0184dca4b/1541009827717/Hnl+Municipal+Forest+Resource+Analysis-2007.pdf (last visited Apr. 7, 2020).
448 *Id.* at 2.
449 *Id.*
450 *Id.* at 9.

451 *Id.* at 18.
452 *Id.* at 18-19.

453 Hawaii Greenhouse Gas Emissions Report for 2015, supra note 10 at 54. The percent of urban tree coverage in Hawaii is a static estimate based on 2005 data and does not consider changes in the percent tree cover, which may have been impacted by urban planning initiatives since 2005. Id. at 55.
454 Vargas, McPherson, Simpson, Peper, Gardner, & Xiao, *supra* note 447, at 2.
455 *Id.* at 19.
456 *Id.*
457 *Id.* at 17.

reduces emissions associated with the use of petroleum-intensive materials and operation of heavy equipment used to repave roads and haul away waste.[458]

E. POTENTIAL CO-BENEFITS

Although urban forests vary greatly between cities, they provide common economic, environmental, and social benefits. Urban trees reduce air and water pollution, reduce heating and cooling costs, and increase real estate values. In 2007, it was estimated that Honolulu's urban trees removed, released, and avoided a net average of 0.41 pounds of air pollutants per tree per year.[459]

According to the U.S. Forest Service, cities generally are warmer than their surrounding areas, commonly referred to as "the heat island effect," which urban forests aid in controlling by providing shade and reducing urban albedo (the fraction of solar radiation reflected back into the environment), and through cooling evapotranspiration.[460] In 2007, the estimated value of the electricity saved annually in Honolulu from both shading and climate effects of urban trees totaled $343,356 or $8 per tree.[461]

Benefits of urban trees such as beautification, privacy, shade providing human comfort, wildlife habitat, and sense of well-being are difficult to translate into economic terms but may be captured in property values.[462] In 2007, the estimated value of the aesthetics, property value increases, and other less tangible improvements of Honolulu's urban trees was $3.16 million.[463]

It was found that an important benefit provided by urban trees in Hawai'i is their ability to reduce the amount of runoff and pollutant loading in receiving waters.[464] In 2007, it was estimated that Honolulu's urban trees reduced stormwater runoff by thirty-five million gallons annually.[465]

Additionally, community urban agroforestry opportunities may contribute to food security, fresh quality products, volunteer engagement, community well-being, and increased local income opportunities.[466] Urban trees may also improve physical and mental health and strengthen social connections.[467]

F. RISKS AND POTENTIAL UNINTENDED CONSEQUENCES

According to the City and County of Honolulu's Division of Urban Forestry, careful tree selection and maintenance are paramount considerations for the urban forest.[468] Some biological transfer of seeds and pollen between urban and natural ecosystems is inevitable and could lead to the introduction of invasive species potentially threatening native forests; therefore, aggressive introduced species should be avoided.[469] Another factor to consider is that a mature tree canopy may also compete with surrounding trees and other landscaping and obscure desired access to sunlight and public views.[470] Additionally, tree roots can cause damage to infrastructure such as sidewalks, gutters, roads, and sewer pipes.

A study conducted in 2015 for the State of Hawai'i's Division of Forestry & Wildlife and Kaulunani Program and Smart Trees Pacific suggested that Honolulu was losing urban tree canopy—nearly five percent of the total urban tree canopy over four years.[471] The majority of losses were in non-public zoning areas. Residential areas accounted for thirty-nine percent of the loss (355 acres).[472]

Additionally, according to the U.S. Forest Service, urban forests will likely face unique climate change challenges. Climate change may alter water cycles that impact urban forests.[473] Increased summer evaporation and transpiration will likely create water shortages exacerbated by urban soil compaction and impermeable surfaces.[474] More frequent and intense extreme weather events will likely increase severe flooding, uprooting or causing injury to urban trees.[475] Rising temperatures will likely increase pest and pathogen activity.[476] According to the U.S. Forest Service, proactive management will be necessary to protect urban forests from climate-related threats.[477]

G. ECONOMIC FEASIBILITY

The cost to plant and maintain trees for urban forests varies widely by climate, location, and species. Information is not currently available on the current costs to plant and maintain urban trees in Honolulu. However, planting and maintaining urban trees often takes public and private support and

458 Safford, Larry, McPherson, Nowak, & Westphal, *supra* note 440.
459 Vargas, McPherson, Simpson, Peper, Gardner, & Xiao, *supra* note 447, at 2.
460 Safford, Larry, McPherson, Nowak, & Westphal, *supra* note 440.
461 Vargas, McPherson, Simpson, Peper, Gardner, & Xiao, *supra* note 447, at 2.
462 *Id.* at 23.
463 *Id.* at 24.
464 *Id.* at 21.
465 *Id.* at 2.

466 National Agroforestry Center, *supra* note 217.
467 Safford, Larry, McPherson, Nowak, & Westphal, *supra* note 440.
468 City & County of Honolulu, Department of Parks & Recreation, Division of Urban Forestry, Urban Reforestation Master Plan III-2, I-1 to IV-12 (Dec. 2006) *available at* https://static1.squarespace.com/static/59af5d3cd7bdce7aa5c3e11f/t/5bd9ecb521c67ccf9118428d/1541008570899/Hnl+Reforestation+Master+Plan-2006.pdf (last visited Apr. 7, 2020).
469 *Id.* at III-1.
470 *Id.* at III-12.
471 Smart Trees Pacific, Urban Tree Canopy Assessment, https://smarttreespacific.org/projects/honolulu-urban-tree-canopy-assessment/ (last visited Apr. 7, 2020).
472 Total losses equated to at least 76,600 trees. New plantings totaling about 230 acres also occurred, but not at a rate that kept pace with the losses, especially considering the time required to grow a canopy. *Id.*
473 Safford, Larry, McPherson, Nowak, & Westphal, *supra* note 440.
474 *Id.*
475 *Id.*
476 *Id.*
477 *Id.*

resources to be successful.[478]

In 2007, it was estimated that Honolulu spent approximately $1.3 million per year maintaining urban trees.[479] Additionally, the total budget for repairs related to urban forests was approximately $2.5 million. [480] Those costs were attributed specifically to street trees, as park trees were found to have a significantly smaller impact on infrastructure. [481]

H. OVERALL RATING

Urban Forests

High	Medium	Low	
	■		Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
	■		Lack of Risks

Further research needed:

- Analysis of optimal tree species for Hawai'i urban environments based on their lack of invasiveness in native ecosystems, ability to limit root damage to infrastructure, ability to thrive with limited water, resistance to pests and diseases, and potential to provide native wildlife habitat or contribute to human food security; and
- Analysis of Hawai'i urban areas that could benefit most from reduction of "heat island effect" and the potential compatibility of urban tree plantings in those areas.

IX. MARINE ENVIRONMENT

A. OVERVIEW

The marine environment provides various opportunities to sequester and store large quantities of carbon. Project Drawdown currently proposes two marine environment climate change solutions relevant to this report's analysis: *coastal wetland protection* and *coastal wetland restoration*. Forthcoming studies will also consider the carbon sequestration potential of marine ecosystem restoration and regenerative ocean farming.[482] Since many of the issues related to both the *coastal wetland protection* solution and the *coastal wetland restoration* solution are shared, the analysis of these solutions will be combined here.

B. DEFINITIONS

1. Coastal Wetland Protection

Project Drawdown defines the *coastal wetland protection* solution as "the legal protection of carbon-rich mangroves, seagrasses, and saltmarshes, leading to reduced degradation rates and the safeguarding of carbon sinks."[483]

2. Coastal Wetland Restoration

Project Drawdown defines the *coastal wetland restoration* solution as "any process that aims to return a system to a pre-existing condition (whether or not this was pristine) including both natural restoration or anthropogenic-led recovery of carbon-rich mangroves, seagrasses, and saltmarshes."[484]

Project Drawdown notes that unlike most terrestrial ecosystems, coastal wetlands can continue sequestering carbon for centuries without becoming saturated.[485] Similar to peatlands discussed in this report, coastal wetlands have accumulated vast stores of carbon, giving them high global significance despite their small area.[486] For example, belowground carbon storage in vegetated marine habitats can be up to 1,000 metric tons of carbon per hectare,[487] as much as five times the carbon in tropical forests.[488] As a result, a small area of coastal wetlands can have a significant impact on the carbon cycle.[489] Globally, coastal wetlands are being degraded rapidly due to human activity, and relatively few are protected.[490]

As observed in a 2014 assessment of wetlands loss across the state of Hawai'i, "[t]he islands have a wide variety of wetlands, ranging from small, anchialine pools along the coast to large, high-elevation bogs."[491] According to the U.S. Fish and Wildlife Service's National Wetlands Inventory 2010 data, "the most extensive types of wetlands on the main Hawaiian Islands [] are freshwater lowland marshes and montane wet forests and bogs."[492] Hawai'i's coastal wetlands have been much more susceptible to loss since human settlement.[493]s An estimated forty-four percent of Hawai'i's coastal wetlands (approximately 41,761 acres)[494] have been lost.[495] Most of that loss has been concentrated on the islands of O'ahu and Hawai'i, which have lost an estimated seventy-one percent and seventy-five percent of

478 *Id.*
479 Vargas, McPherson, Simpson, Peper, Gardner, & Xiao, *supra* note 447, at 2.
480 *Id.* at 16.
481 *Id.*
482 Drawdown.org, Coastal and Ocean Sinks, https://drawdown.org/sectors/coastal-and-ocean-sinks (last visited Apr. 8, 2020) [hereinafter Coastal and Ocean Sinks].
483 Technical Summary: Coastal Wetland Protection, *supra* note 325.
484 Drawdown.org, Technical Summary: Coastal Wetland Restoration, https://drawdown.org/solutions/coastal-wetland-restoration/technical-summary (last visited Apr. 8, 2020) [hereinafter Technical Summary: Coastal Wetland Restoration] (internal citations removed).
485 Technical Summary: Coastal Wetland Protection, *supra* note 325.
486 Id.
487 N.L. Bindoff, W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin, S. O'Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, & P. Williamson, *Changing Ocean, Marine Ecosystems, & Dependent Communities* in IPCC Special Report on the Ocean and Cryosphere in a Changing Climate 454 (H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer eds., 2019) available at https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/09_SROCC_Ch05_FINAL-1.pdf (last visited Apr. 8, 2020).
488 Drawdown.org, Coastal Wetland Protection, https://drawdown.org/solutions/coastal-wetland-protection (last visited Apr. 8, 2020) [hereinafter Overview: Coastal Wetland Protection].
489 Technical Summary: Coastal Wetland Protection, *supra* note 325.
490 Overview: Coastal Wetland Protection, *supra* note 550.
491 Charles B. Van Rees & J. Michael Reed, *Wetland Loss in Hawai'i Since Human Settlement*, 34 Wetlands 335-336, 335-350 (2014).
492 *Id.* at 336.
493 *Id.* at 346.
494 Or 169 square kilometers. *Id.* (Table 2).
495 *Id.*

their coastal wetlands, respectively.[496] Urbanization is the primary threat to Hawai‘i's coastal wetlands.[497]

C. POTENTIAL APPLICATION TO HAWAI‘I LANDS

According to Project Drawdown, the *coastal wetland protection* solution secures otherwise vulnerable coastal wetlands whose destruction would be a source of greenhouse gasses.[498] The *coastal wetlands restoration* solution recovers coastal wetlands ecosystems capacity as carbon sinks.[499] Although the U.S. Fish & Wildlife Service and the Hawai‘i wetlands loss assessment use a broader definition of "wetlands,"[500] Project Drawdown limits its definitions of the *coastal wetland protection* solution and *coastal wetland restoration* solution specifically to mangroves, seagrasses, and saltmarshes.[501]

Broadly speaking, there is an estimated 213 square kilometers (approximately 52,633 acres) of wetlands distributed across O‘ahu, Hawai‘i Island, Maui, Kaua‘i, and Moloka‘i (see the table below).[502] It is not clear however, how much of Hawai‘i's wetlands might include saltmarshes and seagrasses. Non-endemic mangroves also exist in Hawai‘i, but it is unclear how much of Hawai‘i's wetlands include them.

Estimated wetland area on Hawaiian Islands in 2014 (square kilometers).[503]

Island	Coastal Wetland Area
O‘ahu	10,823 acres (43.8 sq. km)
Hawai‘i	1,483 acres (6.0 sq. km)
Maui	8,995 acres (36.4 sq. km)
Kaua‘i	21,300 acres (86.2 sq. km)
Moloka‘i	9,860 acres (39.9 sq. km)
Total	52,633 acres (213.0 sq. km)

D. POTENTIAL GREENHOUSE GAS BENEFITS

1. Sequestration

Using global data and modeling, Project Drawdown estimated the sequestration rates for the *coastal wetland protection* solution and *coastal wetland restoration* solution as follows:

Coastal Wetland Protection Solution[504]	Sequestration rate (tons of CO_2e)
Mangroves	Not provided
Salt marshes	7.0 per hectare/yr (2.85 per acre/yr)
Seagrasses	4.4 per hectare/yr (or 1.8 per acre/yr)

***Coastal Wetland Restoration* Solution[505]**	**Sequestration rate (tons of CO_2e)**
Mangroves	24.1 per hectare/yr (or 9.8 per acre/yr)
Salt marshes	3.4 per hectare/yr (1.4 per acre/yr)
Seagrasses	3.6 per hectare/yr (or 1.5 per acre/yr)

2. Emissions Reductions

Project Drawdown provided carbon emissions rates for the *coastal wetland protection* solution as follows (similar emissions rates were not provided for the *coastal wetland restoration solution)*:

Coastal Wetland Protection Solution[506]	**Emissions rate (tons of CO_2e)**
Deforested or Degraded Mangroves	32.75 per hectare/yr (or 13.25 per acre/yr)
Degraded Salt marshes	14.29 per hectare/yr (or 5.78 tons per acre/yr)
Degraded Seagrass Beds	3.81 per hectare/yr (or 1.54 tons per acre/yr)

In Hawai‘i, mangroves are an alien species and widely considered to be highly invasive in the islands. Mangroves were likely introduced around 1902. [507] Efforts have been ongoing since the early 1980s to remove mangroves from around the state, but it is not clear how many acres are typically removed each year.[508]

E. POTENTIAL CO-BENEFITS

Coastal wetlands provide a wide range of ecosystem services. Globally, mangroves, salt marshes and seagrasses provide critical habitats for biodiversity and enhance local fisheries production.[509] Globally, mangroves protect coastal communities from sea level rise and storm events.[510] In

496 *Id.*
497 *Id.* at 347.
498 Technical Summary: Coastal Wetland Protection, *supra* note 325.
499 Technical Summary: Coastal Wetland Restoration, *supra* note 484.
500 "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water." Federal Geographic Data Committee, Wetlands Subcommittee, Classification of Wetlands and Deepwater Habitats of the United States (Aug. 2013) available at https://www.fws.gov/wetlands/documents/Classification-of-Wetlands-and-Deepwater-Habitats-of-the-United-States-2013.pdf (last visited Apr. 8, 2020).
501 Technical Summary: Coastal Wetland Protection, *supra* note 325; Technical Summary: Coastal Wetland Restoration, *supra* note 484.
502 Van Rees & Reed, *supra* note 491, at 346.
503 *Id.* (Table 2).
504 Technical Summary: Coastal Wetland Protection, *supra* note 325.
505 Technical Summary: Coastal Wetland Restoration, *supra* note 484.
506 Technical Summary: Coastal Wetland Protection, *supra* note 325.
507 Patricia Tummons, In Hawai‘i, Mangrove's Drawbacks Outweigh Benefits, Environment Hawai‘i (Jan. 30, 2015) available at https://www.environment-hawaii.org/?p=7092 (last visited Apr. 8, 2020).
508 *Id.*
509 Bindoff, Cheung, Kairo, Arístegui, Guinder, Hallberg, Hilmi, Jiao, Karim, Levin, O'Donoghue, Purca Cuicapusa, Rinkevich, Suga, Tagliabue, & Williamson, *supra* note 487, at 454.
510 *Id.*

Hawai‘i, coastal wetlands also provide sediment retention and organic matter export.[511]

F. RISKS AND POTENTIAL UNINTENDED CONSEQUENCES

There are important negative economic and ecological impacts of mangroves in Hawai‘i. The introduction of mangroves has had a negative impact on native ecosystems in anchialine pools. For example, mangroves have resulted in a reduction in habitat quality for endangered waterbirds (e.g., Hawaiian stilt).[512] Mangroves have also overgrown native Hawaiian archaeological sites.[513] Mangroves may also have indirect impacts on inland ecosystems by potentially reducing the amounts of groundwater entering coastal areas.[514]

The primary threat to broadly defined coastal wetlands in Hawai‘i is urban development.[515] Demand for coastal settlements, tourism, and agriculture all compete with protection of coastal wetlands. Climate change and sea level rise also threaten coastal wetlands in Hawai‘i.[516] These problems are amplified on geologically younger islands with relatively high rates of subsidence (e.g., Hawai‘i and Maui).[517]

G. ECONOMIC FEASIBILITY

As with the *forest protection* and *tropical forest restoration* solutions, Project Drawdown did not model the financials for the *coastal wetlands protection* or *coastal wetlands restoration* solutions because it was assumed that the costs would not be carried out by the landowner or land manager.[518]

H. OVERALL RATINGS

Coastal Wetland Protection **Solution**

High	Medium	Low	
	■		Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
■			Lack of Risks

Coastal Wetland Restoration **Solution**

High	Medium	Low	
		■	Potential for Greenhouse Gas Benefits
	■		Potential for Co-Benefits
	■		Lack of Risks

Further research needed:

- Data and maps that reflect the location and extent of saltmarshes and seagrasses in Hawai‘i;
- Data and maps that reflect the location and extent of mangroves in Hawai‘i; and
- Potential greenhouse benefits that might be provided by man-made wetlands in Hawai‘i, including taro patches and fishponds.

X. COMPARISON, RANKING, AND INCENTIVES

A. COMPARISON OF SOLUTIONS FOR HAWAI‘I

1. Highest Performers Based on GHG Benefits Alone

If the Project Drawdown solutions were ranked based on their potential greenhouse gas benefits to Hawai‘i alone, the top performers appear to be the *forest protection* solution, the *multistrata agroforestry* solution, the *perennial staple crops* solution, the *tree plantations (on degraded land)* solution, the *tropical forest restoration* solution, and *silvopasture* solution (see Appendix B for full table):

GHG-only Ranking	Solution	Potential GHG Benefits	Land Use/ Land Cover Type
1	Forest Protection	~198 million tons of CO_2e (one-time avoided emissions)	Non-protected Forest
2	Multistrata Agroforestry	~5 million tons CO_2e /year (sequestration) minus the potential reduction for emissions from soil disturbance	Non-degraded Grassland
3	Perennial Staple Crops	~3.8 million tons CO_2e /year (sequestration)	Degraded Grassland
4	Tree Plantations (on degraded land)	~3.7 million tons CO_2e /year (sequestration)	Degraded Grassland

Based on Project Drawdown's global data and analysis, these solutions would appear to have the greatest potential to provide greenhouse gas benefits in Hawai‘i.

It should be noted, however, that the *multistrata agroforestry* a solution has the potential to increase emissions through soil disturbance, if they are pursued in an area with high soil

511 James A. Allen, Mangroves as alien species: the case of Hawai‘i, Global Ecology & Biogeography Letters 66-67, 61-71 (1998) available at https://www.fs.fed.us/psw/publications/allen/psw_1998_allen001.pdf (last visited Apr. 8 2020).
512 *Id.* at 67.
513 *Id.* at 67-68.
514 *Id.* at 68.
515 Van Rees & Reed, *supra* note 491, at 347.
516 R. J. Nicholls, *Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios*, 14 Global Environmental Change 69–86 (2004).
517 K.R. Ludwig, B.J. Szabo, J.G. Moore, & K.R. Simmons, *Crustal subsidence rate off Hawai'i determined from 234U/238U ages of drowned coral reefs*, 19 Geology 171–174 (1991).
518 Technical Summary: Coastal Wetland Protection, *supra* note 325; Technical Summary: Coastal Wetland Restoration, *supra* note 484.

carbon stocks (such as areas with Andisols). Additionally, the potential emissions related to the need to ship timber to markets outside the state of Hawaiʻi were not factored into Project Drawdown's model for the *tree plantations (on degraded land)* solution.

2. Highest Performers Based on Co-Benefits Alone

All of the fully analyzed solutions in this report scored high (green) or medium (yellow) providing some combination of co-benefits, including water quality, soil health, food security, biodiversity, human health, crop yield, reduced fuel use, reduced labor needs, and financial benefits to the land manager. The highest scoring solutions were the *silvopasture*, *conservation agriculture*, *regenerative annual cropping*, *tree intercropping*, *multistrata agroforestry*, and *forest protection* solutions. See Appendix C for full table.

3. Highest Performers Based on Lack of Risks Alone

Nearly all of the fully analyzed solutions in this report presented some risks or potential unintended consequences. Generally, the risks and unintended consequences included invasive species potential, land competition, water competition, potential cultural impacts, lack of market signal, lack of necessary infrastructure, potential for greenhouse gas emissions increase, and risk of reduced yields. The solutions with the least amount of risk or potential for unintended consequences were the *forestry protection* and *coastal wetland protection* solutions. The solutions that presented the greatest number of risks or potential for unintended consequences were the *conservation agriculture*, *regenerative annual cropping*, *silvopasture*, and *tree plantations (on degraded land)* solutions. See Appendix D for full table.

B. RANKING OF SOLUTIONS FOR HAWAIʻI

Important information is lacking in Hawaiʻi to allow for a ranking of these solutions with any kind of precision. Information about land degradation status, slope, soil type, climate, water availability, and land use history, as well as the potential plant species to be used in a given solution would greatly affect its appropriateness and potential benefit in Hawaiʻi. Therefore, the ranking of solutions provided below is not quantitative, but rather a reflection of the relative strengths and weaknesses that were identified in this study. See Appendix A for full table.

Ranking	Solution	Land Use/ Land Cover Type	Priority for Land Use/Land Cover Type
1	Forest Protection	Forest (non-degraded)	A
2	Tree Intercropping	Degraded Cropland	A
3	Coastal Wetland Protection	Coastal Wetlands (non-degraded)	A
4	Perennial Staple Crops	Degraded Grassland	A
5	Tropical Forest Restoration	Degraded Forest	A
6	Urban Forests	Urban Forests	A
7	Multistrata Agroforestry	Grassland (non-degraded)	A
8	Regenerative Annual Cropping	Cropland (non-degraded)	A
9	Coastal Wetlands Restoration	Degraded Coastal Wetlands	A
10	Conservation Agriculture	Cropland (non-degraded)	B
11	Silvopasture	Grassland (non-degraded)	B
12	Managed Grazing	Grassland (non-degraded)	C
13	Tree Plantations (on degraded land)	Degraded Grassland	B

Hawaiʻi Priority of Solutions by Land Use/Land Cover Type

Cropland	Degraded Cropland	Grassland	Degraded Grassland	Forest	Degraded Forest	Developed/ Urban
1. Regenerative Annual Cropping	1. Tree Intercropping	1. Multistrata Agroforestry	1. Perennial Staple Crops	1. Forest Protection	1. Tropical Forest Restoration	1. Urban Forests
2. Conservation Agriculture		2. Silvopasture	2. Tree Plantations (on degraded land)	2. Coastal Wetland Protection	2. Coastal Wetlands Restoration	
		3. Managed Grazing				

As reflected in the table above, there are three solutions potentially applicable to the non-degraded grassland land use/land cover type. Before pursing any of these solutions at a specific site, it will be very important to understand how much carbon is already stored in the grassland site. If the soil carbon stocks are high, the *multistrata agroforestry* or *silvopasture* solutions could release more carbon than would be recaptured. For the *multistrata agroforestry* solution, it will be important to consider whether the land manager has the necessary permissions, long-term land tenure, and financial stability. For the *managed grazing* solution, improvements to the infrastructure necessary to increase Hawaiʻi's local consumption of locally raised livestock could change this solution's ranking, particularly if it was pursued on grassland sites that already store high levels of carbon.

C. POTENTIAL INCENTIVES TO SUPPORT TOP-RANKED SOLUTIONS

There are existing incentive programs that may support the implementation of these high-ranked solutions for Hawai'i. A brief description of some of the local, state, and federal incentives for each of the top-ranked solutions by land use/land cover type are provided below.

1. Top-Ranked Forest Solutions

As discussed in this report, the main threats, challenges, and costs for implementing the *forest protection* solution and the *tropical forest restoration* solution in Hawai'i are biological – specifically hoofed animals, invasive plants, fire, and disease (e.g. ROD). Lack of community connection or support for costly native forest protection and restoration efforts can also be a challenge. The main threats, challenges, and costs for implementing the *coastal wetland protection* and *coastal wetland restoration* solutions are urban development and competition with coastal settlements, tourism, and agriculture. Potential sources of revenue that could be compatible with private or public lands pursuing these forest solutions include ecotourism, compensation or benefits to landowners or managers related to water quality and quantity, pollination services, or other biodiversity protection.

Existing incentive programs that may support the implementation of the forest solutions include:

County Programs	
Clean Water and Natural Lands Fund (City and County of Honolulu)	Can provide land acquisition funds to landowners with qualifying lands that fulfill the purposes of: protection of watershed lands to preserve water quality and water supply; preservation of forests, beaches, coastal areas and agricultural lands; public outdoor recreation and education, including access to beaches and mountains; preservation of historic or culturally important land areas and sites; protection of significant habitats or ecosystems, including buffer zones; conservation of land in order to reduce erosion, floods, landslides, and runoff, and acquisition of public access to public land and open space.[519]
Hawaii Public Access, Open Space, and Natural Resources Preservation Fund (Hawaii County)	Provides acquisition funds to landowners with qualifying lands worthy of preservation and recommended by the Commission.[520]
Kauai Public Access, Open Space, and Natural Resources Preservation Fund (Kauai County)	Provides acquisition funds to landowners with qualifying lands worthy of preservation and recommended by the Commission.[521]
Maui Public Access, Open Space, and Natural Resources Preservation Fund (Maui County)	Provides acquisition funds to landowners with qualifying lands that fulfill the purposes of: public outdoor recreation and education; preservation of historic or culturally important land areas; protection of significant habitat or ecosystems, including buffer zones; preserving forests, beaches, coastal areas and agricultural lands; protecting watershed lands to preserve water quality; conserving land for the purpose of reducing erosion, floods, landslides, and runoff.[522]
State Programs	
Kukulu Ola: Living Hawaiian Culture Program (HTA)	Provides funding to community-based nonprofits in Hawai'i with projects that strengthen the relationship between the visitor industry and the Hawaiian community, nurture the Hawaiian culture by supporting Hawaiian programs and cultural practitioners, craftsmen, musicians, and other artists that preserve and perpetuate the Hawaiian culture.[523]
Land Conservation Fund (DLNR)	Funding to purchase interests or rights in land with preservation value. Available to state agencies, counties, and nonprofit land conservation organization landowners interested in selling their fee title or establishing a permanent conservation easement or agricultural easement with the State. Fund available for acquisition of interests or rights in land having value to the State for the preservation of: watershed protection; coastal areas, beaches, and ocean access; habitat protection; cultural and historical sites; recreational and public hunting areas; parks; natural areas; agricultural production; and open spaces and scenic resources.[524]
Federal Programs	
Land & Water Conservation Fund (USNPS)	Federal grants to counties acquiring or developing public lands, including purchase of wetlands. Funding generated from revenues from offshore, oil and gas extraction, provides federal grants for the acquisition and development of public lands to meet the needs of all Americans for outdoor recreation and open space.[525]
Rivers, Trails, and Conservation Assistance Program (USNPS)	Rivers, Trails, and Conservation Assistance Program (USNPS): Provides technical assistance and planning support to state and local agencies, tribes, nonprofit organizations, or citizen groups for community-led natural resource conservation and outdoor recreation projects.[526]

519 City and County of Honolulu, Clean Water & Natural Lands, http://www.honolulu.gov/cwnl.html (last visited Apr. 14, 2020).
520 Hawai'i County, Process for Property Acquisition with Funds from the Public Access, Open Space and Natural Resources Preservation Fund, http://records.hawaiicounty.gov/weblink/1/doc/97127/Page1.aspx (last visited Apr. 14, 2020).
521 County of Kaua'i, Open Space Commission, https://www.kauai.gov/OpenSpace (last visited Apr. 14, 2020).
522 County of Maui, Ordinance No. 3128 (June 9, 2003), https://www.mauicounty.gov/DocumentCenter/View/13423/Ord-3128?bidId= (last visited Apr. 14, 2020).
523 Hawai'i Tourism Authority, Hawaiian Culture, https://www.hawaiitourismauthority.org/what-we-do/hta-programs/hawaiian-culture/ (last visited Apr. 14, 2020).
524 State of Hawai'i, Division of Forestry & Wildlife, Legacy Land Conservation Program, https://dlnr.hawaii.gov/ecosystems/llcp/ (last visited Apr. 14, 2020).
525 National Park Service, Land & Water Conservation Fund, https://www.nps.gov/subjects/lwcf/index.htm (last visited Apr. 14, 2020).
526 National Park Service, Rivers, Trails, & Conservation Assistance Program, https://www.nps.gov/orgs/rtca/index.htm (last visited Apr. 14, 2020).

State and Local Assistance Program (USDOI/NPS; DLNR/DSP)	Provides matching grants to states and counties for eligible public outdoor recreation projects; acquisition, development, and renovation of public outdoor recreation areas and facilities. Purpose of the program is to create and maintain a nationwide legacy of high quality recreation areas and facilities and to stimulate non-federal investments in the protection and maintenance of recreation resources across the U.S.[527]
Joint Chiefs' Landscape Restoration Partnership (USDA)	Joint partnership of the U.S. Forest Service and USDA's Natural Resources Conservation Service to improve the health of forests where public forests and grasslands connect to privately owned lands. Projects provide private landowners with conservation resources that enable them to complete restoration efforts on their land for healthier and more resilient forest ecosystems.[528]
The Healthy Forests Reserve Program (USDA-NRCS)	Helps landowners restore, enhance, and protect forestland resources on private and tribal lands through easements and financial assistance. Purpose of promoting the recovery of endangered or threatened species, improving plant and animal biodiversity, and enhancing carbon sequestration.[529]
Small Business Innovation Research Program (USDA)	Provides grants to small businesses and small proprietorships that are in business for profit. Program invites science-based small business firms to submit research proposal for funding. Topic areas include Forests and Related Resources; Plant Production and Protection; Animal Production and Protection; Air, Water, and Soils; Aquaculture; and Marketing and Trade.[530]
Conservation Banking (USFWS)	Conservation banks are permanently protected lands that contain natural resource values. These lands are conserved and permanently managed for species that are endangered, threatened, candidates for listing as endangered or threatened, or are otherwise species-at-risk. Conservation banks function to offset adverse impacts to these species that occurred elsewhere. In exchange for permanently protecting the land and managing it for these species, the U.S. Fish and Wildlife Service approves a specified number of habitat or species credits that bank owners may sell.[531]
Pittman-Robertson Wildlife Restoration Program (USFWS)	Provides grants to states and insular areas fish and wildlife agencies with projects that include providing public use and access to wildlife resources, hunter education, and development and management of shooting ranges.[532]
Coral Reef Conservation Fund (NFWF)	NFWF works with local, state, federal and regional partners to achieve its goals in coral conservation and bolster multi-agency initiatives. The program works to support reef resilience by reducing negative impacts from unsustainable fishing and land-based pollution. A key strategy for this program is to reduce primary threats such as land-based sources of pollution from agricultural runoff, sewage outfall, and erosion from bare soils.[533]
Hawai'i Conservation Program (NFWF)	Aims to address threats, fill knowledge gaps, and provide protection for threatened and endemic species and habitats across Hawaii. Program goals include strategic habitat restoration and predator control to improve and increase critical habitat for forest birds and improving water retention, quality and use practices in a changing landscape and environment through natural infrastructure, fencing of feral ungulates and revegetation to reduce land-based run-off to reefs.[534]
Hawaiian Forest Bird Conservation Program (NFWF)	Established to accelerate local implementation of the most innovative, sustainable, and cost-effective strategies for restoring highly imperiled forest birds, specifically Palila, Maui Parrotbill, and Nihoa Millerbird.[535]
Community Based Restoration Program (NOAA Habitat Conservation-NMFS)	Funding and technical expertise for institutions of higher education, non-profits, commercial (for profit) organizations, U.S. territories, and state, local, and Native American tribal governments. Program invests in high-priority habitat restoration projects that instill strong conservation values and engage citizens in hands-on activities and actively restore coastal, marine, and migratory fish habitat.[536]

2. Top-Ranked Grassland and Cropland Solutions

The main threats, challenges, and costs for implementing the *perennial staple crops, tree intercropping,* and *multistrata agroforestry* solutions in Hawai'i are high labor costs, the need for long-term access to land, dynamic and complex land management, management of the competition for water and nutrients between trees and crops, careful advanced planning, and higher initial investment and operational costs. There are additional unique threats, challenges, and costs for implementing the *regenerative annual cropping* solution in Hawai'i including lack of affordable no-till equipment for small farms and access to on-island compost for farm-scale use. Potential sources of revenue that could be compatible with pursuing these solutions include: compensation or benefits to landowners or managers related to biodiversity or increased habitat, pest and disease reduction, or wind damage, erosion, and pesticide drift reduction; food security increases; diversified or waste stream products; and agro- or eco-tourism enterprises.

Existing incentive programs that may support the implementation of these grassland and cropland solutions include:

527 National Park Service, State & Local Assistance Programs Division, https://www.nps.gov/orgs/1600/index.htm (last visited Apr. 14, 2020).
528 USDA, Natural Resources Conservation Service, Joint Chiefs' Landscape Restoration Partnership, https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/features/?cid=stelprdb1244394 (last visited Apr. 14, 2020).
529 USDA, Natural Resources Conservation Service, Farm Bill, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/farmbill/ (last visited Apr. 14, 2020).
530 USDA, National Institute of Food & Agriculture, Small Business Innovation Research Program, https://nifa.usda.gov/program/small-business-innovation-research-program-sbir (last visited Apr. 15, 2020).
531 U.S. Fish & Wildlife Service, For Landowners – Conservation Banking, https://www.fws.gov/endangered/landowners/conservation-banking.html (last visited Apr. 14, 2020).
532 U.S. Fish & Wildlife Service, Wildlife & Sport Fish Restoration Program, https://wsfrprograms.fws.gov/subpages/grantprograms/wr/wr.htm (last visited Apr. 15, 2020).
533 NFWF, Coral Reefs, https://www.nfwf.org/coralreef/Pages/home.aspx (last visited Apr. 14, 2020).
534 NFWF, Hawai'i Conservation Program, https://www.nfwf.org/hawaiiconservation/Pages/home.aspx (last visited Apr. 14, 2020).
535 NFWF, Hawaiian Forest Birds, https://www.nfwf.org/hawaiiconservation/hawaiianbirds/Pages/home.aspx (last visited Apr. 14, 2020).
536 NOAA Fisheries, Coastal & Marine Habitat Restoration Grants, https://www.fisheries.noaa.gov/grant/coastal-and-marine-habitat-restoration-grants (last visited Apr. 15, 2020).

County Programs	
Hawaii Food Producers Fund (Kohala Center; HDOA; County of Hawaii; Kiva)	0% interest loans to Hawai'i-based farmers and food processors utilizing at least one Hawai'i-grown ingredient. Purpose of the fund is to increase the amount of capital available to local food producers and stimulate local food production in Hawai'i.[537]
State Programs	
Hawaii Agricultural Development and Food Security Special Fund (HRS 141-10) (HDOA)	Grants for farmers related to agricultural production or processing for activities, acquisition of real property, improvement of real property, dams, reservoirs, irrigation systems, and transportation networks, equipment purchases, market research and testing, promotion and marketing, water quality testing and improvement.[538]
Alternative Energy Loan Program (HDOA)	Loans and direct funding opportunities to full-time farmers, ranchers, and aquaculturalists to reduce dependence on fossil fuel by producing renewable energy through sources such as photovoltaic, hydroelectric, wind, methane, biodiesel, and ethanol. Also allows for loans for food safety projects to ensure a safe food supply for Hawai'i's people.[539]
Important Agricultural Lands Tax Credit (HDOTAX, HDOA)	Tax credit for agricultural business with more than 50% of the land used deemed "important agricultural land." Tax credits must be certified by HDOA. Applicants claiming credits must submit annually an outcome assessment report to HDOA. Tax credit refunds qualified agricultural costs such as roads or utilities, agricultural processing facilities, water wells, reservoirs, dams, pipelines, agricultural housing, feasibility studies, legal and accounting services, and equipment.[540]
Kukulu Ola: Living Hawaiian Culture Program (HTA)	Provides funding to community-based nonprofits in Hawai'i with projects that strengthen the relationship between the visitor industry and the Hawaiian community, nurture the Hawaiian culture by supporting Hawaiian programs and cultural practitioners, craftsmen, musicians, and other artists that preserve and perpetuate the Hawaiian culture.[541]
Federal Programs	
Conservation Innovation Grants (USDA-NRCS)	Federal grants that require 1-1 matching for non-federal governmental or nongovernmental organizations, American Indian Tribes, or individuals. Purpose of grants is to drive public and private sector innovation in resources conservation. Public and private grantees develop the tools technologies, and strategies to support next-generation conservation efforts on working lands and develop market-based solutions to resource challenges.[542]
Small Business Innovation Research Program (USDA)	Provides grants to small businesses and small proprietorships that are in business for profit. Program invites science-based small business firms to submit research proposal for funding. Topic areas include Forests and Related Resources; Plant Production and Protection; Animal Production and Protection; Air, Water, and Soils; Aquaculture; and Marketing and Trade.[543]
Regional Conservation Partnership Program (USDA-NRCS)	Funding available for activities that would be included in the USDA's Environmental Quality Incentives Program (EQUIP), Conservation Stewardship Program (CSP)(excluding the Grassland Conservation Initiative authority), Agricultural Conservation Easement Program (ACEP), Healthy Forest Reserved Program (HFRP), Public Law 83-566 Watershed Program (excluding the Watershed Rehabilitation authority), and Conservation Reserve Program (CRP). Projects must have lead partners that are an agricultural or silvicultural producer association or other group or producers, a state or unit of local government, an Indian Tribe, a farmer cooperative, a water district or other organization with specific water delivery authority to agricultural producers, a municipal water or wastewater treatment entity, an institution of higher education, an organization or entity with an established history of working cooperatively with producers on agricultural land, an entity that has a farmland or grassland protection program that purchases agricultural land easements, or a conservation district. RCPP projects must be carried out on agricultural or nonindustrial private forest land or associated land.[544]
Agricultural Management Assistance (USDA-NRCS)	Helps agricultural producers manage financial risk through diversification, marketing or natural resource conservation practices. Producers may construct or improve water management structure or irrigation structures; plant trees for windbreaks or to improve water quality; and mitigate risk through production diversification or resource conservation practices, including soil erosion control, integrated pest management, or transition to organic farming. Producers must be engaged in livestock or agricultural production.[545]
Environmental Quality Incentives Program (USDA-NRCS)	Provides financial and technical assistance to agricultural and forestry producers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, reduced soil erosion and sedimentation, and improved or created wildlife habitat. NRCS helps producers develop a conservation plan and financial assistance covers part of the costs from implementing conservation practices.[546]
Conservation Stewardship Program (USDA-NRCS)	Helps agricultural producers maintain and improve their existing conservation systems and adopt additional conservation activities to address priority resources concerns. Participants earn CSP payments for conservation performance—the higher the performance, the higher the payment.[547]

537 The Kohala Center, Rural & Cooperative Business Development Services, https://kohalacenter.org/business/microloan-kiva (Apr. 15, 2020).
538 Haw. Rev. Stat. § 141-10 (2104), *available at* https://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0141/HRS_0141-0010.htm (last visited Apr. 15, 2020).
539 State of Hawai'i, Agricultural Loan Division, Alternative Energy Loan Program, https://hdoa.hawaii.gov/agl/alternative-energy-loan-program/ (last visited Apr. 15, 2020).
540 State of Hawai'i, Department of Agriculture, Important Agricultural Lands Update, http://hdoa.hawaii.gov/important-ag-lands-ial/ (last visited Apr. 15, 2020).
541 Hawai'i Tourism Authority, *supra* note 523.
542 USDA, Natural Resources Conservation Service, Conservation Innovation Grants, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/cig/ (last visited Apr. 15, 2020).
543 USDA, *supra* note 530.
544 USDA, Natural Resources Conservation Service, Regional Conservation Partnership Program, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/rcpp/ (last visited Apr. 15, 2020).
545 USDA, Natural Resources Conservation Service, Agricultural Management Assistance, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ama/ (last visited Apr. 15, 2020).
546 USDA, Natural Resources Conservation Service, Environmental Quality Incentives Program, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/ (last visited Apr. 15, 2020).
547 USDA, Natural Resources *Conservation Service, Conservation Stewardship Program*, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/ (last visited Apr. 15, 2020).

Agricultural Conservation Easement Program (USDA-NRCS)	Helps landowners, land trusts, and other entities protect, restore, and enhance wetlands, grasslands, and working farms and ranches through conservation easements.[548]
ConocoPhillips SPIRIT of Conservation Program (NFWF)	Public-private partnership focused on improving habitat quality and landscape connectivity in ways that facilitate migrations of avian and terrestrial species, with an emphasis on working lands within focal geographies. The program awards grants to help reduce barriers to migration, restore priority habitats and improve conservation practices on working lands. One of the funding priorities helps working land managers/producers develop management plans, implement conservation practices, and enroll in Farm Bill programs to improve working lands function and enhance migration pathways.[549]
Conservation Partners Program (NFWF & USDA-NRCS)	Provides grant funding to support organizations that provide staff and technical assistance to private landowners in order to maximize the benefits of Farm Bill programs on working lands.[550]
Coral Reef Conservation Fund (NFWF)	NFWF works with local, state, federal and regional partners to achieve its goals in coral conservation and bolster multi-agency initiatives. The program works to support reef resilience by reducing negative impacts from unsustainable fishing and land-based pollution. A key strategy for this program is to reduce primary threats such as land-based sources of pollution from agricultural runoff, sewage outfall, and erosion from bare soils. [551]
Monarch Butterfly and Pollinators Conservation Fund (NFWF)	Supports work that advances the conservation of the monarch butterfly and other at-risk native insect pollinators. Competitive grants are awarded in two categories: (1) Technical Assistance for Private Working Lands and (2) Habitat Improvement. The technical assistance grants are awarded to projects that support implementation of technical assistance to increase the number of private landowners engaged in monarch butterfly and pollinator conservation practices on working lands.[552]

3. Urban Solution

The main threats, challenges, and costs for implementing the *urban forests* solution in Hawai'i are: the need for careful tree selection and planning; tree root damage to city infrastructure; urban tree canopy loss in non-public zoning areas (particularly in residential areas); water access and pest or pathogen susceptibility; and maintenance and repair costs. Potential sources of revenue that could be compatible with pursuing *urban forests* include compensation or benefits to landowners or managers related to reducing air and water pollution and heating and cooling costs; increasing real estate values; providing wildlife habitat; and contribution to food security.

Existing incentive programs that may support the implementation of *urban forests* include:

County Programs	
Clean Water and Natural Lands Fund (City and County of Honolulu)	Can provide land acquisition funds to landowners with qualifying lands that fulfill the purposes of: protection of watershed lands to preserve water quality and water supply; preservation of forests, beaches, coastal areas and agricultural lands; public outdoor recreation and education, including access to beaches and mountains; preservation of historic or culturally important land areas and sites; protection of significant habitats or ecosystems, including buffer zones; conservation of land in order to reduce erosion, floods, landslides, and runoff, and acquisition of public access to public land and open space.[553]
Hawaii Public Access, Open Space, and Natural Resources Preservation Fund (Hawai'i County)	Provides acquisition funds to landowners with qualifying lands worthy of preservation and recommended by the Commission.[554]
Kauai Public Access, Open Space, and Natural Resources Preservation Fund (Kauai County)	Provides acquisition funds to landowners with qualifying lands worthy of preservation and recommended by the Commission.[555]
Maui Public Access, Open Space, and Natural Resources Preservation Fund (Maui County)	Provides acquisition funds to landowners with qualifying lands that fulfill the purposes of: public outdoor recreation and education; preservation of historic or culturally important land areas; protection of significant habitat or ecosystems, including buffer zones; preserving forests, beaches, coastal areas and agricultural lands; protecting watershed lands to preserve water quality; conserving land for the purpose of reducing erosion, floods, landslides, and runoff.[556]

548 USDA, Natural Resources Conservation Service, Agricultural Conservation Easement Program, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/acep/ (last visited Apr. 15, 2020).
549 NFWF, ConocoPhillips SPIRIT of Conservation, https://www.nfwf.org/spirit/Pages/home.aspx (last visited Apr. 15, 2020).
550 NFWF, Conservation Partners Program, https://www.nfwf.org/conservationpartners/Pages/home.aspx (last visited Apr. 15, 2020).
551 NFWF, supra note 533.
552 NFWF, Monarch Butterfly & Pollinators Conservation Fund, https://www.nfwf.org/monarch/Pages/home.aspx (last visited Apr. 15, 2020).
553 City and County of Honolulu, *supra* note 519.
554 Hawai'i County, *supra* note 520.
555 County of Kaua'i, *supra* note 521.
556 County of Maui, *supra* note 522.

State Programs	
Land Conservation Fund (DLNR)	Funding to purchase interests or rights in land with preservation value. Available to state agencies, counties, and nonprofit land conservation organization landowners interested in selling their fee title or establishing a permanent conservation easement or agricultural easement with the State. Fund available for acquisition of interests or rights in land having value to the State for the preservation of: watershed protection; coastal areas, beaches, and ocean access; habitat protection; cultural and historical sites; recreational and public hunting areas; parks; natural areas; agricultural production; and open spaces and scenic resources. [557]
Federal Programs	
Land & Water Conservation Fund (USNPS)	Federal grants to counties acquiring or developing public lands, including purchase of wetlands. Funding generated from revenues from offshore, oil and gas extraction, provides federal grants for the acquisition and development of public lands to meet the needs of all Americans for outdoor recreation and open space. [558]
Pittman-Robertson Wildlife Restoration Program (USFWS)	Provides grants to states and insular areas fish and wildlife agencies with projects that include providing public use and access to wildlife resources, hunter education, and development and management of shooting ranges.[559]
Rivers, Trails, and Conservation Assistance Program (NPS)	Provides technical assistance and planning support to state and local agencies, tribes, nonprofit organizations, or citizen groups for community-led natural resource conservation and outdoor recreation projects. [560]
State and Local Assistance Program (USDOI/NPS; DLNR/DSP)	Provides matching grants to states and counties for eligible public outdoor recreation projects; acquisition, development, and renovation of public outdoor recreation areas and facilities. Purpose of the program is to create and maintain a nationwide legacy of high quality recreation areas and facilities and to stimulate non-federal investments in the protection and maintenance of recreation resources across the U.S. [561]
Coral Reef Conservation Fund (NFWF)	NFWF works with local, state, federal and regional partners to achieve its goals in coral conservation and bolster multi-agency initiatives. The program works to support reef resilience by reducing negative impacts from unsustainable fishing and land-based pollution. A key strategy for this program is to reduce primary threats such as land-based sources of pollution from agricultural runoff, sewage outfall, and erosion from bare soils. [562]

557 State of Hawai'i, *supra* note 524.
558 National Park Service, *supra* note 525.
559 U.S. Fish & Wildlife Service, *supra* note 532.
560 National Park Service, *supra* note 526.
561 National Park Service, *supra* note 527.
562 NFWF, *supra* note 533.

XI. CONCLUSIONS

As discussed in detail in this report, Hawaiʻi lacks a lot of data that would allow for a more precise translation of Project Drawdown's solutions to Hawaiʻi's natural and working lands and nearshore waters. Nevertheless, this broad assessment of these solutions for Hawaiʻi provides a starting point and identifies opportunities for public and private land managers to help reduce greenhouse gases in our atmosphere while maximizing co-benefits and minimizing risks and unintended consequences for Hawaiʻi.

There are many areas of further research that will be needed to most appropriately take advantage of these opportunities in Hawaiʻi's land use and land management decisions. These areas include a better understanding of the degradation status of cropland and grassland across the state and a better understanding of where Hawaiʻi's major soil carbon sinks are located and how best to protect them. Information on the costs to implement some of these solutions in Hawaiʻi will provide a better understanding of their financial feasibility for specific landowners or land managers.

As the most isolated archipelago on the planet, Hawaiʻi faces unique challenges in achieving the potential benefits of the solutions explored in this study. Some of these challenges include preventing the introduction and spread of invasive species and diseases that threaten our native ecosystems while developing and supporting the locally produced inputs (e.g. animal feed, fertilizer, soil amendments, etc.), infrastructure, and markets that farmers and ranchers need to sell more of their products within the state. Supporting farmers and ranchers to keep working lands in production and utilizing land management practices that provide greenhouse gas benefits and other co-benefits provides value to the entire state.

Hawaiʻi has unique advantages when considering opportunities to limit greenhouse gas emissions and increase sequestration. These advantages include the uniquely high occurrence of soils with great carbon sequestration potential (such as Andisols), as well as some areas with soil carbon stocks that are already high, and the large percentage of land across the islands that remain forested. Preserving these carbon sinks and further understanding when there are opportunities to enhance their health and ability to sequester carbon should be prioritized.

As observed by the IPCC, there are urgent and transformative changes that must be put into action by people, corporations, and governments around the world in the next ten years to avoid the worst impacts of climate change. These changes reach far beyond the land sector into every aspect of modern life: energy production, industry, buildings, transportation, and cities. All of these changes will be critical. This study suggests that there are many opportunities for Hawaiʻi's land use and land management decisions to contribute to that effort with active support from its community of consumers, researchers, landowners and land managers, and public decision makers.

APPENDIX A | OVERALL RATING

Solution	Land Type Prioritized by Project Drawdown	GHG Sequestration + Emissions Reduction Potential (1 = red, 2= yellow, 3 = green)	Hawaiʻi Specific Adjustments (+/-1 per factor)	Co-Benefits (0-10)	Lack of Risks (-10 to 0)	Overall Score (sum)	Rank for Hawaiʻi
Forest Protection	Non-Protected Forest	197M tons of CO_2e (one-time avoided emissions)	(+1) significantly higher GHG benefits than all other solutions considered	8	-2	10	Priority 1
Tree Intercropping	Degraded Cropland	483k tons of CO_2e/year (sequestration)		9	-3	8	Priority 1
Coastal Wetland Protection	Non-degraded Coastal Wetlands/Forest	752K tons of CO_2e (one-time avoided emissions) + 150k tons of CO_2e/year (sequestration)		6	-2	6	Priority 2
Perennial Staple Crops	Degraded Grassland	3.4M tons of CO_2e/year (sequestration)	(-1) likely emissions for volcanic soil disturbance	7	-3	6	Priority 2
Tropical Forest Restoration	Degraded Forest	3.5M tons of CO_2e/yr (sequestration)		7	-4	6	Priority 2
Urban Forests	Urban/Developed	400K tons of CO_2e (total sequestered) + 2K tons CO_2e/yr (emissions reduction)		7	-4	5	Priority 2
Multistrata Agroforestry	Non-degraded Grassland	5M tons of CO_2e/yr (sequestration)	(-1) likely emissions for volcanic soil disturbance	8	-5	5	Priority 2
Regenerative Annual Cropping	Non-degraded Cropland	340K tons of CO_2e/yr (sequestration) + 44K tons CO_2e/yr (emissions reduction)		9	-7	4	Priority 2
Coastal Wetland Restoration	Degraded Coastal Wetlands/Forest	73k tons of CO_2e/yr (sequestration)		6	-3	4	Priority 2
Conservation Agriculture	Non-degraded Cropland	221k tons of CO_2e/yr (sequestration) + 44K tons CO_2e/yr (emissions reduction)		9	-7	4	Priority 2
Silvopasture	Non-Degraded Grassland	3.1M tons of CO_2e/yr (sequestration)	(-1) likely emissions for volcanic soil disturbance and (-1) emissions related to shipping cattle to the mainland for finishing	10	-8	3	Site-specific information needed to proceed
Managed Grazing	Non-Degraded Grassland	758k tons of CO_2e/year (sequestration)	(-1) emissions related to shipping cattle to the mainland for finishing	6	-5	2	Site-specific information needed to proceed
Tree Plantations (on degraded land)	Degraded grassland	3.7M tons of CO_2e/yr (sequestration)	(-1) likely emissions for volcanic soil disturbance and (-1) emissions related to shipping timber out of state to market	5	-8	-2	Site-specific information needed to proceed

Legend:	Total Overall Score
High:	7 to 10
Medium:	4 to 6
Low:	<0 to 3

APPENDIX B | GREENHOUSE GAS BENEFITS

Solution	High	Medium	Low	Sequestration Rate (tons C/ha/yr)	Sequestration Rate (tons CO2e/ha/yr)	Sequestration Rate (tons CO2e/acre/yr)	Available Land in Hawaiʻi (acres)	Total Sequestration Potential (tons CO2e/yr)	Emissions Reduction Rate (tons CO2e/ha/yr)	Emissions Reduction Rate (tons CO2e/acre/yr)	Total Emissions Reduction Potential (tons CO2e/yr)
Forest Protection				NA		NA	703,000		281.1	113.76	197,613,300.00
Multistrata Agroforestry				4.45	16.3315	6.61	761,816	5,034,943.85	NA	NA	NA
Perennial Staple Crops				3.34	12.2578	4.96	761,816	3,779,036.51	NA	NA	NA
Tree Plantations (on degraded land)				3.3	12.111	4.90	761,816	3,733,778.59	NA	NA	NA
Tropical Forest Restoration				4.4	16.148	6.53	532,760	3,481,519.39	NA	NA	NA
Silvopasture				2.7	9.909	4.01	761,816	3,054,909.75	NA	NA	NA
Coastal Wetland Protection				1.92	7.0464	2.85	52,633	150,087.28	14.29	5.78	752,125.57
Urban Forests					0	0.00	-	400,000.00	NA	NA	1,796.00
Managed Grazing				0.67	2.4589	1.00	761,816	758,070.20	NA	NA	
Regenerative Annual Cropping				1.2	4.404	1.78	191,175	340,719.41	0.23	0.09	43,970.25
Tree Intercropping				1.7	6.239	2.52	191,175	482,685.83	NA	NA	NA
Conservation Agriculture				0.78	2.8626	1.16	191,175	221,467.62	0.23	0.09	43,970.25
Coastal Wetland Restoration				0.93	3.4131	1.38	52,633	72,698.53	NA	NA	NA

Legend:	Total sequestration + reduction potential (per year or in total)
High:	>1M tons of CO2e
Medium:	>100k and <1M tons of CO2e
Low:	<100k tons of CO2e

Note: Orange columns reflect the final units of greenhouse gas benefits that were used to compare each of the solutions.

APPENDIX C | CO-BENEFITS

Solution	High	Medium	Low	Climate resilience	Water	Soil Health	Food Security	Ecology	Health	Livelihoods	Yield Benefits	Reduced Fuel Use	Operations Benefits	Increased Market	Total Co-Benefits Score
Silvopasture				X	X	X	X	X	X		X	X	X	X	10
Conservation Agriculture/ Regenerative Annual Crops				X	X	X	X	X	X		X	X	X		9
Tree Intercropping					X	X	X	X	X		X	X	X	X	9
Multistrata Agroforestry				X	X	X	X	X	X		X		X		8
Forest Protection				X	X	X	X	X	X	X				X	8
Urban Forests					X		X	X	X	X		X		X	7
Perennial Staple Crops					X	X	X	X			X	X	X		7
Tropical Forest Restoration				X	X	X	X	X		X				X	7
Managed Grazing					X	X	X	X			X		X		6
Coastal Wetland Protection/Restoration				X	X	X	X	X		X					6
Tree Plantations (on degraded land)				X			X	X	X			X			5

Legend:	Total Co-Benefits Score
High:	8 to 10
Medium:	5 to 7
Low:	0 to 4

APPENDIX D | LACK OF RISKS

Solution	High	Medium	Low	Invasive Species	Land Competition	Water Competition	Food Security Impact	Potential Cultural Impacts	Lack of Market Signal	Infrastructure Lacking	Operations Risks	GHG Emissions Risk	Risk of Yield Reductions	Total Lack of Risk Score
Forest Protection								X			X			-2
Coastal Wetland Protection					X	X								-2
Tree Intercropping				X							X		X	-3
Perennial Staple Crops									X	X	X			-3
Coastal Wetland Restoration				X		X		X						-3
Urban Forests				X	X	X					X			-4
Tropical Forest Restoration								X	X		X		X	-4
Multistrata Agroforestry				X	X	X					X		X	-5
Managed Grazing				X					X	X	X	X		-5
Conservation Agriculture/ Regenerative Annual Cropping					X	X			X	X	X	X	X	-7
Silvopasture				X		X	X	X	X		X	X	X	-8
Tree Plantations (on degraded land)				X	X	X	X	X	X	X		X		-8

Legend:	Total Lack of Risk Score
High:	0 to -2
Medium:	-3 to -6
Low:	-7 to -10

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