Soil Carbon Inventory and Working Lands Baseline

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Purpose

Development of data resources required to generate a baseline and short/long term benchmarks for increasing GHG sequestration, soil health, and yields in natural and working lands (e.g., pasture, agriculture, agroforests) in Hawaii's AFOLU sector

Scope of Work

1. Compilation of available geospatially explicit datasets for soil carbon inventory and other attributes across natural and working lands (e.g., pasture, agriculture, agroforests)
2. Collect soil health, yield, and GHG sequestration data from a network of productive lands, farms, and ongoing trials as required for initialization of soil carbon-related planning tools

Project Approach#1: Datasets

A. Thorough literature review

- GHG emissions, soil C storage
- Land use
- Soil C data

B. Compile geospatial datasets

- NCSS, NRCS, published/unpublished datasets
- SoilGrids (system for global digital soil mapping; machine learning)
- Land use datasets

1A: Known References for GHG data in Hawaii's NWL

Natural, Working Land Sector	Management systems	Management or Land cover	References
Cropland	Crops Intensive sugarcane cultivation	Conventional tillage and fertilizer management	Matson et al., 1996; Tran and Yanagida, 2019; Zachariassen et al., 1996; Pawlowski et al., 2017 and 2018
	Tropical perennial grasses	Zero tillage, sugarcane and related bioenergy feedstocks, e.g., energycane, napier grass (*Cenchrus purpureum)*,Guinea grass (*Megathyrsus maximus)* and others.	Pawlowski et al., 2017 and 2018; Meulemans, 2016; Crow et al., unpublished; Sumiyoshi et al., 2016
	Biochar	Biochar	Meulemans, 2016; Biegert, 2015
	Organic	Organic amendments	Meulemans, 2016; Biegert, 2015
	Residue management	Burning crop residues (what crop?)	Miller et al., 1997
Aquaponics		Vegetable production	Wongkiew et al., 2018
		Fish production	Hue et al., 2013
Forests		Tropical rainforest	Hall and Asner, 2007
		Montane forest	Hedin et al., 2003
		Fertility practices	Hall and Matson, 1999
		Invasive species	Litton et al., 2006; Litton et al., 2008; Litton et al., 2011; Hall and Asner, 2007
		Litter mineralization, and abiotic factors	Riley and Vitousek, 2000; Holtgrieve et al., 2006
		Forest fires	Howbaker et al., 2017
Peatlands/ wetlands			Chimner, 2004; Beilman et al. unpublished

N=24

1A: Known References for GHG data in Hawaii's NWL

Key Findings

- Croplands: Potential for napiergrass (reduced GHG emissions, water use); Biochar effect is soil dependent (Mollisol=reduced GHG emissions; Oxisol=increased GHG emissions)
- Aquaponics: High potential for N recovery from effluent via vegetables; Higher feeding rates correlated with increased N emissions
- Forests: N fluxes from nitrification in mesic tropical forests but denitrification in wetter sites; Soil organic C turnover about 0.39 Mg C/ha/year
- Pastures: GHG flux not directly quantified in Hawaii yet

1A: References for Soil C data in Hawaii's NWL

Land sector	Management systems	Land cover	References
Forests		Silvopasture	Blackmore and Vitousek, 2000; Krueger and Ryals (unpublished)
		Forest (non- specified, or diverse species)	Ares and Fownes, 2001; Burke et al., 2003; Scowcroft et al., 2004; McGrath 2019; Melone et al., 2021
		Humid tropical forest	Giardina et al., 2004
		Tropical Dry forest	Elmore and Asner, 2006; Litton et al., 2006; Litton et al., 2008; Litton et al., 2011; Chadwick et al., 2007
		Tropical rainforest	Hall and Matson 2003; Hall and Asner, 2007; Rillig et al., 2001
		Montane forest	Bothwell et al., 2014; Funk, 2005; Gower and Vitousek, 1989; Herbert and Fownes, 1999; Hobbie, 2000; Idol et al., 2007; Kitayama et al., 1997; Riley and Vitousek, 1995; Rillig et al., 2001; Schuur et al, 2001; Selmants et al., 2014; Selmants et al., 2016; Chadwick et al., 2007; Hedin et al., 2003; Giardina et al., 2014
		Native forest/ Forest reserves	Austin, 2002; Austin and Vitousek, 1998; Chadwick et al., 2007; Chorover et al., 2004; Crews et al., 1995; Cusack et al., 2012; Hughes and Denslow, 2005; Hughes and Uowolo, 2006; Kao-Kniffin and Balser, 2008; Kramer et al., 2012; Mascaro et al., 2012; Neff et al., 2000; Osher et al., 2003; Sanderman and Kramer, 2013; Stewart et al., 2011; Giardina et al. 2014
		Eucalyptus and Albizia	Binkley et al., 1992; Kaye et al., 2000; Resh et al., 2002
		Eucalyptus plantation	Giardina and Ryan, 2002; Binkley et al., 1992; Kaye et al., 2000; Resh et al., 2002; Ryan et al., 2008; Crow et al., 2016; Zou and Bashkin, 1998
		Koa forest	Idol et al., 2007; Litton et al., 2011; Scowcroft et al., 2004; Ares and Fownes, 2001;
		O'hia forest (Metrosideros polymorpha)	Grant et al., 2019; Hobbie and Vitousek, 2000; Hughes and Uowolo, 2006; Kao-Kniffin and Balser, 2008; Kramer et al., 2012; Mascaro et al., 2012; Neff et al., 2000; Nusslein and Tiedje, 1999; Rilling et al., 2001; Sandermand and Kramer, 2013; Torn et al., 1997; Torn et al., 2005; Townsend et al., 1995; Townsend et al., 1997; Giardina et al., 2014
		Fern (*Dicranopteris linearis*)	Stewart et al., 2011
		Ōlapa (*Cheirodendron trigynum*)	Stewart et al., 2011
	Forest with Invasive species		Litton et al., 2006; Litton et al., 2008; Litton et al., 2011; Melone et al. 2021
	Soil fertility/ Nutrient management practices		Giardina et al., 2003; Giardina et al., 2004; Gower and Vitousek, 1989; Hobbie , 2000; Hobbie and Vitousek, 2000; Neff et al., 2000; Ryan et al., 2008; Idol et al., 2007
Converted lands	Abandoned to forest	Pasture-abandoned/grassland-koa forest	Scowcroft et al., 2004; Idol et al., 2007
	Plantation to Pasture, Secondary forest or forest		Bashkin and Binkley, 1998; Binkley and Resh, 1999; Binkley et al., 2004; Guo and Gifford, 2002; Kaye et al., 2000; Zou and Bashkin, 1998
	Forest to Pasture, crop or managed forest		Guo and Gifford, 2002; Nüsslein and Tiedje, 1999
	Pasture to Forest, secondary Forest, plantation or crop		Crow et al., 2016; Guo and Gifford, 2002
	Intensive cultivation to perennial grass with zero tillage		Crow et al. 2020

1A: References for Soil C data in Hawaii's NWL

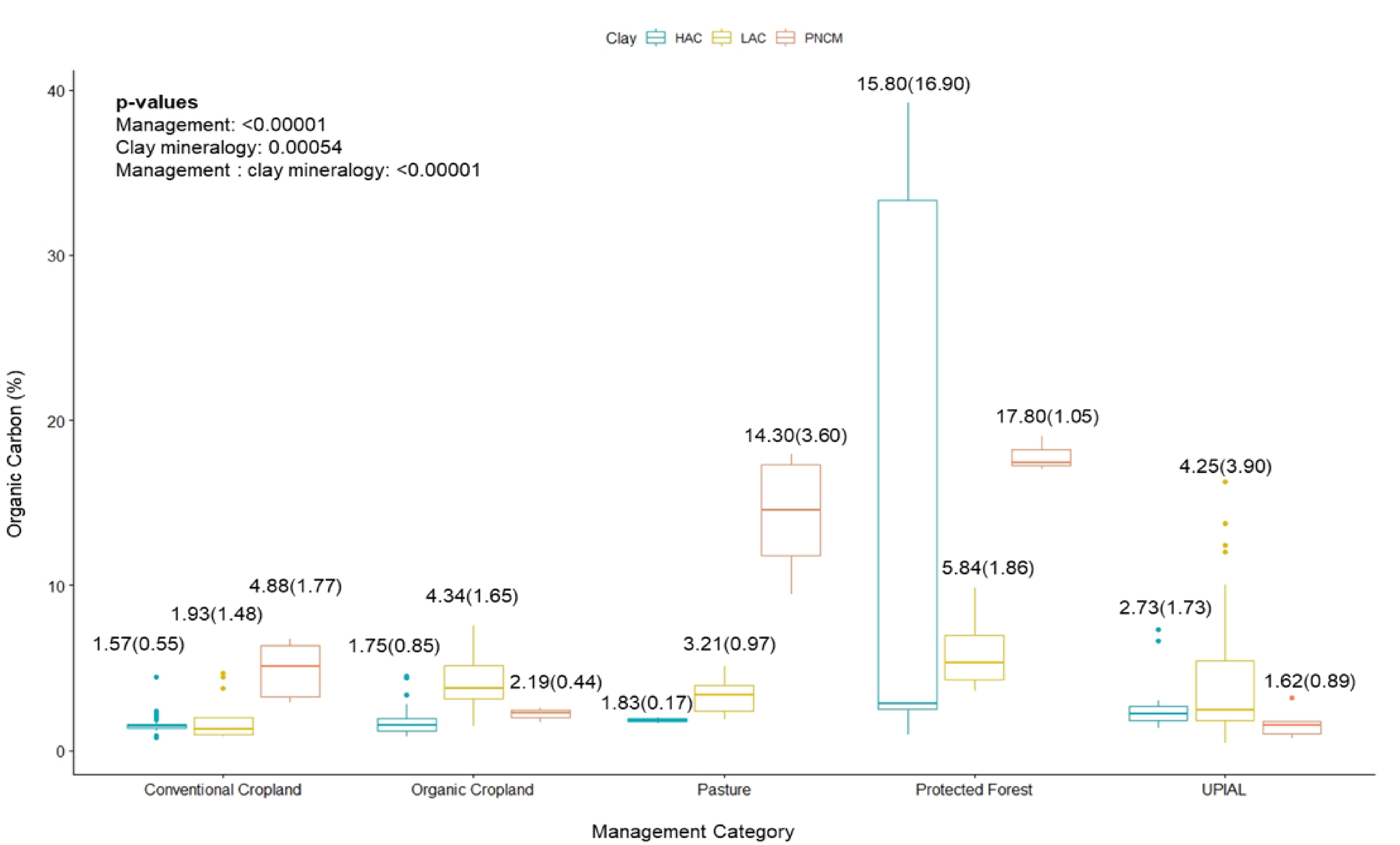
Land sector	Management systems	Land cover	References
Agricultural land	Crop production		Cusack et al., 2013
		Sugarcane (*Saccharum officinarum)*	Burke et al., 2003; Pawlowski et al., 2018; Tirado-Corbalá et al., 2015
		Napiergrass (*Pennisetum purpureum)*	Pawlowski et al., 2017 and 2018; Sumiyoshi et al., 2017
		Guinea grass (*Megathyrsus maximus*)	Sumiyoshi et al., 2017
		Energycane (*Saccharum. officinarum x S. robustum cv. MOL-6081*)	Crow et al. 2020
	Orchards	Coffee	Youkhana and Idol, 2009; Youkhana and Idol, 2016
Ash soils- no vegetation			Perez, 2001
Pasture		Mixed	Burke et al., 2003; Cusack et al., 2013; Chadwick et al., 2007
		Kikuyu pasture (*Pennisetum clandestinum*)	Cusack et al., 2012; Nusslein and Tiedje, 1999; Torn et al., 1997; Townsend et al., 1995; Townsend et al., 1997; Blackmore and Vitousek, 2000; Crow et al. 2016
		Bufflegrass (*Cenchrus ciliaris*)	Torn et al., 1997
Grasslands			Kramer and Chadwick, 2016; Scowcroft et al., 2004; Chadwick et al., 2007
Shrublands			Kramer and Chadwick, 2016; Chadwick et al., 2007
Shrubland			Chadwick et al., 2007
Peatlands/ Wetlands			Beilman et al.
Hawaiʻi inventories and reports			Drawdown report 2020

1A: References for Soil C data in Hawaii's NWL

Key Findings

- Croplands: Sugarcane plantations were a significant C source so potential for energy/fuel crops; Mulching and litter practices can increase soil C by 2.9 C Mg/ha
- Pasture: Importance of organic residues and minimized disturbance; Soil C stocks nearly similar between pasture and forest (9.5 kg C/m2 vs 12.7 kg C/m2), both more than sugarcane plantation
- No vegetation: dead tissue increased soil organic C vs living plants (Perez 2001)
- Converted Lands: Four years of perennial grass with zero tillage increased soil C stock from 18.0 kg C/ha to 22.6 kg C/ha in top 1m; Conversion of dry forest to non-native grass invasion reduced soil C storage at landscape scale

Hawaii Soil C data possibilities…



Courtesy E. Vizka

1B: Soil C Mapping

Table 2: Compiled data to estimate soil organic carbon (SOC) stocks

Dataset	Samples *n*	Depth information	Years measured
Literature review (papers *n* = 42)	239	varies; data often aggregated	1995-2019
Hawaii Soil Health (unpublished)	146	only 0-15 cm	2017-2020
Unpublished collaborator	10	every 15 cm; 0-100 cm	2019
Unpublished collaborator	66	only 0-20 cm	2019
Unpublished collaborator	30	only 0-15 cm	2019
Unpublished collaborator	21	only 0-15 cm	2018-2019
Unpublished collaborator	1020	every 15 cm; 0-100 cm	2015-2017
Rapid Carbon Assessment (unpublished)	754	by horizon; to ~100 cm	2014
National Cooperative Soil Survey	2,256	by horizon; to ~100 cm	1949-2014
Total	**4909**		

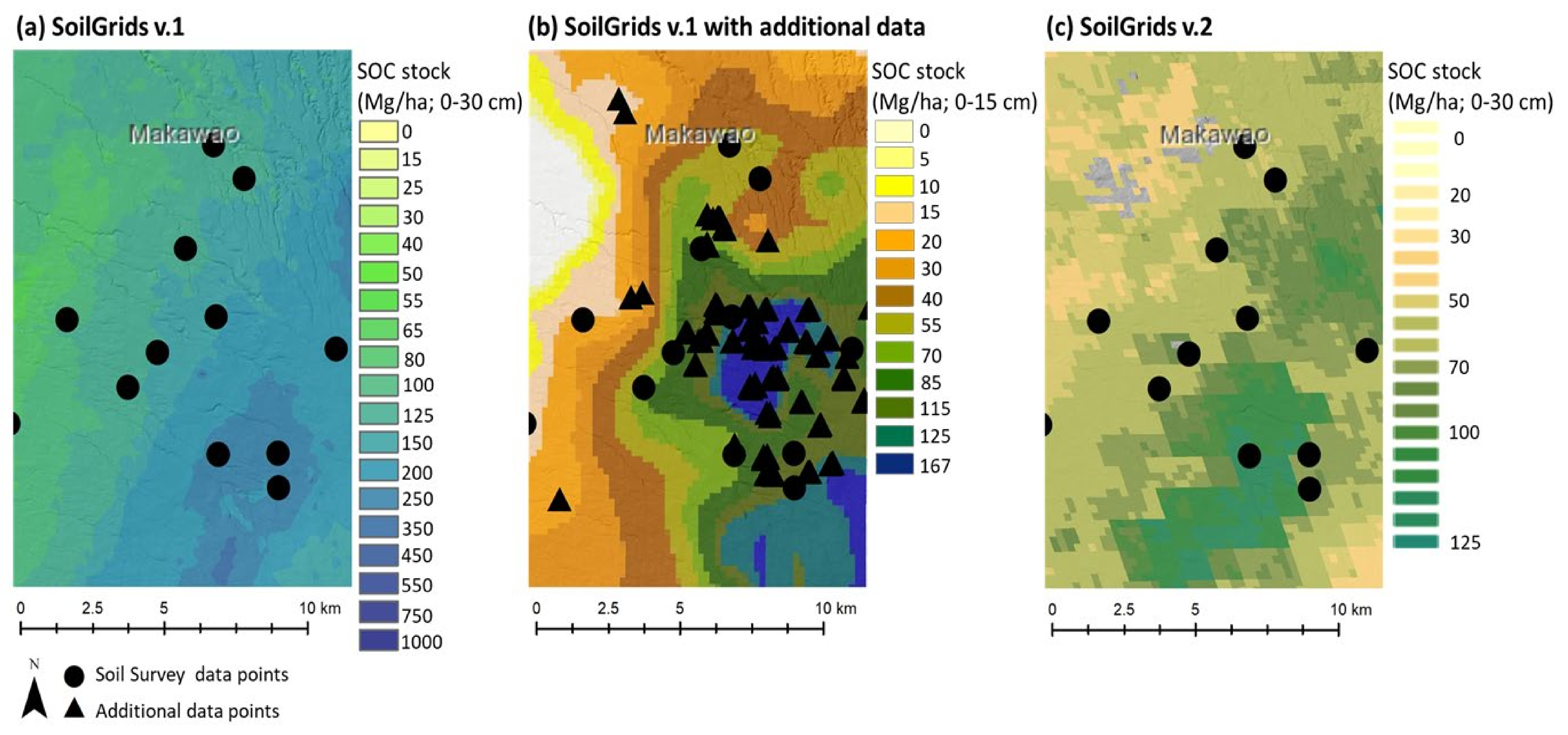
- Compared Soil Survey vs Additional Data
- 250m resolution
- 0-30cm depth vs 0-15cm depth
- Quantile Random Forest Model (5% and 95% quantiles)
- SoilGrids v1 (interpolate→ calculate)
  SoilGrids v2 (calculate→ interpolate)

*Limitations

- SoilGrids: under-estimate C for high organic soils

1B: Soil C Mapping Example

Summary: More data = More detail



1B: Compiled Land Use Datasets

Land cover data layer	Description	Citation
Important Agricultural Lands (IAL)	Classification based on importance of agricultural lands; integrates ALISH; criteria: https://www.capitol.hawaii.gov/hrscurrent/Vol04_Ch0201-0257/HRS0205/HRS_0205-0044.htm	State Land Use Commission 2019
Carbon Assessment of Hawai'i Land Cover (CAH)	**Land cover by biomes & invasion status; integration of HI-GAP, C-CAP, LF, and updates using very high resolution imagery**	**U.S. Geological Survey 2017**
Agricultural Land Use Baseline (ALUB)	**Agricultural land use based on WorldView-2 satellite imagery (2011-2013), data provided by landowners and stakeholders, County Real Property Tax and Agricultural Water Use data; verified by site visits and stakeholder meetings.**	**Spatial Data Analysis and Visualization Lab 2015**
Pre-contact Native Hawaiian Footprint	Map of pre-contact Native Hawaiian land use based on archaeological evidence, information on native habitats, and natural condition information.	The Nature Conservatory & Office Hawaiian Affairs 2014
Coast Change Analysis Program Land Cover (C-CAP)	Land cover classification using multispectral analyses based on Landsat and high-resolution imagery; specifically for coastal lands	NOAA 1992-2012
LANDFIRE Vegetation (LF)	Vegetation cover created by regression tree landscape models based on field data, satellite imagery, biophysical gradients	U.S. Geological Survey 2009
Gap Analysis Program Land Cover (HI-GAP)	Land cover using classification and regression trees based on Landsat TM satellite imagery 1999-2001, supplemented with Multi-Resolution Land Characteristic imagery and environmental data	Gon et al. 2006
Agricultural Land Use Maps (ALUM)	Hand drafted maps from State Planning and Development Section & US Soil Conservation Service information; digitized	State Department of Agriculture 1978-1980
Agricultural Lands Importance (ALISH)	Classified important agricultural lands into prime, unique, and other important lands; hand drafted; digitized	State Department of Agriculture 1977
Land Use Cover (LULC)	Manual interpretation based on 1970's aerial photography	U.S. Geological Survey 1976
Land Study Bureau (LSB)	Land classification and productivity rating based on aerial photography and topographic maps; hand drafted onto paper; digitized	Land Study Bureau 1972

1B: Compiled Land Use Datasets

HSH land cover categories	ALUB categories	CAH land cover categories (major)
Organic cropland	Diversified crop	Agriculture
Conventional cropland	Seed production	Grassland
Pasture	Sugar/pineapple	Shrubland
Unmanaged grassland	Flowers/foliage	Forest
Agroforest	Orchard	Other
Protected forest	Dairy	Not vegetated
Unmanaged forest	Pasture	Developed
	Commercial forestry	Wetland
	Wetland taro	
	Aquaculture	

ALUB vs CAH

- ALUB: 2011-2015, stakeholder input, only agricultural lands
- CAH: includes other table layers, 2014, NWL

ArcGIS 10.4.1

- "Joined" CAH & ALUB layers
- NAD 83 Zone 4N

Hawai`i Soil Health Data

- Ground-truth data points
- Collected 2017-2020 (up-to-date)

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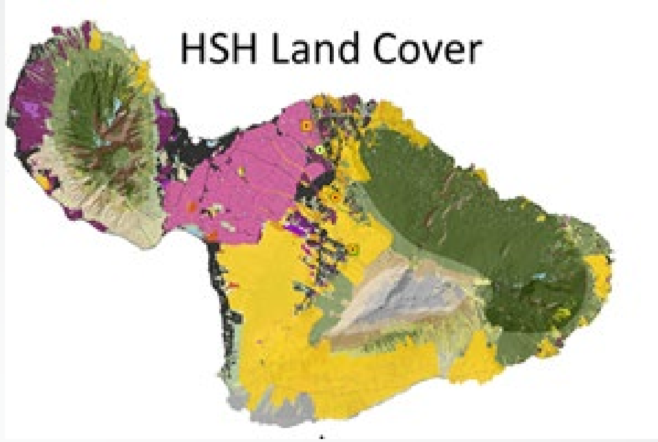
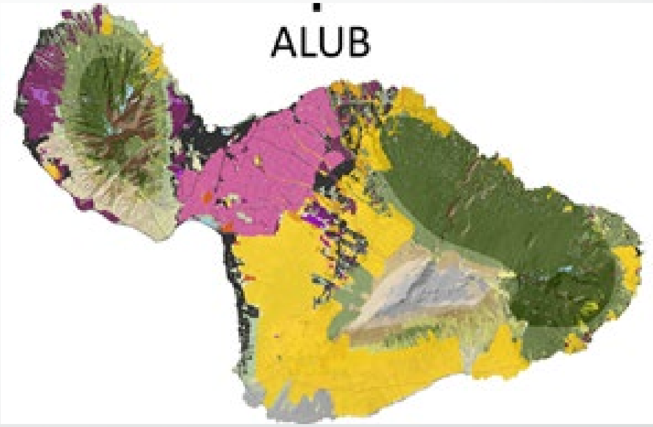
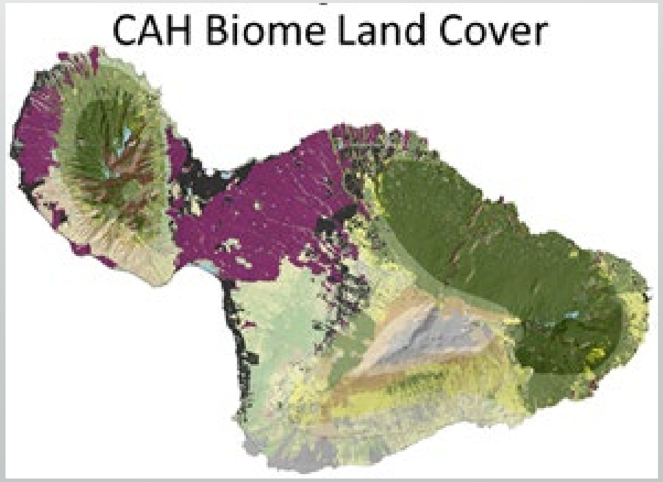
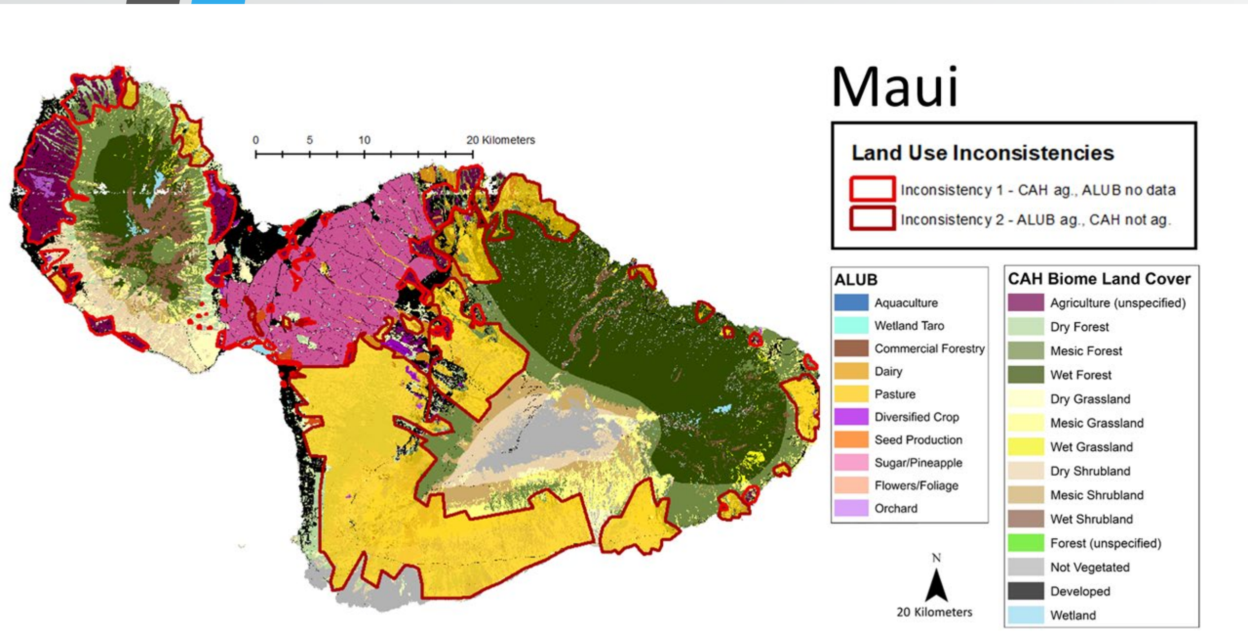
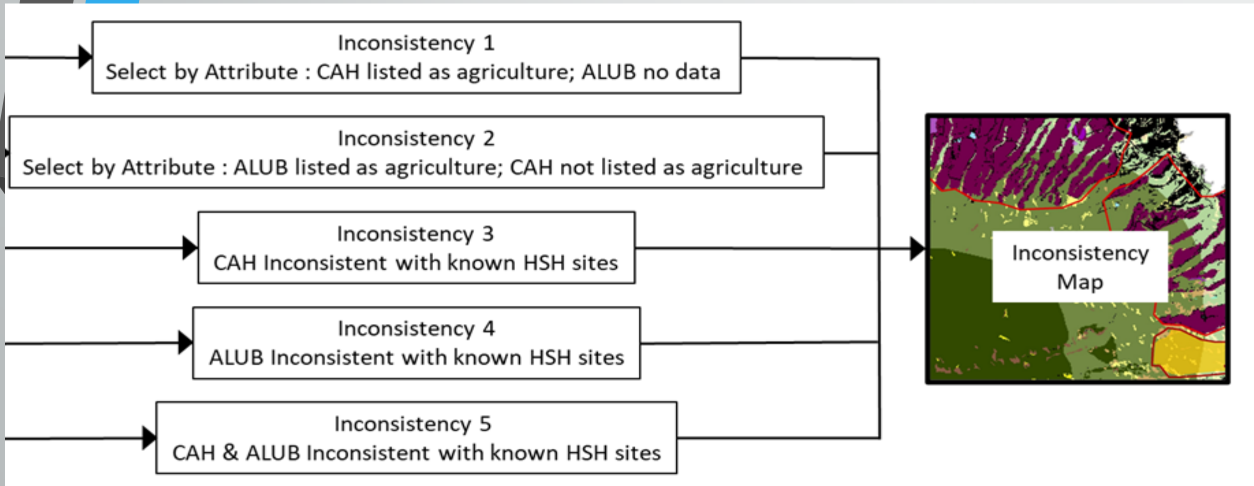






1B: Compiled Land Use Datasets





CAH: Larger general ag lands, but most pasture lands not classified ag

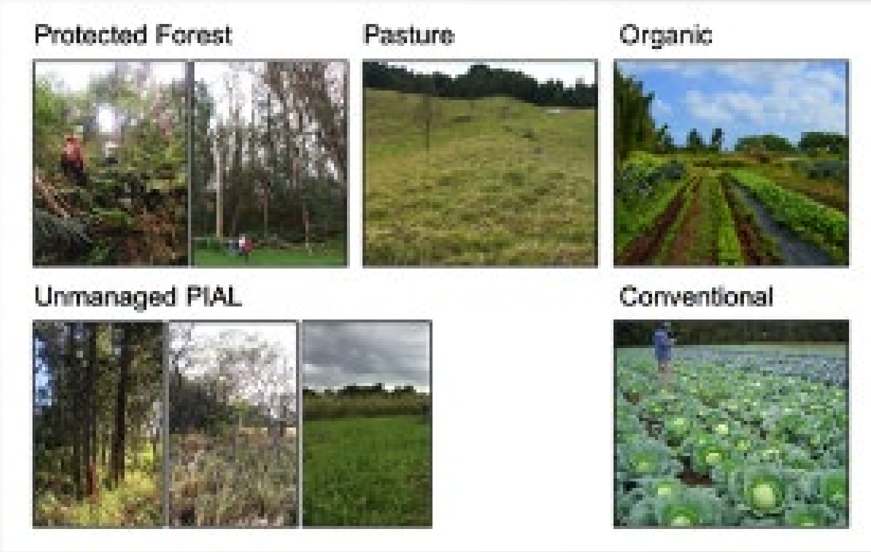
ALUB: Larger range of pasture lands, but did not distinguish developed areas (e.g. roads, structures)

HSH: Showed some ALUB lands were abandoned, unmanaged (up-to-date)

Project Approach#2: Soil Health Data

A. Collect soil from diverse natural and working land types

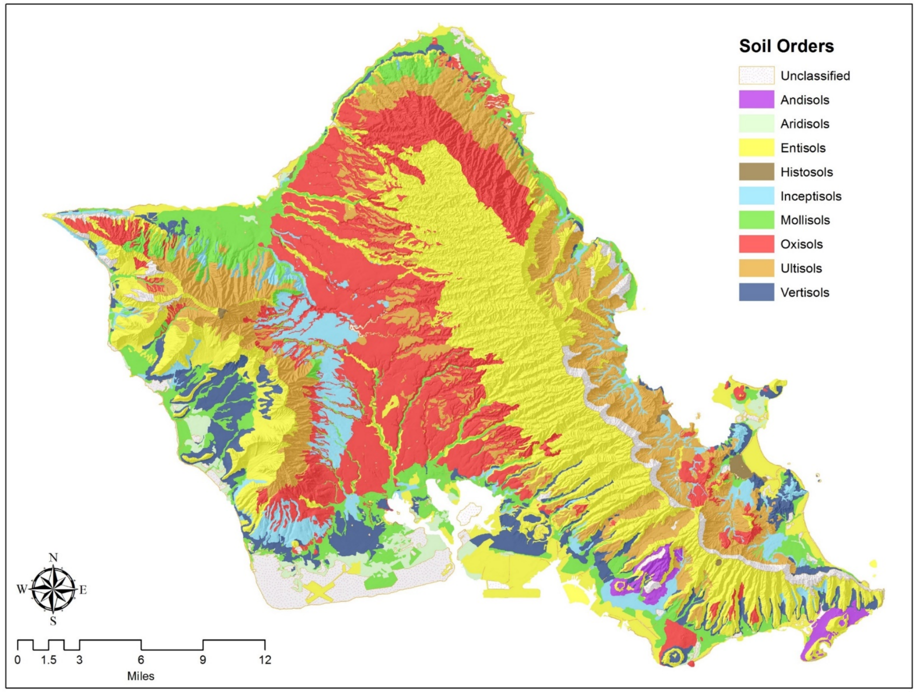
- Partnered projects, baseline data network
- Land use history and change; soil-carbon-building practices



B. Quantify soil health parameters

- Physical, chemical, biological (11 key parameters)

Samples Collected in Network



- # of sites= 14
  # samples= 47
- Land-use change (new) v. Benchmarks (long-term e.g. forested)
- Soil Types= Vertisols, Mollisols, Oxisols, Inceptisols

Implemented Soil C Promoting Practices

Compost, Organic Soil Amendments

Cover Cropping

Agroecology
Restoration

Analyses

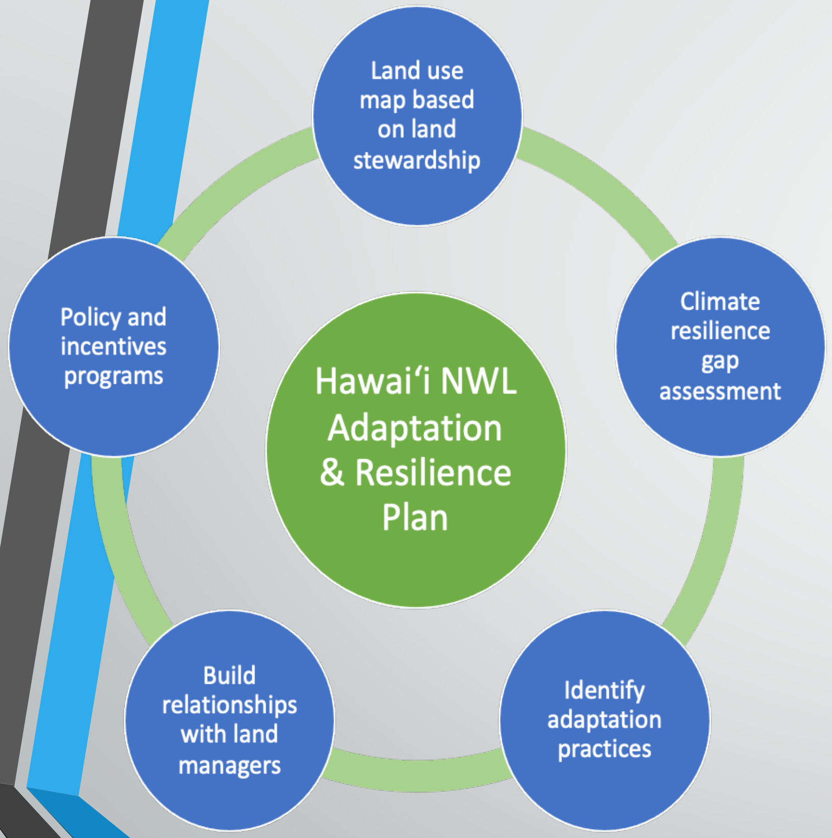
	Recommended Indicator	Soil Function(s) Relation
Biological	24 hr CO_2 burst	Soil life, nutrient cycling, carbon storage and cycling
	Beta-glucosiminidase	
	Beta-glucosidase	
	Mineralizable nitrogen	
Chemical	Total organic C %	Carbon storage, soil life, nutrient cycling
	DOC: DON	
	Hot water extractable organic C	
	pH	
Physical	Water holding capacity %	Plant growth, soil life, water infiltration and supply, carbon cycling and storage
	Water stable meta-aggregates %	
	Bulk density	

Summarized Soil Health Results (Averages)

Site	PIAL.	Current LU	Min	%OC	CO_2 burst	PMN	pH	DOC:DON	HW EC	WHC	mega-WSA	BD
1	PIAL	Unmanaged	LAC	2.67	73.60	24.78	5.29	116.70	91.0	77.08	7.89	1.10
2	none	Protect Forest	LAC	6.68	371.26	175.92	7.22	13.27	1,223.	130.24	13.41	1.05
3	none	Organic	HAC	1.20	63.40	8.45	7.77	7.80	279.2	100.21	1.71	0.85
4	PIAL	Convent.	HAC	1.54	45.73	6.08	7.01	19.66	321.3	89.56	1.50	1.00
5	PIAL	Convent.	HAC	2.23	34.33	4.73	6.48	11.98	241.1	79.94	1.44	0.90
6	PIAL	Convent.	HAC	1.42	15.75	0.77	8.14	17.69	117.0	77.19	2.50	1.10
7	none	Organic	HAC	1.22	18.98	2.48	7.42	11.26	146.3	75.66	6.14	0.80
8	none	Protect Forest	LAC	15.16	133.16	78.79	5.15	88.84	1,172	129.50	39.66	1.10
9	PIAL	Unmanaged	LAC	10.04	405.27	124.28	7.64	159.19	1,286	104.94	10.16	1.10
10	PIAL	Unmanaged	LAC	7.86	371.20	111.55	6.91	113.06	454.2	107.40	7.95	1.10
11	PIAL	Unmanaged	HAC	6.09	307.59	104.17	7.88	158.94	600.2	84.69	14.21	1.25
12	PIAL	Unmanaged	HAC	10.39	69.95	29.12	5.89	47.34	155.3	133.61	11.38	1.25
13	none	Flood plain	HAC	6.62	309.69	95.37	6.97	101.41	350.1	117.54	21.01	1.13
14	N	Beach	Sand	25.88	49.04	21.87	7.91	135.43	147.5	42.00	0.59	1.48
Ex	PIAL	---	---	2.1	37.2	11.6	6.42	203.0	197.3	69.7	29.5	0.94
Ex	N	---	---	11.0	195.2	83.7	6.43	94.1	2,378.1	108.5	67.4	0.69

Source: Hubanks 2019

Summary



- Gaps:
    - GHG fluxes from pasturelands
    - Soil C sequestration rates from ag lands and converted lands
    - Inconsistencies in GIS data layers
- Future work (outside of this project)
    - Updating NWL data layers to create tool
    - Publications to assist land managers, soil C building practices

Mahalo!

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