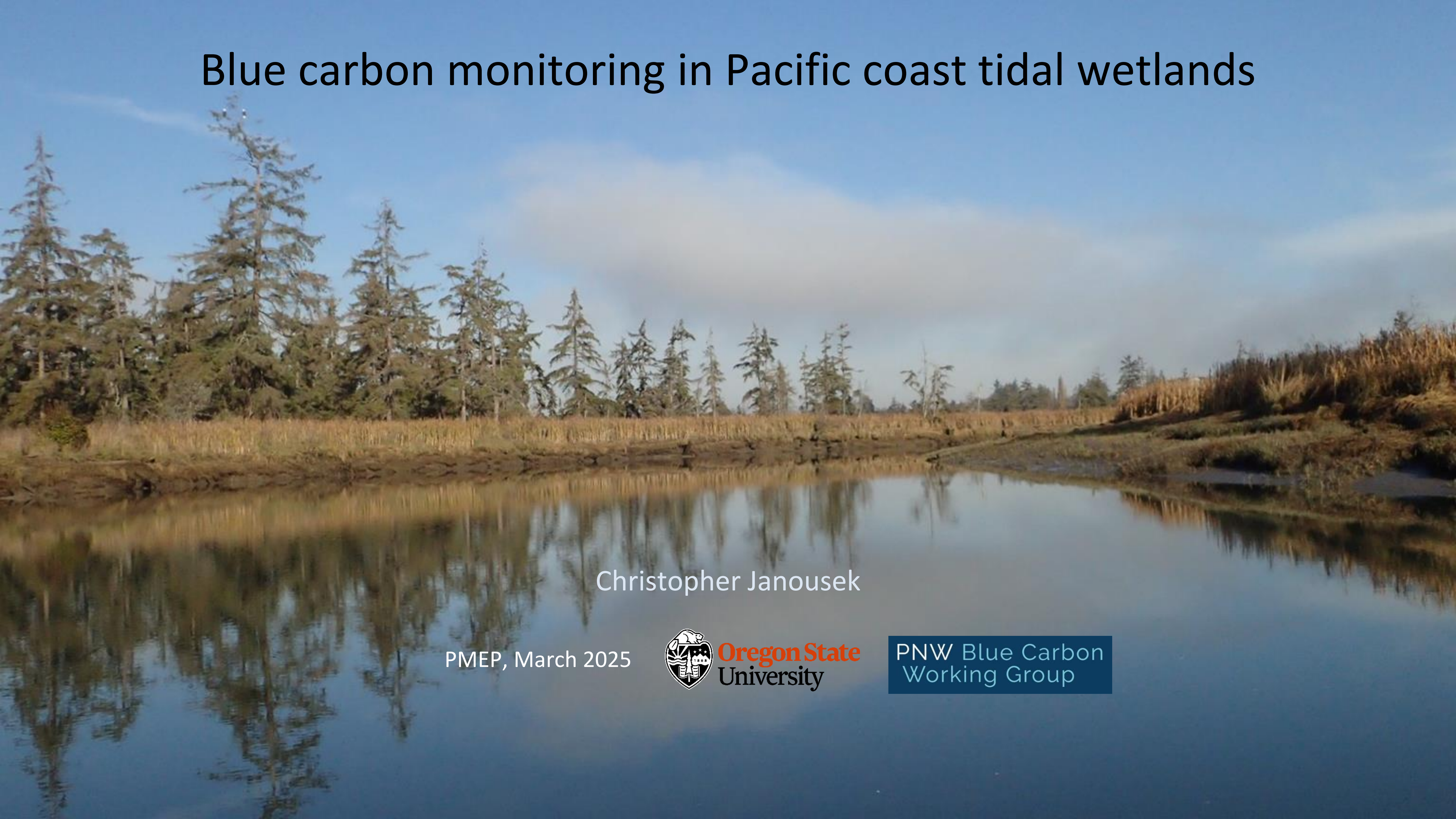
Blue carbon monitoring in Pacific coast tidal wetlands



Christopher Janousek

PMEP, March 2025

Oregon State University

PNW Blue Carbon Working Group

Outline

- Additional background for west coast blue carbon
- Introduction to Northeast Pacific Blue Carbon Database
  - Regional data synthesis
  - How to access the data
- Monitoring for blue carbon functions
  - Stocks
  - Sequestration rates
  - GHG emissions
- Final comments on good monitoring practices

Background

Blue carbon components

	CO_2	CH_4	N_2O
100 yr Global warming potential	1	32	263
100 yr Sustained GWP	1	45	270

In situ photosynthesis

C sequestration {

Flux from watershed

respiration

GHG emissions

methanogenesis

nitrification & denitrification

Lateral export

Stocks (long-term storage)

Bridgham et al. 2013, Neubauer & Megonigal 2015, Foster & Fulweiler 2016

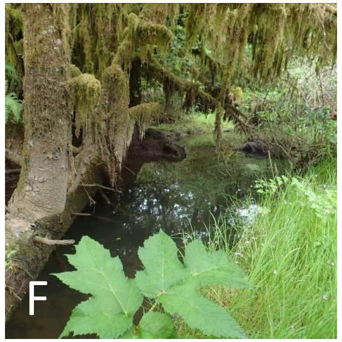
Where is blue carbon stored?

- Blue carbon pools include:
  - Above-ground plant biomass
  - Below-ground plant biomass
  - Dead plant matter (wood)
  - Soils

PNW ecosystem	Belowground %
Seagrass	99.6%
Low marsh	98.7%
High marsh	98.5%
Tidal swamp	79.3%

Kauffman et al. 2020

US west coast blue carbon ecosystems

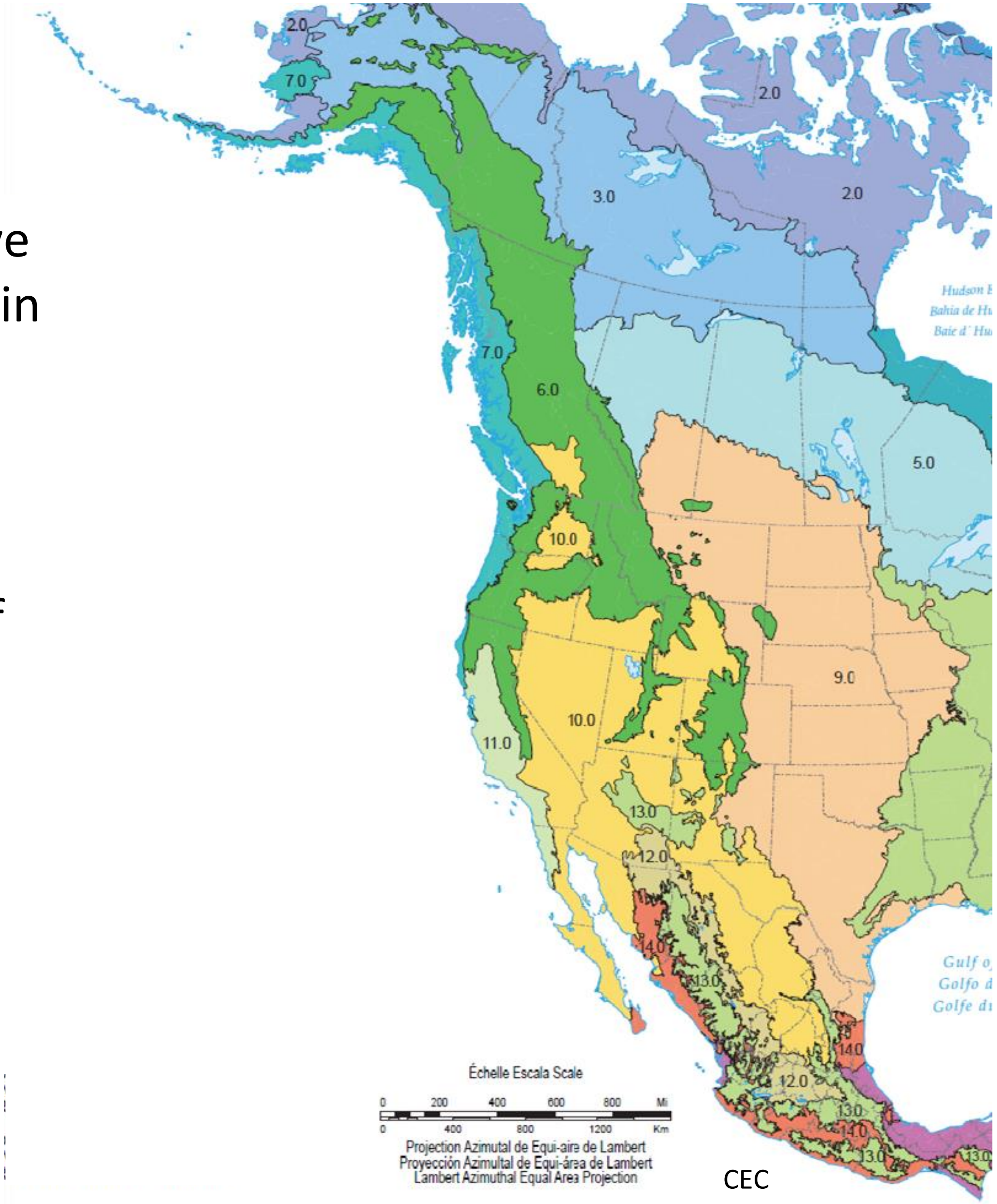


Ecosystem	**Kelp forests**	**Tideflats**	**Seagrass**	**Tidal marsh**	**Scrub-shrub tidal swamps**	**Forested tidal swamps**
Vegetation	Giant kelp; bull kelp	--	Emergent	Emergent	Shrubs	Trees
Elevation	Subtidal to low intertidal	Subtidal to low intertidal	Subtidal to low intertidal	Usu. upper ½ intertidal	Upper ¼ intertidal	Upper ¼ intertidal
Salinity	Saline	Fresh to euhaline	Brackish to euhaline	Fresh to euhaline	Fresh to brackish	Fresh to brackish
Distribution	Outer coast, Salish Sea	Throughout estuaries	Outer coast, estuaries	Throughout estuaries	Rare, CA Delta & PNW estuaries	Rare, PNW estuaries

West coast blue carbon database

Northeast Pacific blue carbon database

- Initiated with a NERRS Science Collaborative grant to PNW Blue Carbon Working Group in 2016 National Estuarine Research Reserve System Science Collaborative
- Goal: compile all regional blue carbon data available
- Started in the PNW then expanded to all of western North America
- C stocks, C sequestration, GHG emissions
- Linked series of flat files



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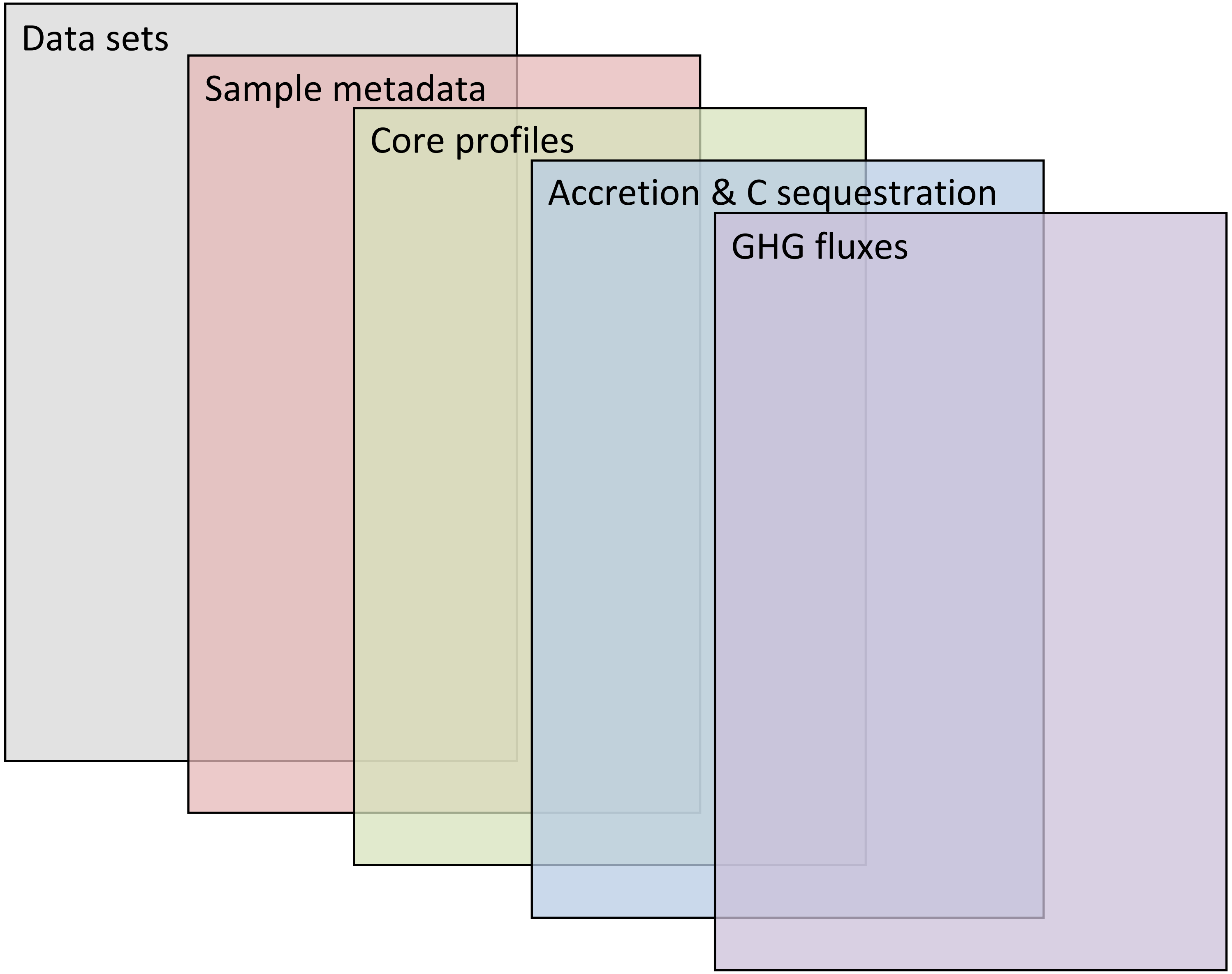
Database structure



- Environmental data include
  - Wetland elevation
  - Salinity
  - pH
  - Sediment grain size
  - Vegetation communities
  - Soil nitrogen
  - Soil temperature
  - Groundwater level

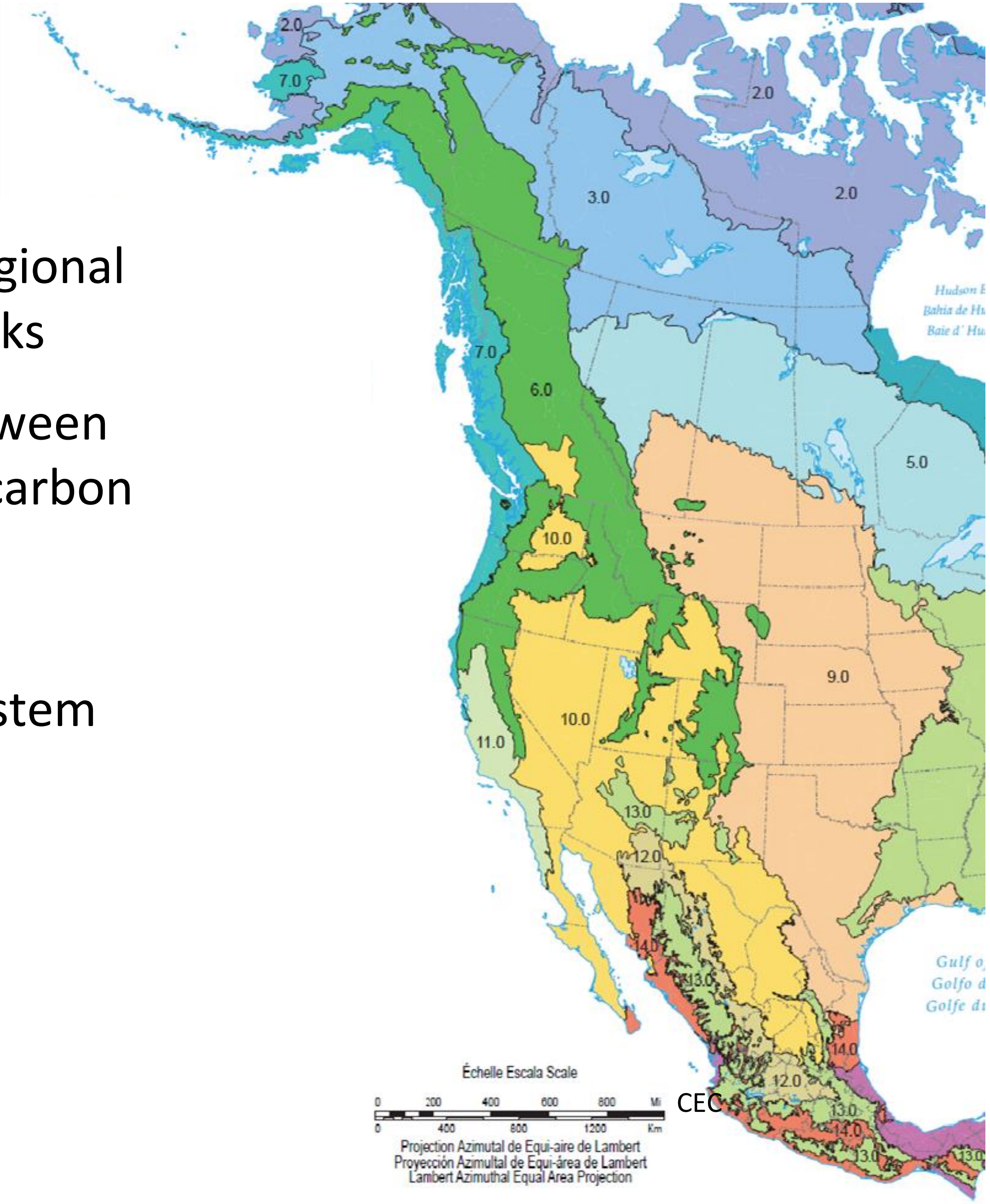
Example data

						Core/subsample dimensions				Bulk									Carbon									Soil C stocks (kg/m2)					Sediment grain size				
SampID	Study ID	StudySampID	Wetl type	State/prov	Lvl 2 Ecoreg	Tot C depth (cm)	Samp depth interval	Extrapol depth interval	Extra pol samp	BD type	BD (g/cm3)	C method	OM type	CN type	%OM, LOI	%C, CHN	%N, CHN	Calc C:N	Rep CD (g/cm3)	Calc CD by CN (g/cm3	Calc CD by LOI (g/cm3	Sfc CD meth	Sfc CD dpth range	Calc sfc CD (0-10)	Rhiz CD meth	Rhiz CD dpth	Calc rhiz CD (20-30)	Rep stk	Calc stk & metho	Calc stk, 0.3m	Calc stk, 0.5m	Calc stk, 1m	% gravel	% sand	% silt	% clay	% fines
0	X	0	EM	CA	11	137															EM	CHN	0-10	0.058	CHN	20-30	0.052	45.1	CHN	8.76	32.96	44.21	NA	NA	NA	NA	NA
0a							0-10	0-15	15	M	0.8	CHN&LOI	M	M	13.0	7.3	0.7	10.4	NA	0.058	0.041	FO/SS		0.042	MG				8.76				0	13	65	22	87.0
0b							20-30	15-30	15	M	0.8	CHN&LOI	M	M	13.0	6.5	0.8	8.1	NA	0.052	0.028	FL/SG		Not yet	PA-7				7.80				NA	NA	NA	NA	NA
0c							35-40	30-50	50	M	0.8	CHN&LOI	M	M	13.0	4.1	0.5	8.2	NA	0.033	0.036	EM-7	PNW						16.40				NA	NA	NA	NA	NA
0d							75-80	50-100	37	M	0.8	CHN&LOI	M	M	13.0	3.8	0.4	9.5	NA	0.030	0.041	EM-11	CA						11.25				NA	NA	NA	NA	NA
126	1	COO-MIL-HM6	EM	OR	7.1	300															NA	CHN	abt 5-1	0.025	CHN	abt 20-	0.027	NA	CHN	7.72	12.90	26.18	NA	NA	NA	NA	NA
126a			EM	OR	7.1		abt 5-10	0-15	15	M	0.397	CHN	NA	M	NA	6.29	0.47	13.3	0.025	0.025	NA								3.74				NA	NA	NA	NA	NA
126b			EM	OR	7.1		abt 20-25	15-30	15	M	0.383	CHN	NA	M	NA	6.92	0.56	12.4	0.027	0.027	NA								3.98				NA	NA	NA	NA	NA
126c			EM	OR	7.1		abt 38-43	30-50	20	M	0.552	CHN	NA	M	NA	4.69	0.36	13.0	0.026	0.026	NA								5.18				NA	NA	NA	NA	NA
126d			EM	OR	7.1		abt 73-78	50-100	50	M	0.723	CHN	NA	M	NA	3.68	0.33	11.3	0.027	0.027	NA								13.29				NA	NA	NA	NA	NA
126e			EM	OR	7.1		>100	100-300	200	M	0.768	CHN	NA	M	NA	2.56	0.19	13.2	0.020	0.020	NA								39.28				NA	NA	NA	NA	NA
127	1	SKA-WIL-HM1	EM	WA	7.1	273															NA	CHN	abt 5-1	0.025	CHN	abt 20-	0.106	NA	CHN	19.70	24.54	35.02	NA	NA	NA	NA	NA
127a			EM	WA	7.1		abt 5-10	0-15	15	M	0.519	CHN	NA	M	NA	4.90	0.27	18.0	0.025	0.025	NA								3.81				NA	NA	NA	NA	NA
127b			EM	WA	7.1		abt 20-25	15-30	15	M	2.101	CHN	NA	M	NA	5.04	0.30	16.6	0.106	0.106	NA								15.89				NA	NA	NA	NA	NA
127c			EM	WA	7.1		abt 38-43	30-50	20	M	0.431	CHN	NA	M	NA	5.61	0.29	19.2	0.024	0.024	NA								4.83				NA	NA	NA	NA	NA
127d			EM	WA	7.1		abt 73-78	50-100	50	M	0.694	CHN	NA	M	NA	3.02	0.17	18.1	0.021	0.021	NA								10.48				NA	NA	NA	NA	NA
127e			EM	WA	7.1		>100	100-273	173	M	1.086	CHN	NA	M	NA	1.45	0.10	13.9	0.016	0.016	NA								27.22				NA	NA	NA	NA	NA
128	1	SKA-WIL-HM2	EM	WA	7.1	300															NA	CHN	abt 5-1	0.023	CHN	abt 20-	0.025	NA	CHN	7.31	12.78	23.13	NA	NA	NA	NA	NA
128a			EM	WA	7.1		abt 5-10	0-15	15	M	0.494	CHN	NA	M	NA	4.75	0.27	17.4	0.023	0.023	NA								3.52				NA	NA	NA	NA	NA
128b			EM	WA	7.1		abt 20-25	15-30	15	M	0.574	CHN	NA	M	NA	4.41	0.27	16.1	0.025	0.025	NA								3.79				NA	NA	NA	NA	NA
128c			EM	WA	7.1		abt 38-43	30-50	20	M	0.487	CHN	NA	M	NA	5.61	0.28	20.2	0.027	0.027	NA								5.46				NA	NA	NA	NA	NA
128d			EM	WA	7.1		abt 73-78	50-100	50	M	0.727	CHN	NA	M	NA	2.85	0.16	17.4	0.021	0.021	NA								10.35				NA	NA	NA	NA	NA
128e			EM	WA	7.1		>100	100-300	200	M	0.911	CHN	NA	M	NA	2.09	0.14	15.0	0.019	0.019	NA								38.15				NA	NA	NA	NA	NA
129	1	SKA-WIL-HM3	EM	WA	7.1	282															NA	CHN	abt 5-1	0.023	CHN	abt 20-	0.018	NA	CHN	6.12	9.37	20.78	NA	NA	NA	NA	NA
129a			EM	WA	7.1		abt 5-10	0-15	15	M	0.279	CHN	NA	M	NA	8.32	0.36	22.9	0.023	0.023	NA								3.48				NA	NA	NA	NA	NA
129b			EM	WA	7.1		abt 20-25	15-30	15	M	0.210	CHN	NA	M	NA	8.39	0.44	19.1	0.018	0.018	NA								2.64				NA	NA	NA	NA	NA
129c			EM	WA	7.1		abt 38-43	30-50	20	M	0.353	CHN	NA	M	NA	4.60	0.27	17.1	0.016	0.016	NA								3.25				NA	NA	NA	NA	NA
129d			EM	WA	7.1		abt 73-78	50-100	50	M	0.736	CHN	NA	M	NA	3.10	0.17	18.3	0.023	0.023	NA								11.40				NA	NA	NA	NA	NA
129e			EM	WA	7.1		>100	100-282	182	M	0.644	CHN	NA	M	NA	2.60	0.14	18.0	0.017	0.017	NA								30.45				NA	NA	NA	NA	NA
130	1	SKA-WIL-HM4	EM	WA	7.1	276															NA	CHN	abt 5-1	0.022	CHN	abt 20-	0.022	NA	CHN	6.48	10.85	23.40	NA	NA	NA	NA	NA
130a			EM	WA	7.1		abt 5-10	0-15	15	M	0.469	CHN	NA	M	NA	4.61	0.30	15.6	0.022	0.022	NA								3.24				NA	NA	NA	NA	NA
130b			EM	WA	7.1		abt 20-25	15-30	15	M	0.477	CHN	NA	M	NA	4.52	0.30	14.9	0.022	0.022	NA								3.24				NA	NA	NA	NA	NA
130c			EM	WA	7.1		abt 38-43	30-50	20	M	0.269	CHN	NA	M	NA	8.12	0.46	17.7	0.022	0.022	NA								4.37				NA	NA	NA	NA	NA
130d			EM	WA	7.1		abt 73-78	50-100	50	M	0.541	CHN	NA	M	NA	4.64	0.26	18.1	0.025	0.025	NA								12.55				NA	NA	NA	NA	NA
130e			EM	WA	7.1		>100	100-276	176	M	0.927	CHN	NA	M	NA	2.01	0.14	14.8	0.019	0.019	NA								32.73				NA	NA	NA	NA	NA

- Core-level data: Approaching 1800 soil cores
- Subsample-level data: >30,000 lines of data

Stocks synthesis goals

- With a growing dataset, opportunity to conduct a regional synthesis of soil carbon stocks
- Goal 1: Compare stocks between different Pacific coast blue carbon ecosystem types
- Goal 2: Assess the relative influence of different ecosystem drivers



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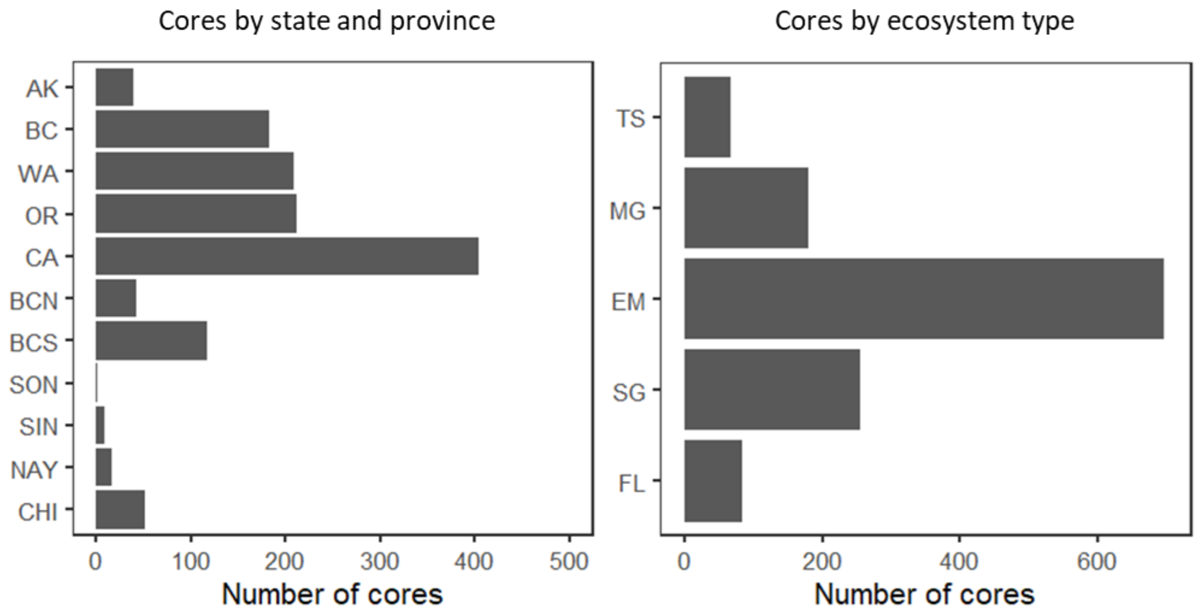
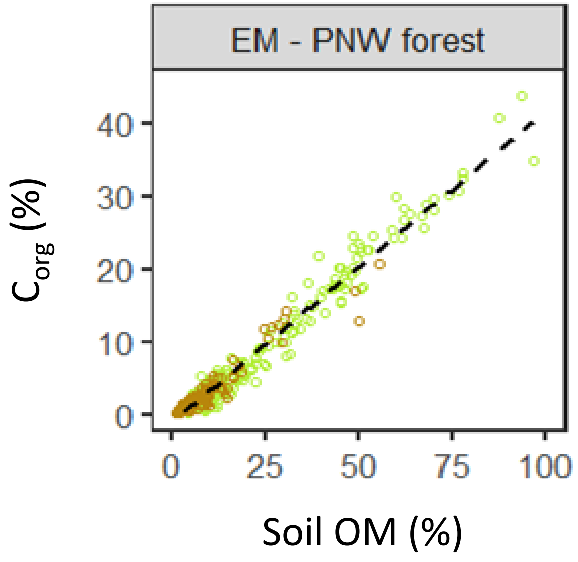
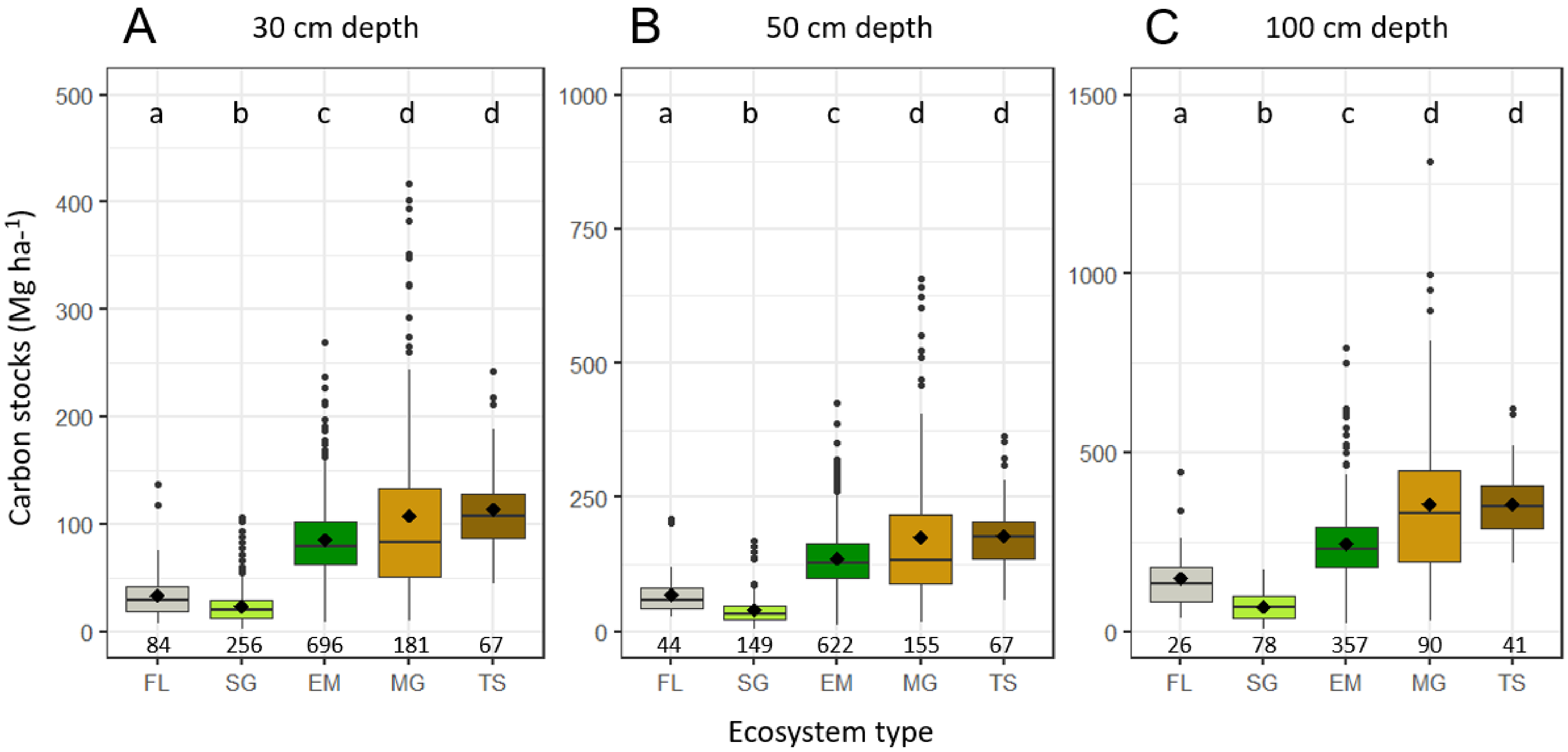
Stocks methods

- 69 datasets for least-disturbed wetlands
- 1284 cores/soil pits
- >6500 km coastline; 86 estuaries/ coastal regions
- Used a standard approach to determine carbon density from bulk density, %C_{org} and %OM data
- Integrated C density over depth to determine carbon stocks to 30, 50 and 100 cm depths (Mg/ha)





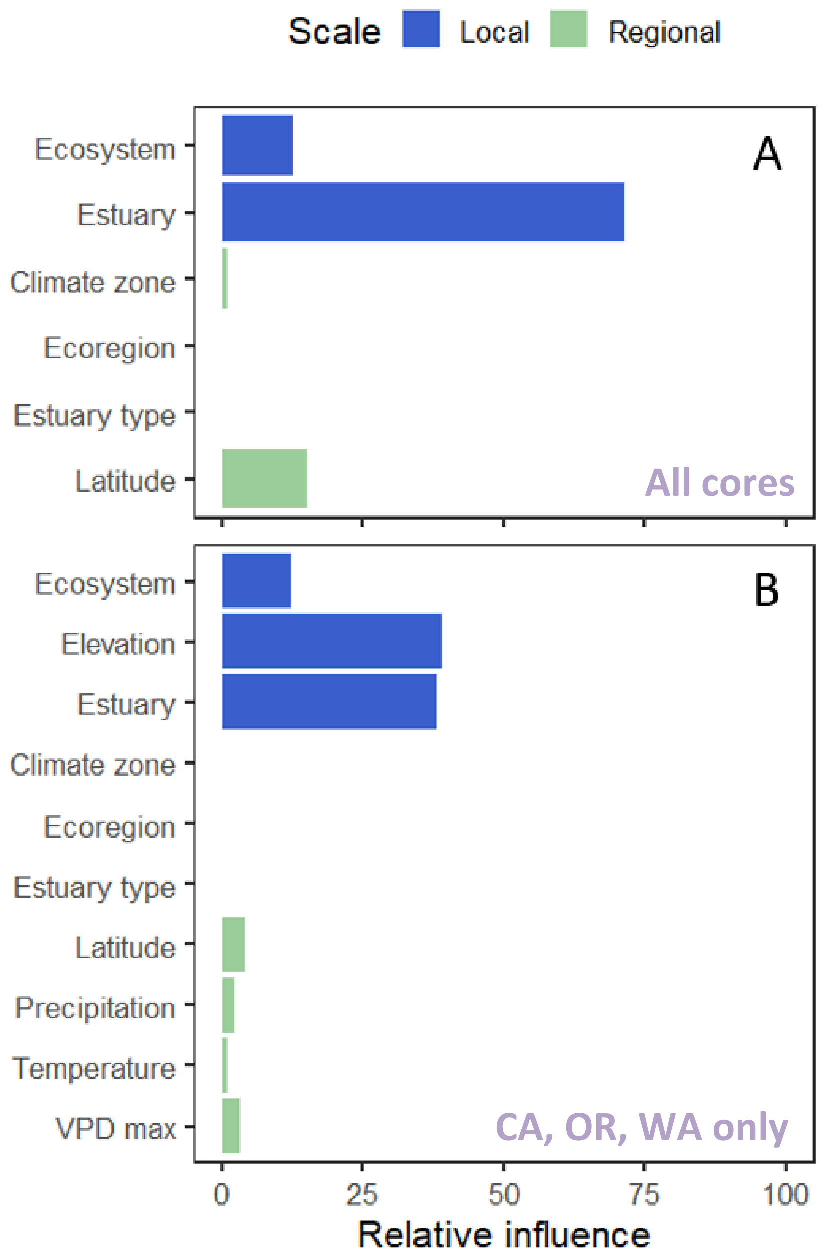
Stocks by blue carbon ecosystem in western North America



Janousek et al., GBC, In Press

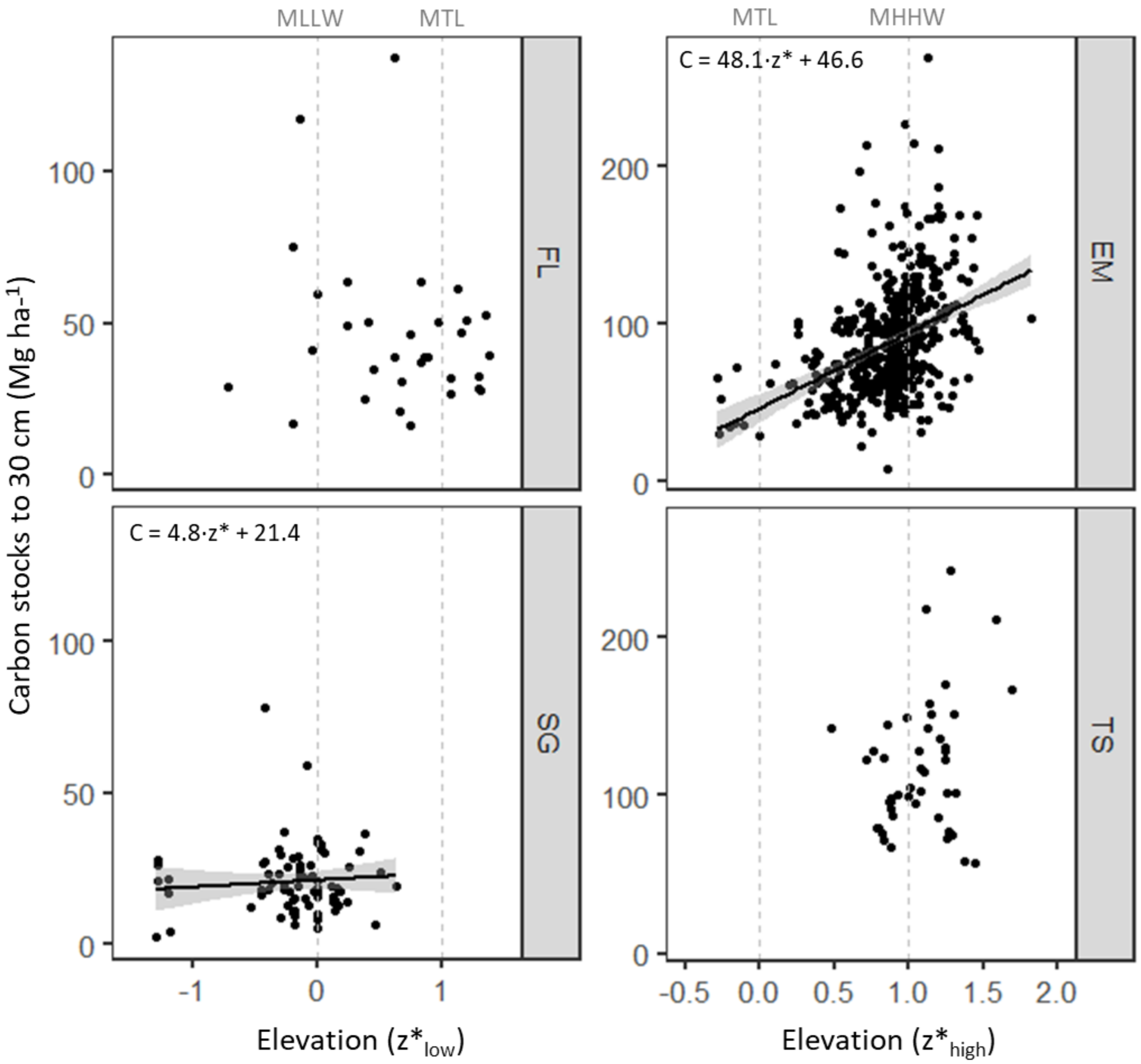
Drivers of western N American blue carbon stocks

- What are the drivers of stocks? (This could help us estimate carbon where data are missing)
- Multivariate machine-learning model, boosted regression trees
- Analysis: Scott Bridgham



Janousek et al., GBC, In Press

Local drivers (elevation)

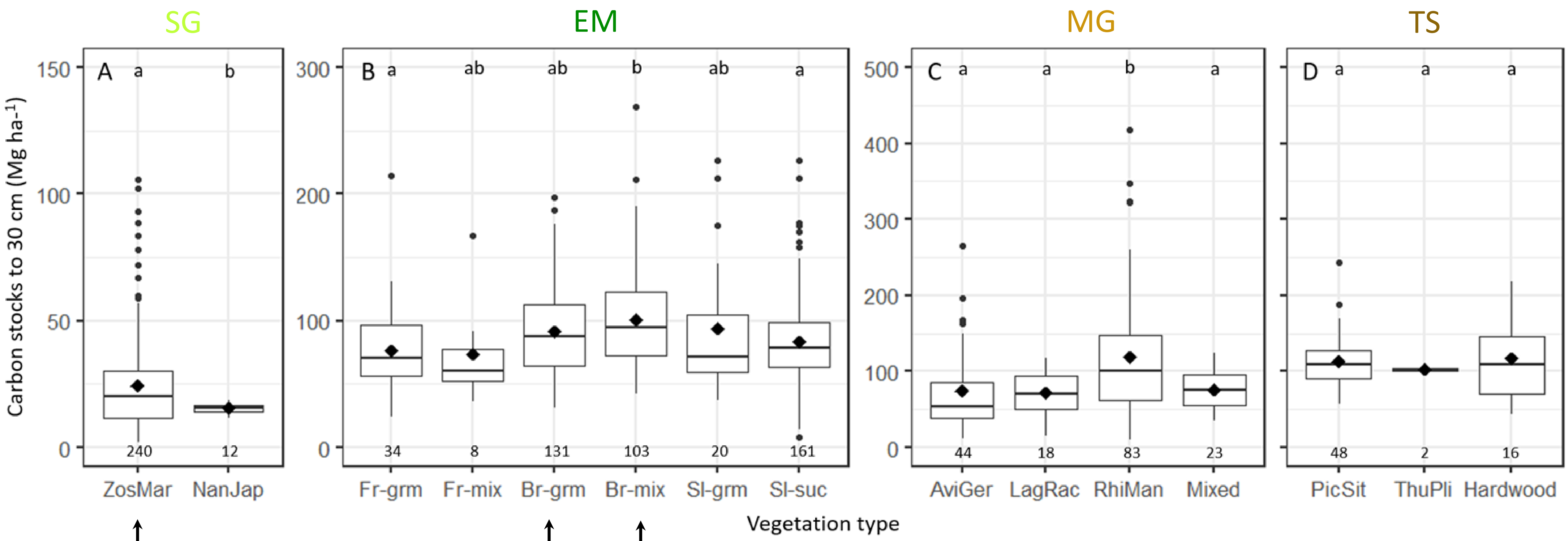


R^2_{adj} = 0.16,
P < 0.0001
n = 477

R^2_{adj} = 0.11,
P = 0.0006
n = 94

Janousek et al., GBC, In Press

Local drivers (plant composition)



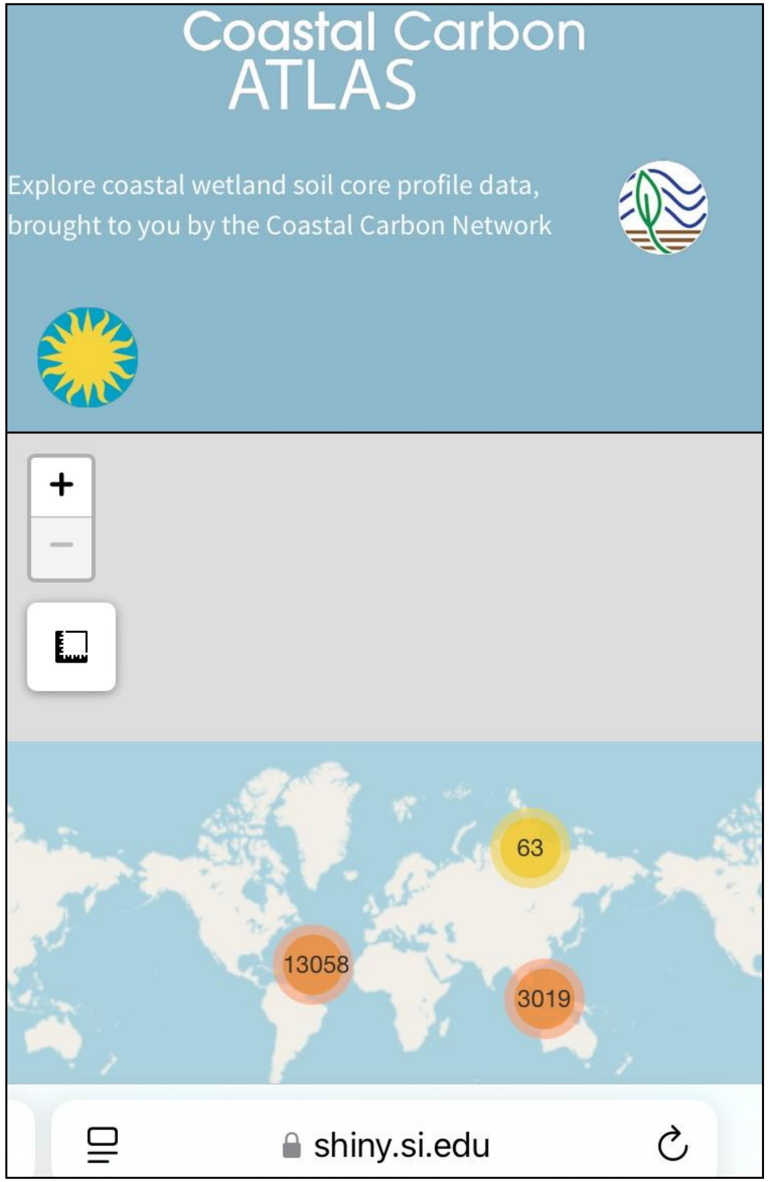
Janousek et al., GBC, In Press

Data needs

- More CH_4 emissions data from fresh and oligohaline tidal wetlands (0-5 ppt). High CH_4 reduces the climate cooling potential of wetlands.
- More data on blue carbon in restored and disturbed tidal wetlands are needed to quantify the positive climate impacts of wetland restoration.
- For accounting, it is also important to understand lateral fluxes of carbon.
- Non-traditional & undersampled blue carbon ecosystems: scrub-shrub wetlands, kelp forests & algal beds, sandy beaches

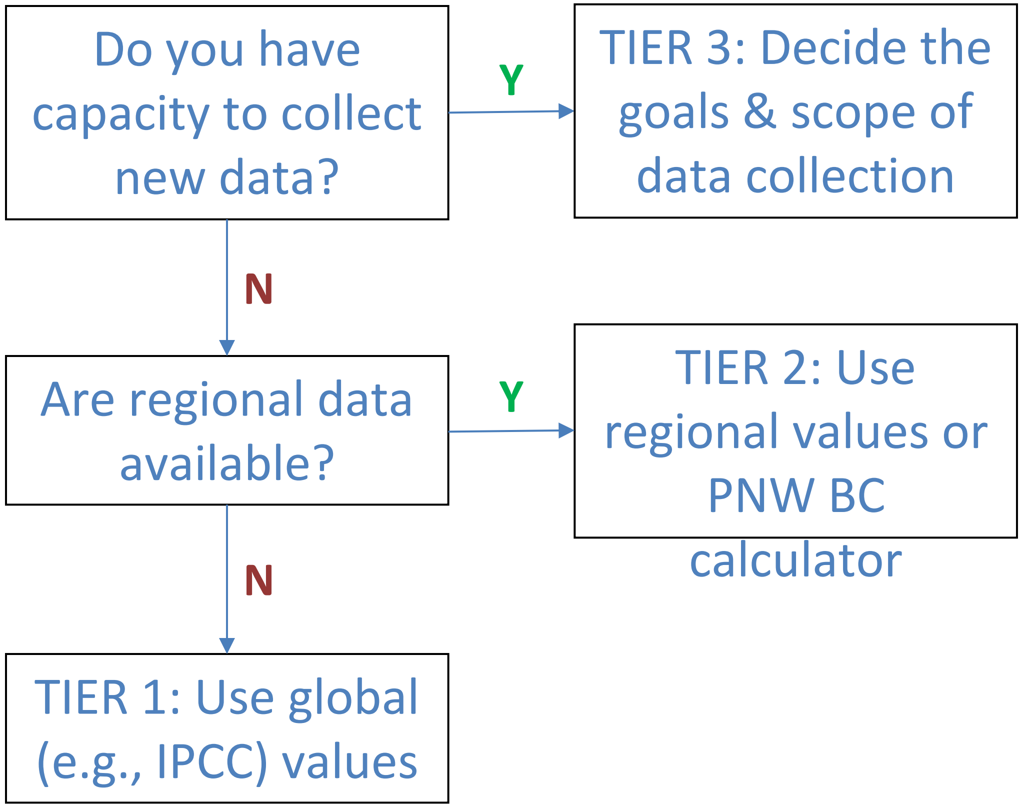
Kandoll Farm restored marsh, Columbia

- For summary stocks data in west coast estuaries, see appendices in Janousek et al. (In Press). *Global Biogeochemical Cycles* or Janousek et al. (2025a) data release
- For methane flux data for the PNW, see Williams et al. (In Press). *Ecological Applications* or Janousek et al. (2025b) data release
- Many west coast datasets are also compiled in the Smithsonian's Coastal Carbon Atlas



Monitoring blue carbon

Monitoring approach



Considerations

- What are your project & monitoring goals? (conservation, restoration, etc.)
- What are your data needs?
- Budget?

Considerations

- What ecosystem(s) are in your project area?
- Does your project involve wetland conversion (e.g., pastureland restored to tidal marsh)?
- How deep in the sediment column are your project's likely impacts?

Example: Emergent marsh, Coos Estuary

Soil carbon (Mg/ha) (to 1 m)	
270 ± 72 (n=39)	TIER 3: Local (Coos)
223 ± 85 (n=180)	TIER 2: Regional (PNW)
231 (global median)	TIER 1: Global synthesis

Maxwell et al. 2023; Janousek et al., GBC, In Press

How to:

- Collect soil cores to at least 50 cm depth
- Section cores vertically into sub-samples
- Analyze sub-samples for bulk density (BD) and carbon content or organic matter content (OM)
- Multiply carbon density by sub-sample length and sum sub-samples to estimate carbon stocks

Monitoring: carbon sequestration

Considerations

- What ecosystem(s) are in your project area?
- Does your project involve wetland conversion (e.g., pastureland restored to tidal marsh)?
- How may changing hydrology impact C sequestration (e.g., restoration or SLR)?

Factors likely to affect C sequestration

- Sediment supply in the watershed
- Hydrologic connectivity including sheet flow (levees, small culverts)
- Wetland elevation
- Above-ground plant biomass

Monitoring: carbon sequestration

How to:

- Collect and section cores as for stocks analysis
- Analyze sub-samples with radiometric dating (^{210}Pb, ^{137}Cs)
- Apply an age-depth model to determine sediment accretion rate
- Multiply your accretion rate by carbon density to estimate CAR

Caveats:

- Radioisotope dating won't work in disturbed sediments (e.g., young restored sites)

Considerations

- Is your study site likely to have high methane emissions?
- Is there land conversion that could result in a change in GHG emissions?

Factors likely to affect CH_4 emissions

- Fresh or oligohaline salinities
- High groundwater levels
- Warmer temperatures
- Low wetland elevation

Williams et al., Ecological Applications, In Press

Monitoring: GHG emissions

How to:

- Evaluate what method(s) is appropriate for your work

Method	Pros	Cons
Use regional or global values for your ecosystem(s)	Rapid and lowest cost	Data are not site-specific and may be inaccurate for your wetland
Field-based chambers/ portable gas analyzer	Good for small sites; portable and rapid	Time consuming; $$; difficult to obtain adequate spatial and temporal replication
Field-based eddy co-variance flux tower	Continuous data over a relatively large footprint. Good for large sites	$$$$$$$$$$$$$$$$ $$$$$$$$$$$$$$$$ $$$$$$$$$$$$$$$$ >1 site difficult
Monitor environmental drivers and apply a statistical model	Fairly low cost; also gain other valuable monitoring data	Statistical and logger expertise needed

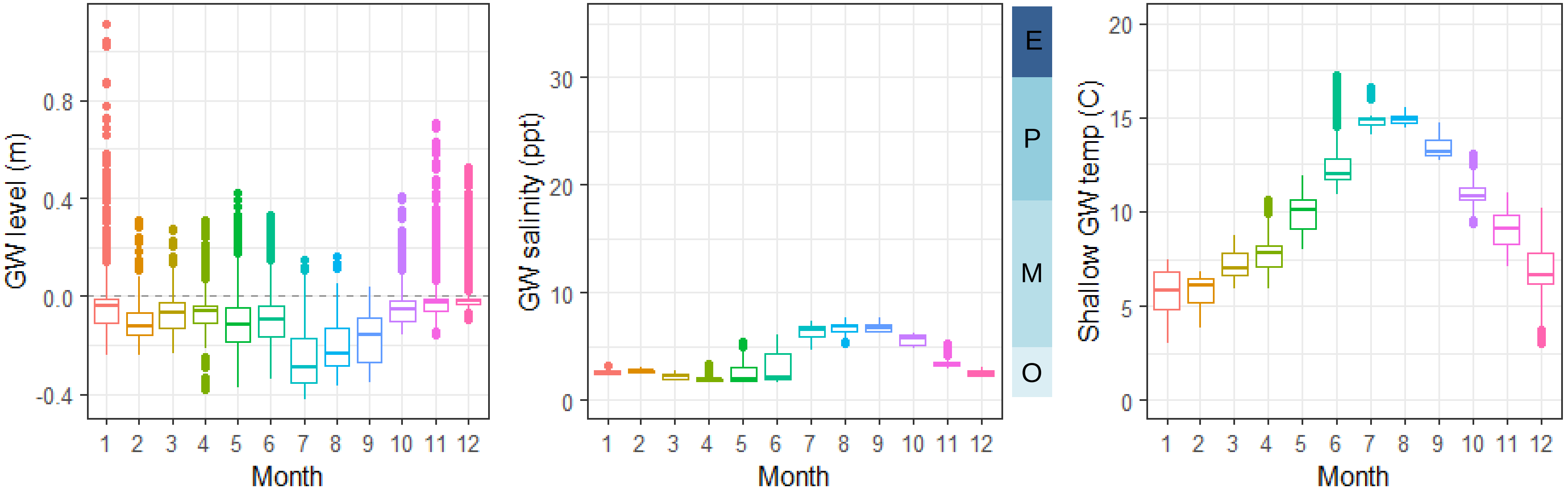
Monitoring: GHG emissions

Monitoring: GHG emissions

Photo credit: Colin Jones, TEP

Monitoring: GHG emissions

- John's River tidal swamp, Grays Harbor Estuary, WA



Data inputs

Annual CH_4 emissions estimate

Tillamook Bay – Southern Flow Corridor project site

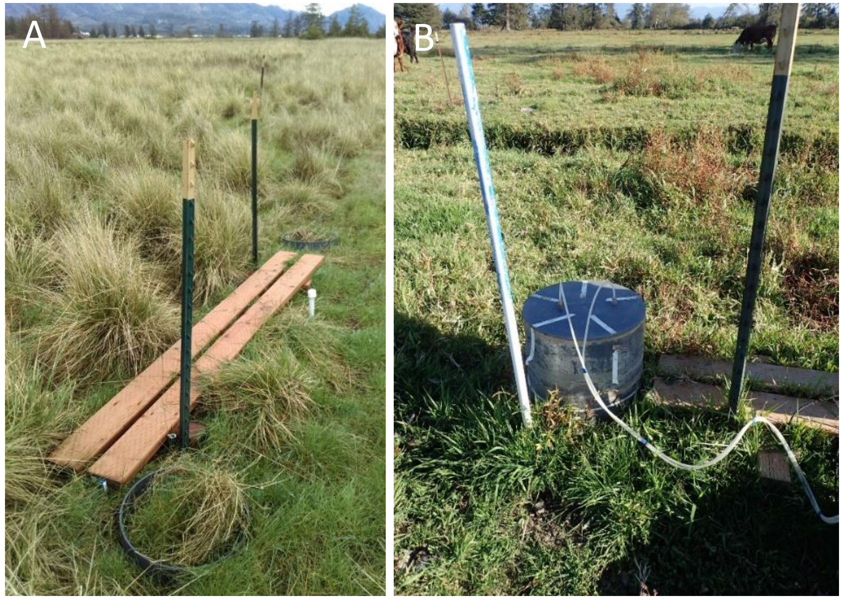
- Restored in 2016
- 179 ha of tidal wetland

What are we measuring?

- Carbon accumulation rates
- GHG emissions, ~1 and ~8 yr after restoration

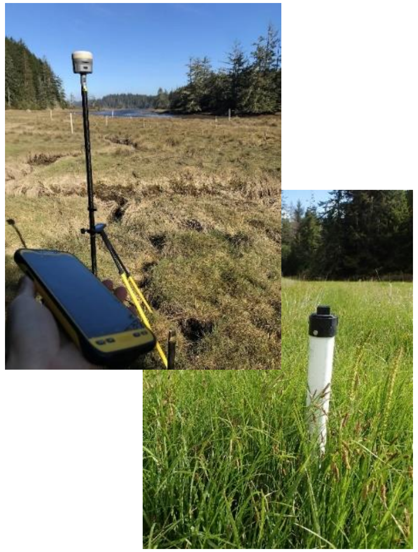
How does this help fill data gaps?

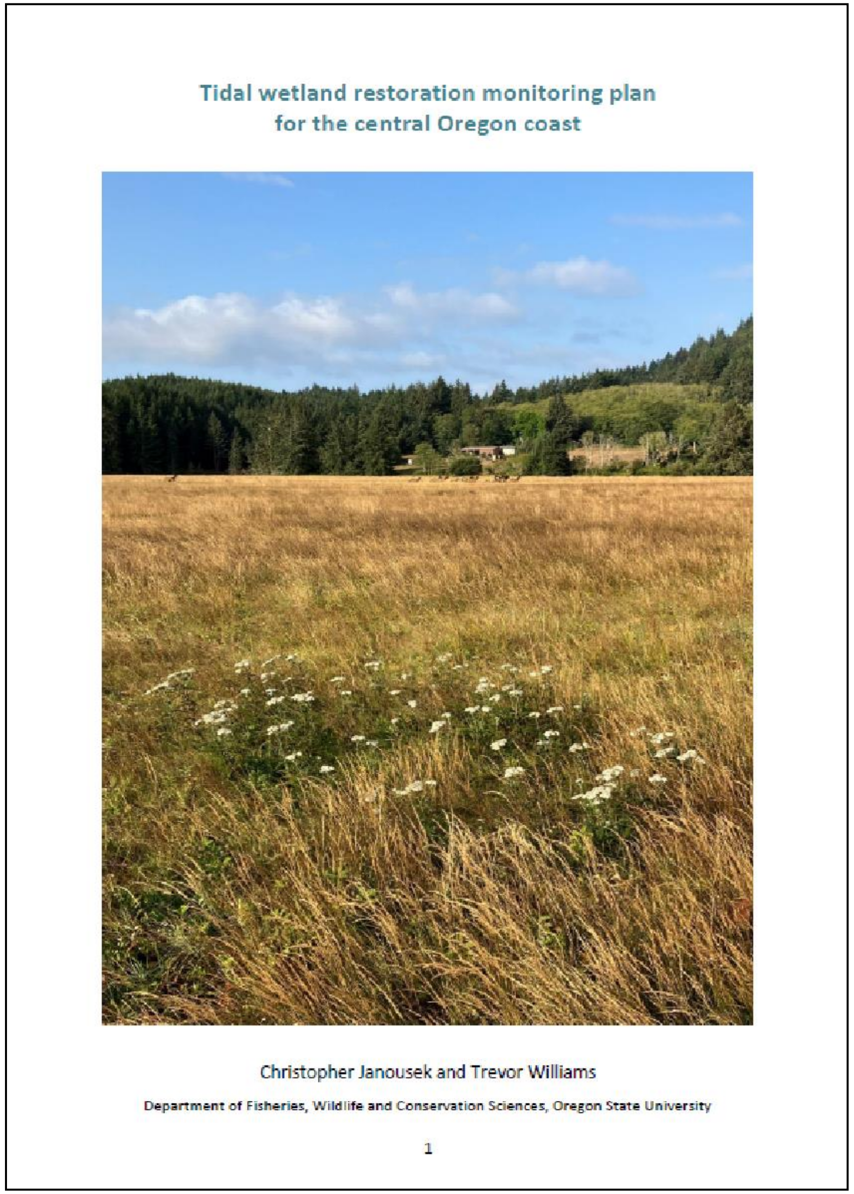
- More insight into blue carbon functions early in the restoration process



Final monitoring thoughts

- Blue carbon monitoring should be accompanied by adequate ecosystem drivers monitoring (elevation, salinity, groundwater, etc.)
- Monitoring associated with restoration should:
  - Use a BACI or BACIPS design
  - Before-after measurements at the restored site
  - Before-after measurements in 1+ reference site(s)
- Suggest monitoring not just for the sake of your project, but to help fill data gaps





Tidal wetland restoration monitoring plan
for the central Oregon coast

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Thank you!

- Trevor Williams, Maggie McKeon, Matt Norwood, Craig Cornu, others for figures and field sampling
- Many data contributors and Brandon Drucker for early work on the database
- Funders: NCCOS | NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE; National Estuarine Research Reserve System Science Collaborative; The Nature Conservancy; Pew

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Marsh and tidal swamp, Grays Harbor Estuary

Notes

Presentation prepared for PMEP Blue Carbon workshop, 4 March 2025

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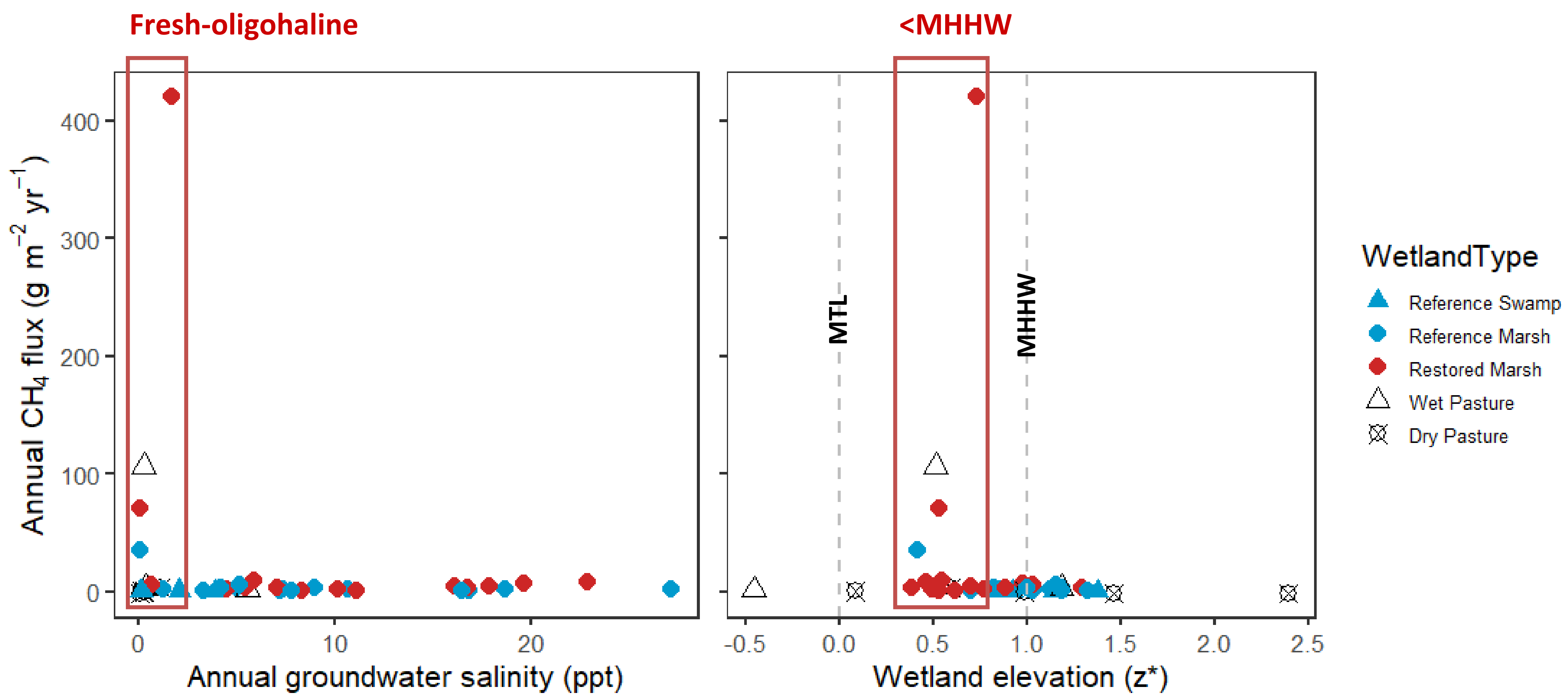
NOTES:

Compiled from presentations to PNWBCWG in April 2023 and WA NWL workshop in Oct 2024 and other sources; current: 17 Oct 2024
Photos by CNJ @ OSU unless otherwise noted. CEC map from the Commission for Environmental Cooperation. Mangrove image is in the public domain

PNW annual methane fluxes



Williams et al., in press