BLUE CARBON SEQUESTRATION ALONG THE U.S. WEST COAST

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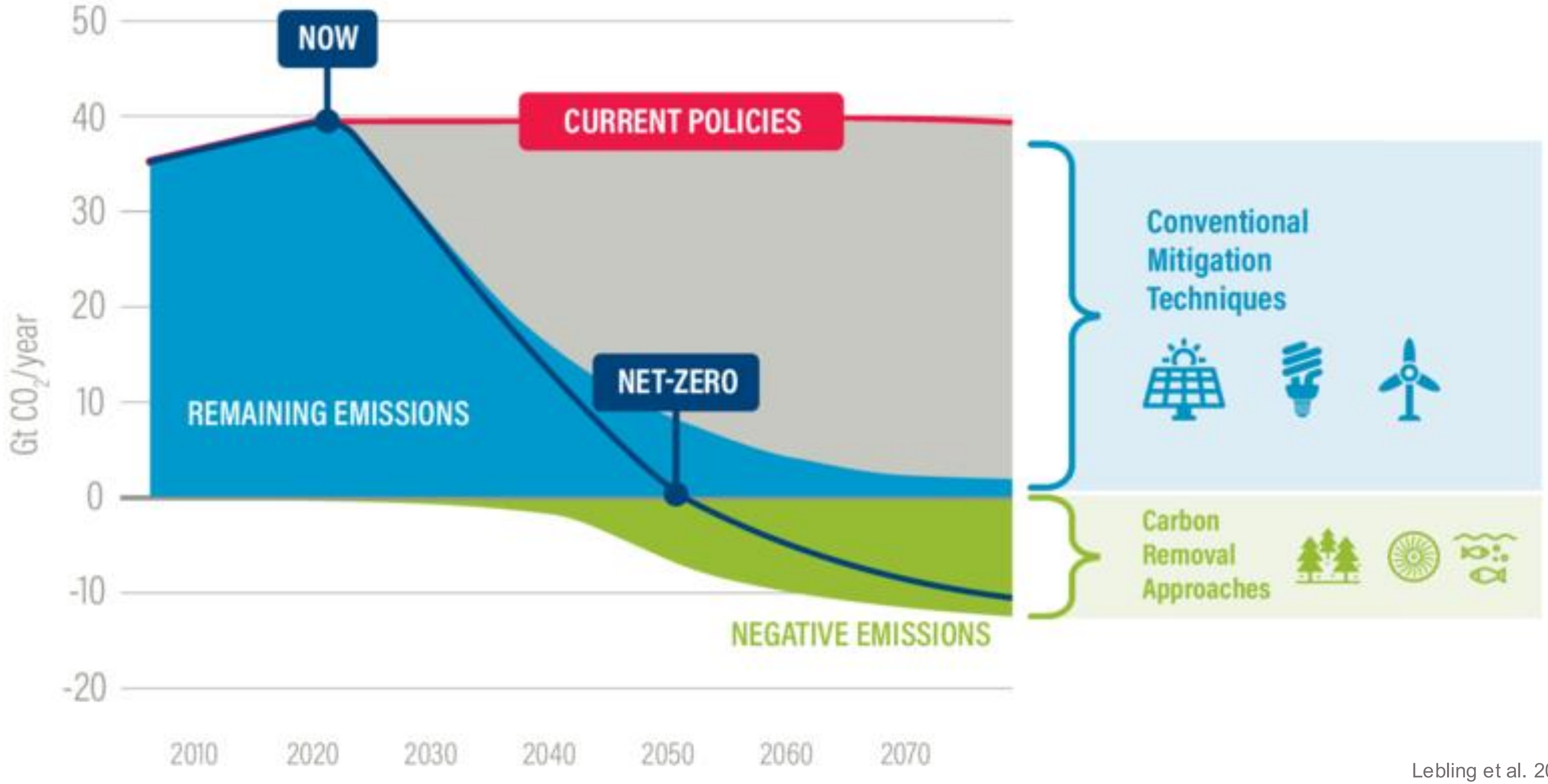
Effective management of blue carbon habitats can advance carbon removal

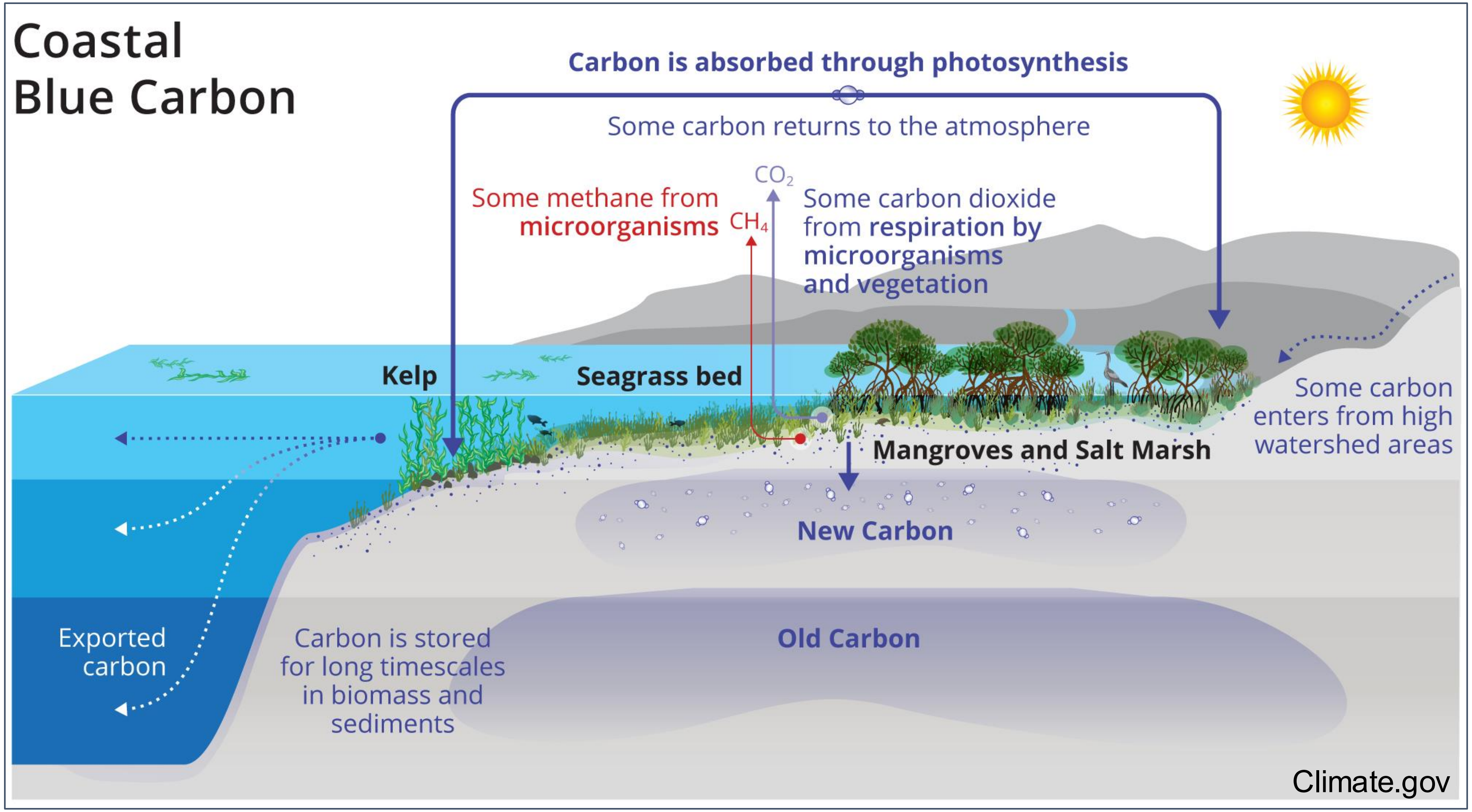
Staying Below 2 Degrees of Global Warming



Lebling et al. 2022

High sediment accumulation and low decomposition lead to high rates of carbon sequestration in traditional blue carbon habitats.

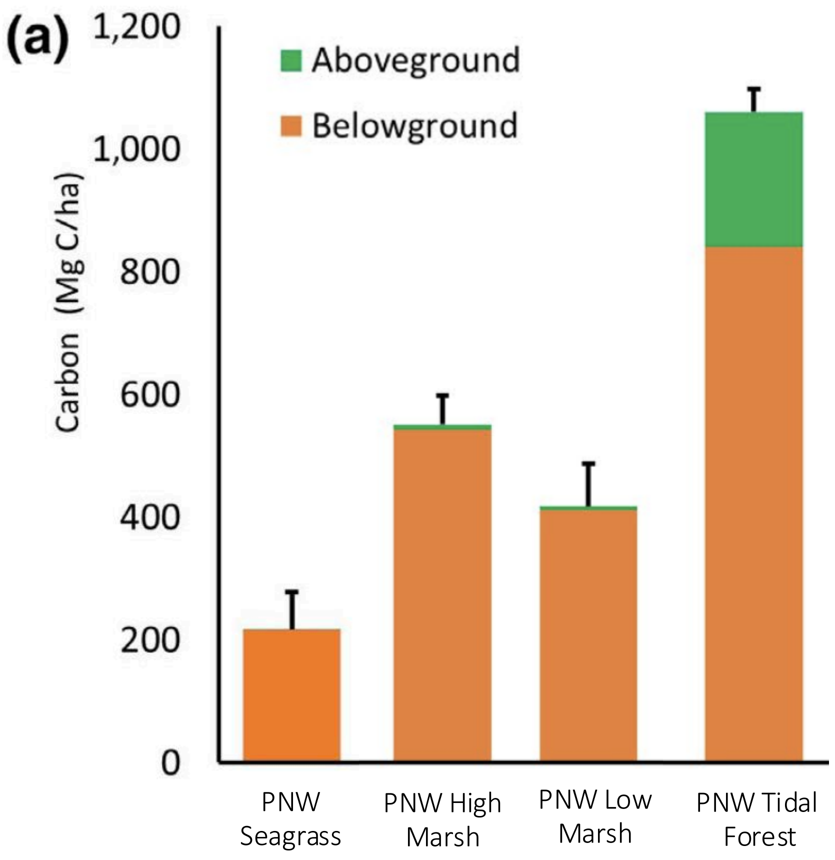
Carbon export to the deep ocean (e.g., seaweed) may offer a more novel mechanism for carbon sequestration.

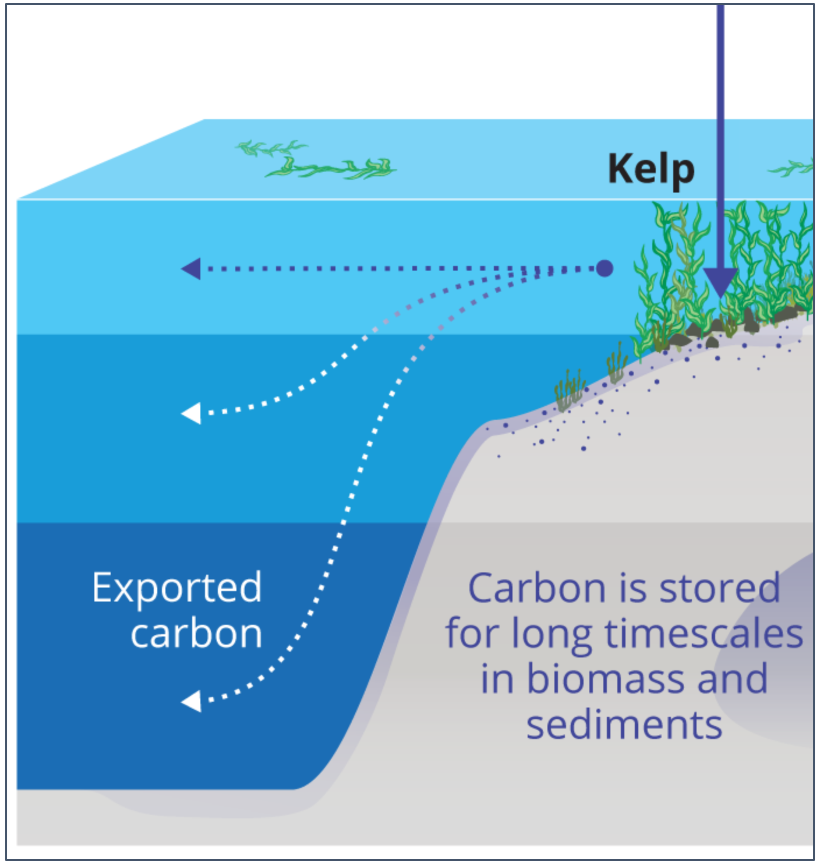


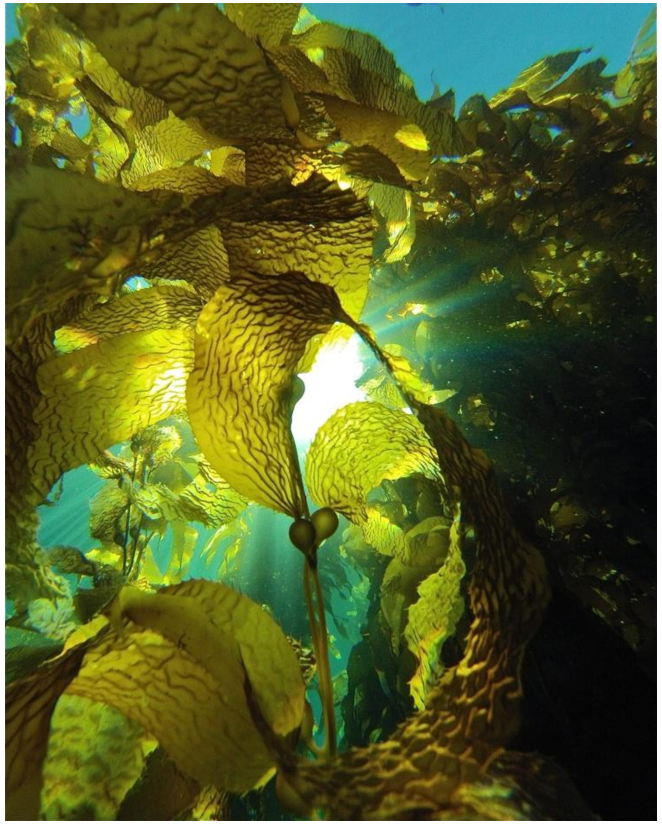
Organic carbon is stored primarily in sediment

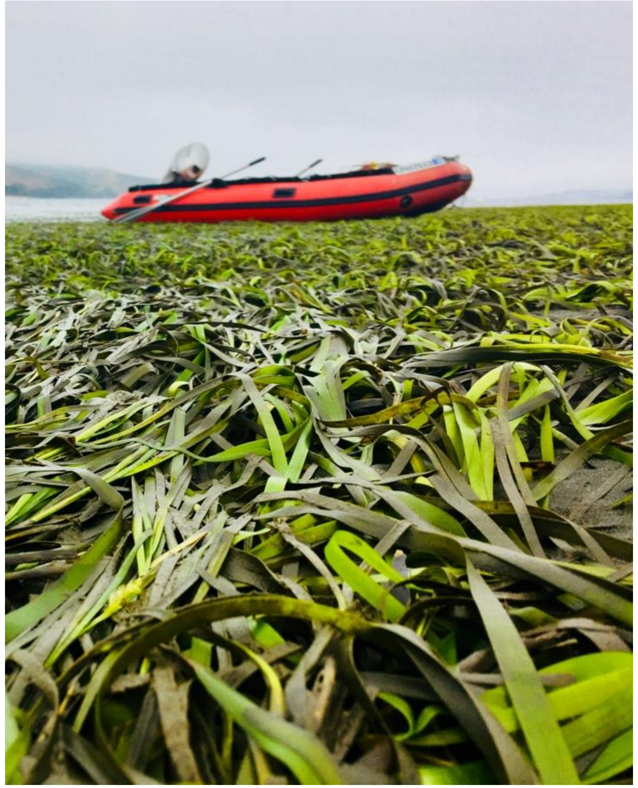
Carbon export to the deep ocean (e.g., seaweed) may offer a more novel mechanism for carbon sequestration.

BOONE KAUFFMAN ET AL. 2020










Blue carbon habitats hold high value on local to global scales

- Support biodiversity & fisheries
- Stabilize sediments
- Eco-tourism + local industries
- Enhance water quality
- Cultural significance
- OA amelioration
- Carbon burial in sediment

Blue Carbon in Global Climate Action

Global Initiative/Commitment	Blue Carbon Relevance
UNFCCC (United Nations Framework Convention on Climate Change)	Treaty called for the management/enhancement of GHG sinks and reservoirs, including blue carbon (1994).
Kyoto Protocol: Clean Development Mechanism (CDM)	CDMs: Early mechanism to support carbon credit projects in blue carbon ecosystems (2005).
Paris Agreement: *NDCs (Nationally Determined Contributions) & Article 6	Aiming to limit global warming, including country's GHG reduction commitments (NDCs) to reach targets. Blue carbon projects are identified to support NDC progress (2015).
Kunming-Montreal Global Biodiversity Framework (e.g., 30x30 initiatives)	Countries pledge to advance restoration and conservation, including restoration and conservation of 30% of land and sea (2022).
UN Decade on Restoration (2021-2030)	Global initiative to prevent/reverse ecosystem degradation (adopted by UN General Assembly).
Sustainable Development Goals (SDGs)	17 global goals to promote sustainable development, which call out blue carbon (SDG 13, SDG 14).
Intragovernmental Panel on Climate Change (IPCC) - Wetlands Supplement	Used to support and guide the incorporation of blue carbon into U.S. NDCs (2013).

** Greenhouse Gas Inventories support the tracking of NDC progress*

Ward et al. (*In Press)* - Annual Reviews

Blue Carbon in U.S. West Coast Climate Action

- Policy Protections (mitigation)
  - CWA, Magnuson-Stevens Conservation and Management Act (2007), California Eelgrass Mitigation Policy (CEMP). State policies in OR and WA.
  - Kelp restoration is more nascent – no mitigation policy and diffuse drivers of loss.

Brian Feulner, SF Chronicle

Target setting: A new era of restoration

- Carbon reduction targets
  - E.g., CA Climate Change Scoping Plans; Natural and Working Lands Climate Smart Strategy
- Protection targets
  - E.g., 30x30 initiatives
- Restoration targets
  - CA: 300 acres of eelgrass in San Francisco Bay by 2030 and 3,000 acres by 2038.
  - CNRA goals: Protect & restore 12.2K acres of wetlands each year (until 2045)
  - WA: 2011: Increase eelgrass area by 4,200 ha by 2020, a 20% increase

How is eelgrass restoration being supported now?

(Ward & Beheshti, 2023)

ECOSPHERE
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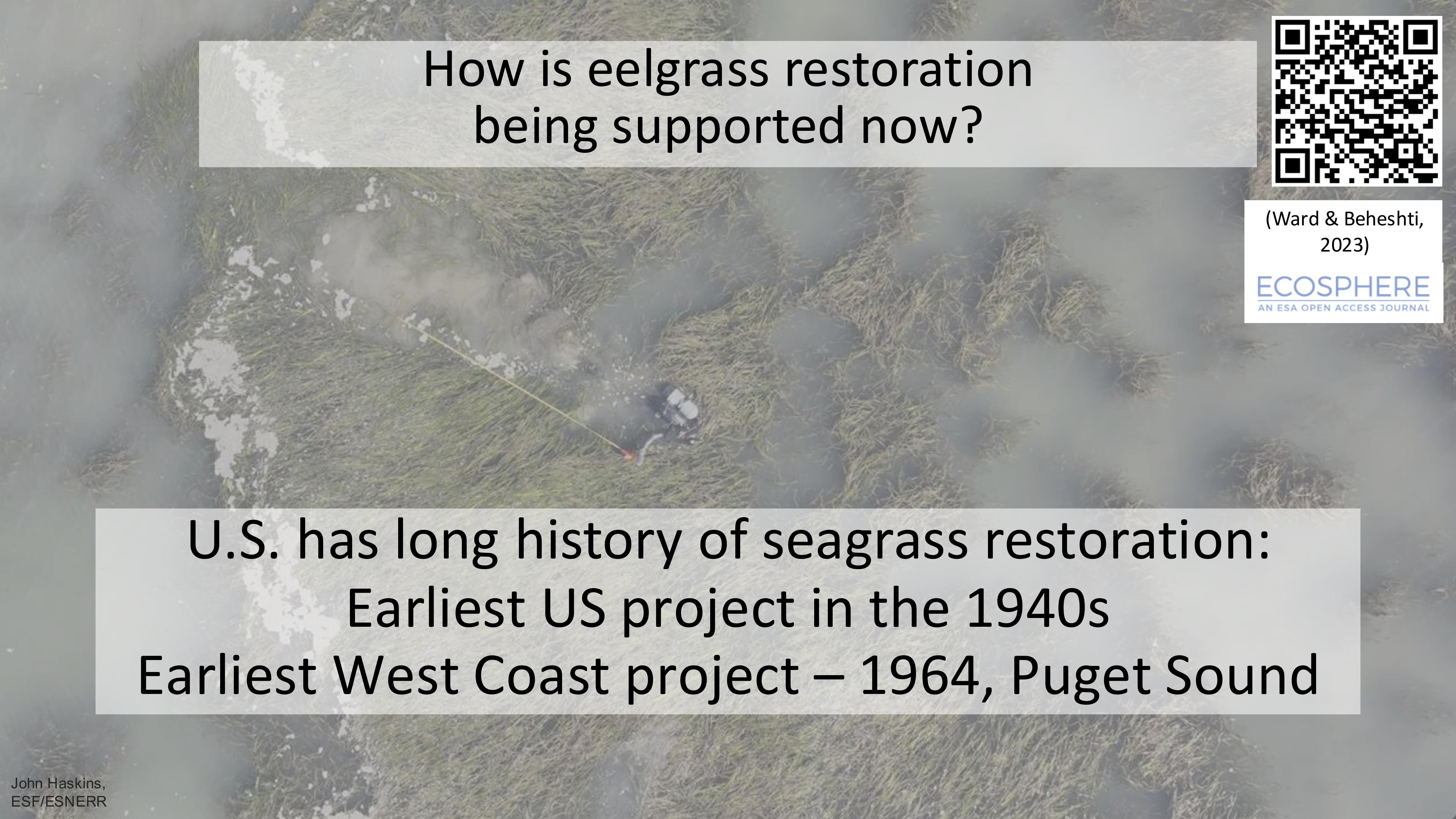


John Haskins, ESF/ESNERR

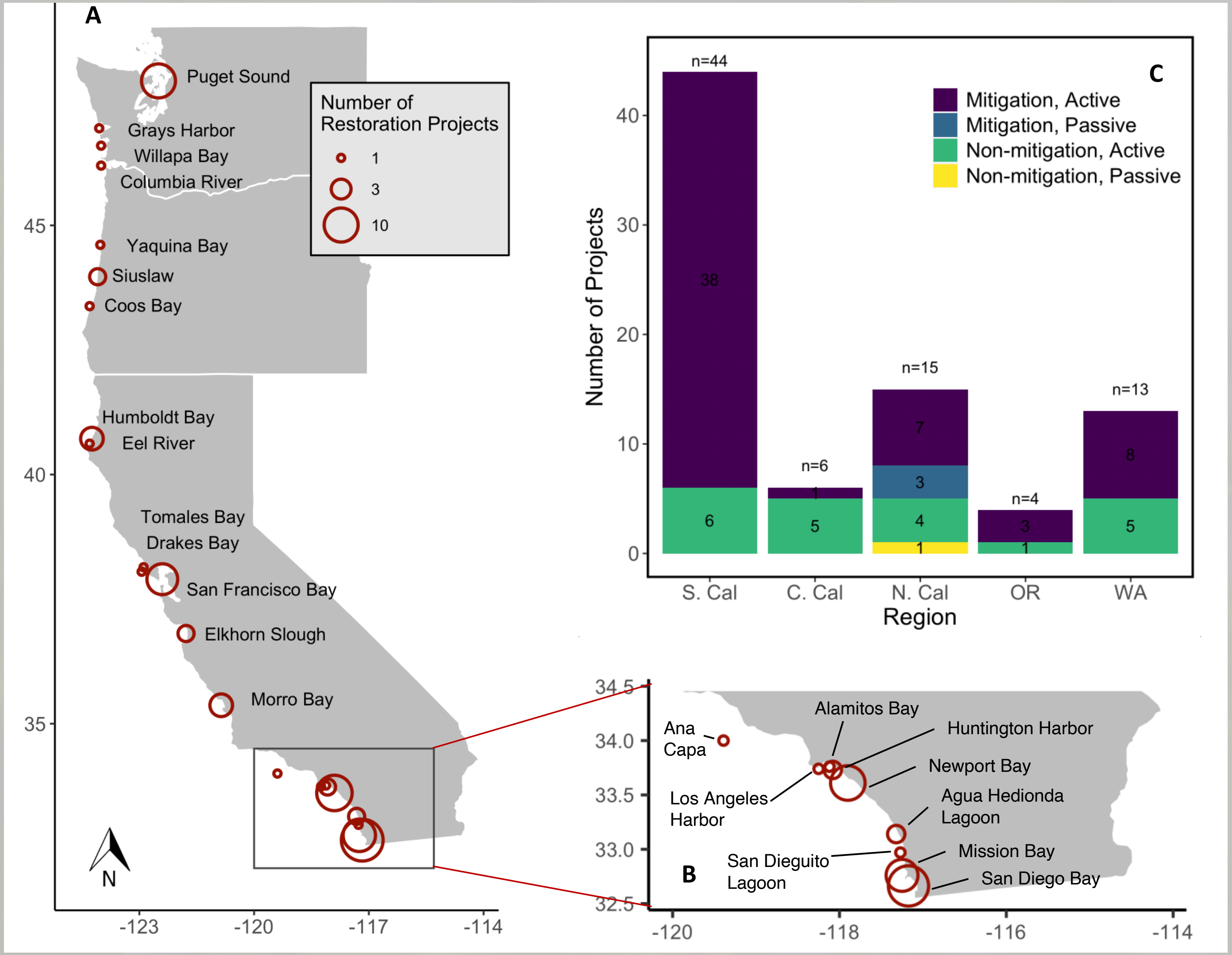
U.S. has long history of seagrass restoration:

Earliest US project in the 1940s

Earliest West Coast project – 1964, Puget Sound

32% – 60% of restored plots failed by project end

- 82 eelgrass restoration projects (1989 – 2020, largely for mitigation
- Very few projects are robustly monitored or published (6 of 82 in the peer-review).
- Mixed results of success



SUCCESS: WHAT'S IN A NAME?

- Does structural success = functional success?
  - 18 of 82 projects evaluated recovery of any function, the vast majority of which were biological functions (Almost no measurement of carbon functions)
  - Varying metrics, methodologies, and reporting prevent cross-comparisons

- How long must a seagrass meadow persist to qualify as restoration success?
  - Success 'for whom'? A juvenile lobster? Or a carbon offset project?
  - Carbon 'functions' could be slow to recover
  - Consideration of seascape/patch dynamics



Restoration is expensive: How do we finance these goals?

Traditional finance: Grants, NGO support, mitigation

- Support biodiversity & fisheries
- Stabilize sediments
- Enhance water quality
- OA amelioration
- Carbon burial in sediment

PLAN VIVO
For nature, climate and communities

Biodiversity Credits?

Verified Carbon Standard

Carbon Credits

Emerging Markets?

Not all restoration approaches are created equally. (What function are you aiming to maximize?)

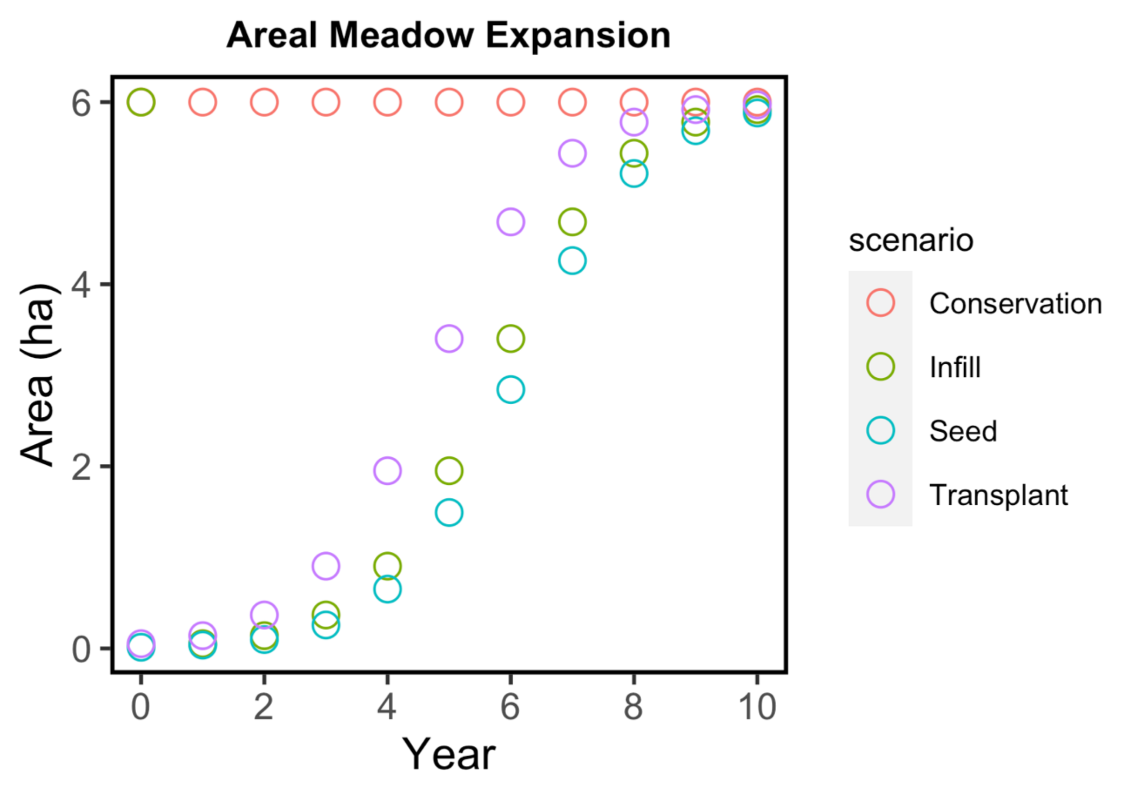
1) Vegetation planting
2) Tidal reconnection/hydrologic restoration
3) Reduced subsidence
4) Sediment management (thin layer placement/beneficial use of dredge material)
5) Conservation (with varying baselines)

California Delta:
In the ~6,000 years prior, about 5 billion m^3 of tidal marsh sediment accumulated in the Delta. In the recent ~150 years, half of this volume is gone, leaving an accommodation space of > 2 billion m^3 below sea level that can be filled by flood waters. (Deverel & Leighton, 2010)

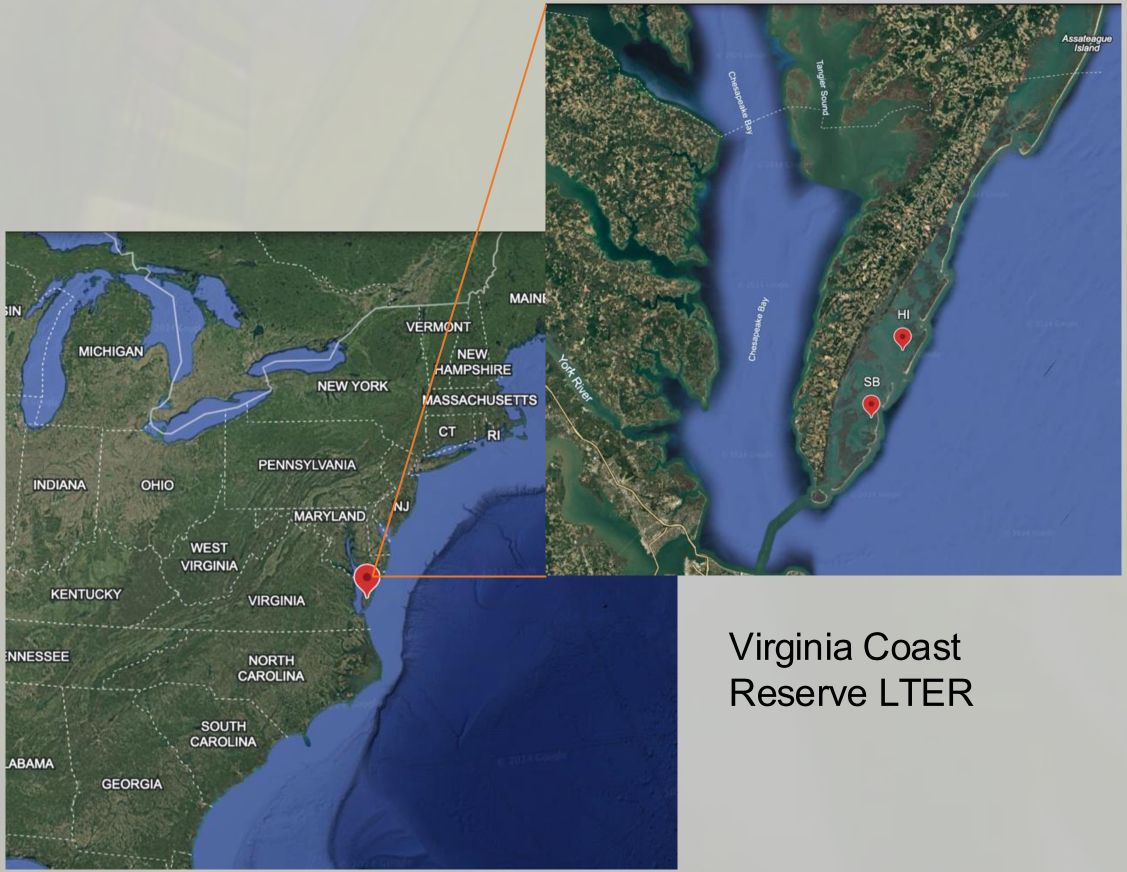
"Management Approach Matters: Meeting Seagrass Recovery and Carbon Mitigation Goals"

1) Model constructed based on a seagrass meadow (logistic growth) under four management approaches: Transplant, seeding, sediment infill, conservation (avoided loss).

2) Use Virginia LTER data for carbon stocks, accumulation rates, biomass and methane and N_2O ("Base" model simulation)



Nature: Ocean Sustainably (Ward et al.; In Press)



Virginia Coast Reserve LTER

Carbon Credits – Are They Worth It?

How much revenue could a project generate?

Ranges reflect two carbon prices: $30 and $70 per tonne:

Scenario	Net carbon gains (MT CO_2eq/Ha)	Revenue ($USD)/Ha	Revenue ($USD): 6 Ha Project	Revenue ($USD): 100 Ha Project
Conservation	219.1	$6,573 - $15,337	$39,438 - $92,022	$657,297 - $1,533,693
Infill	100.7	$3,022 - $7,052	$18,133 - $42,311	$302,225 - $705,196
Seed	6.6	$198 - $462	$1,189 - $2,775	$19,818 - $46,242
Transplant	8.1	$244 - $569	$1,464 - $3,417	$24,406 - $56,946

Over ten years, a seagrass project could generate:

- $20k to $1.5 million in carbon credits (100 ha)
- $1.2k to $92k (6 ha)
- Excluding project implementation costs

Context: ~40 ha of eelgrass were restored in the last 13 years of ongoing restoration in San Francisco Bay

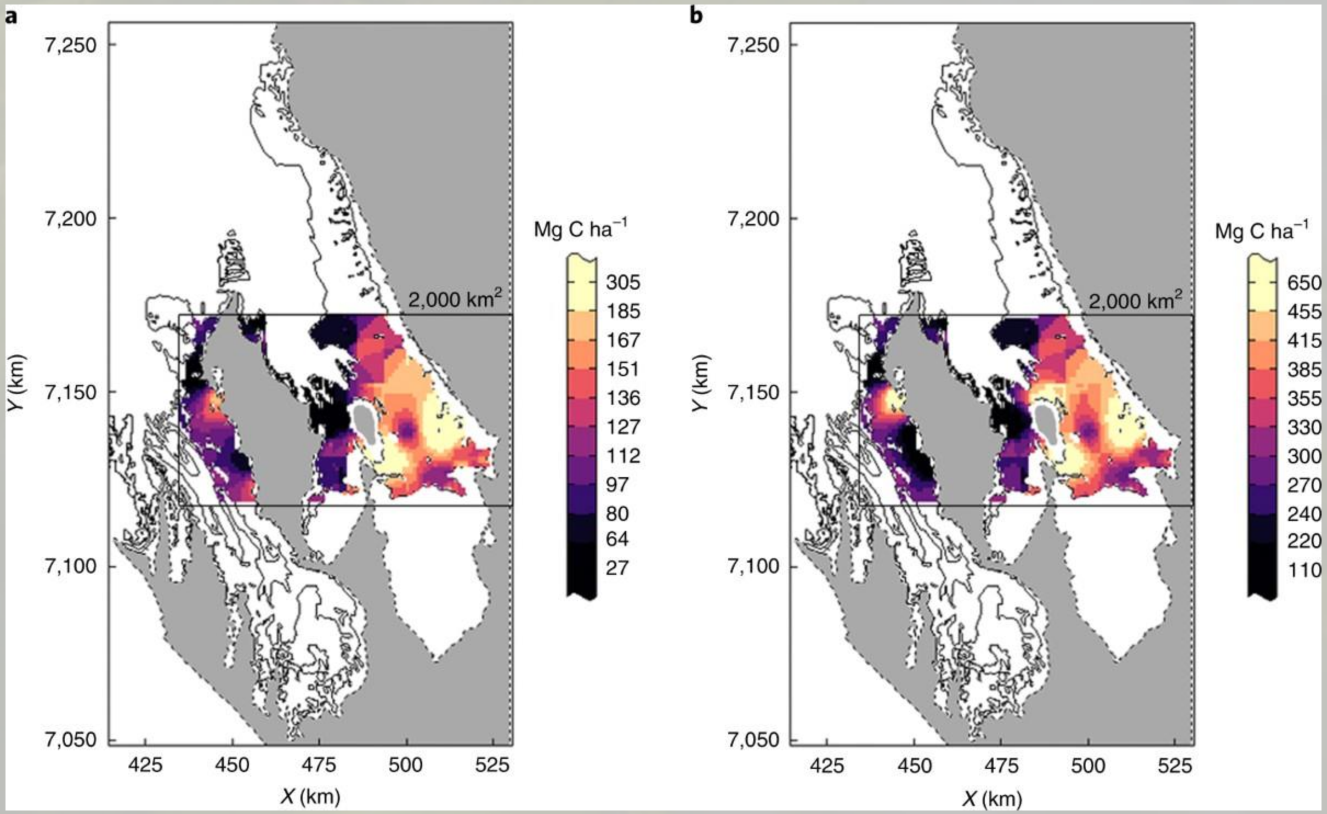
What do these values tell us?

- Restoration that also incorporates sediment management can lead to higher carbon benefits.

- Conservation is essential

- Carbon credits are unlikely to cover the full project costs of most seagrass restoration projects

Arias-Ortiz et al. (2018): A marine heatwave drives massive losses from the world's largest seagrass carbon stocks

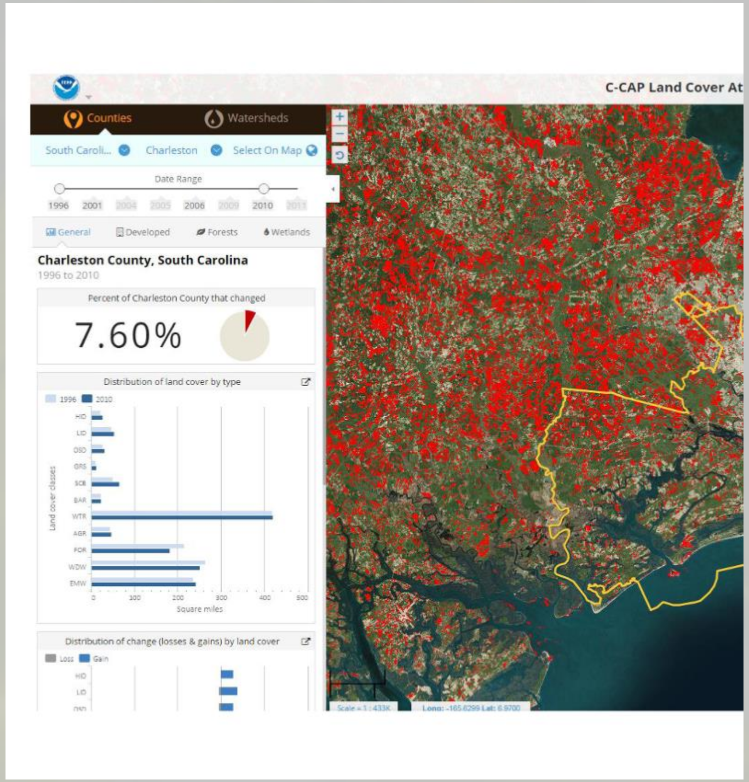


Science Gaps: Blue Carbon & Habitat Management

- Lateral fluxes
  - Particularly relevant for carbon accounting/credit systems

- Mapping and monitoring
  - Mapping can be a challenge in subtidal habitats
  - Limited state-wide regular monitoring – how to track progress against goals?

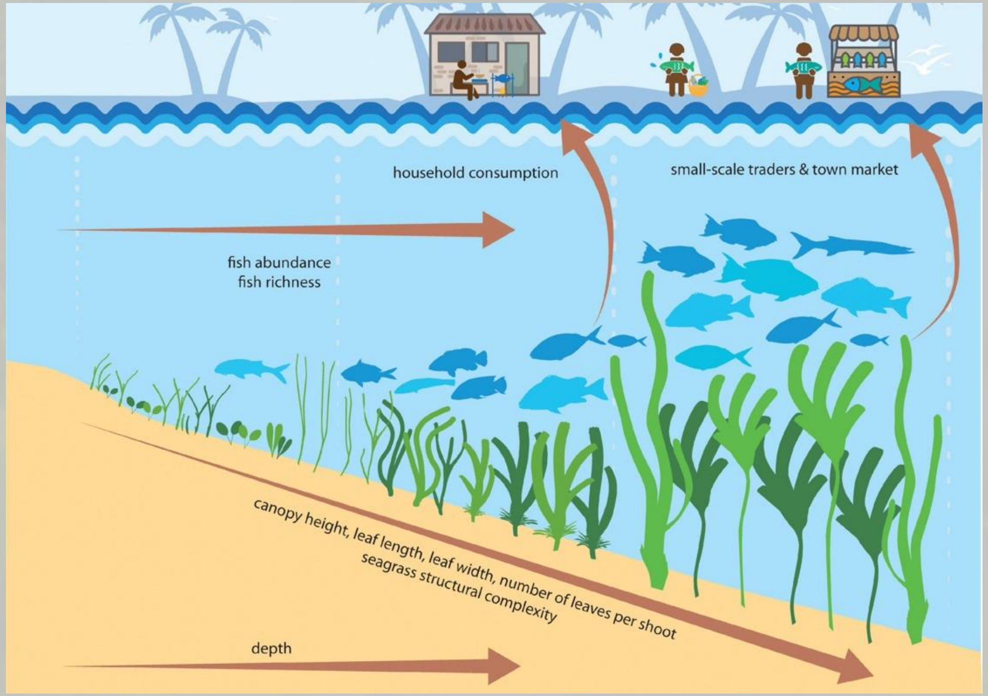
- Modeling
  - Scaling from projects to larger regions, and into the future relies on advanced models



Example of NOAA C-CAP land use change mapping products. (https://coast.noaa.gov/digitalcoast/tools/lca.html)

Science Gaps: Blue Carbon & Habitat Management

- Emissions factor development
  - More system and activity-specific data will improve tools and estimates of GHG benefits.
- Alkalinity, inorganic carbon
  - An unaccounted-for blue carbon benefit?
- Rate of functional return following restoration?
- Novel habitats
  - Tidal swamps, mudflats, seaweed



Seagrass Structural Traits Drive Fish Assemblages in Small-Scale Fisheries (Jones et al. 2021).

Carbon functions?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THANK YOU
QUESTIONS?
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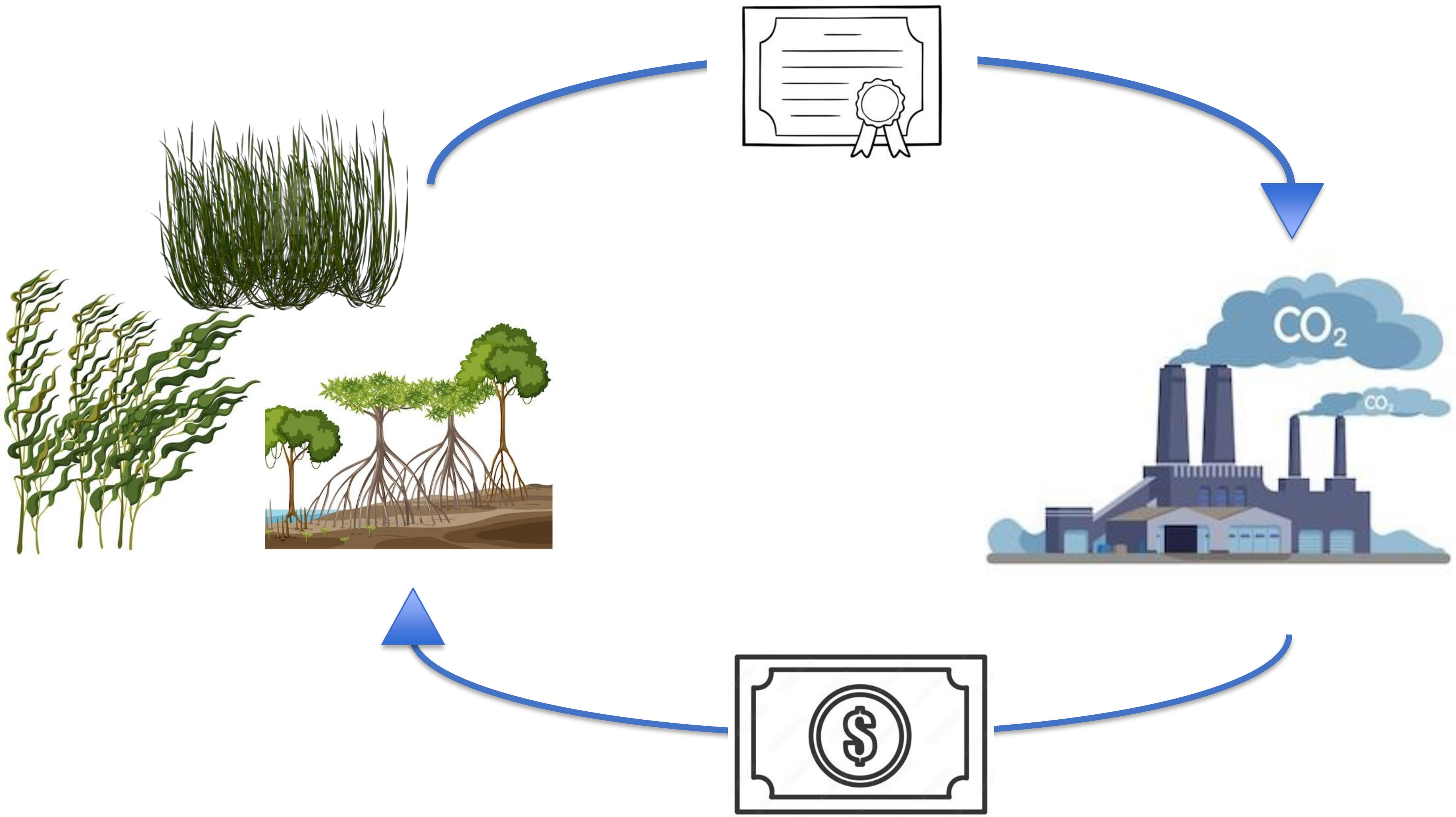
Nature-based Solutions and the Voluntary Carbon Market



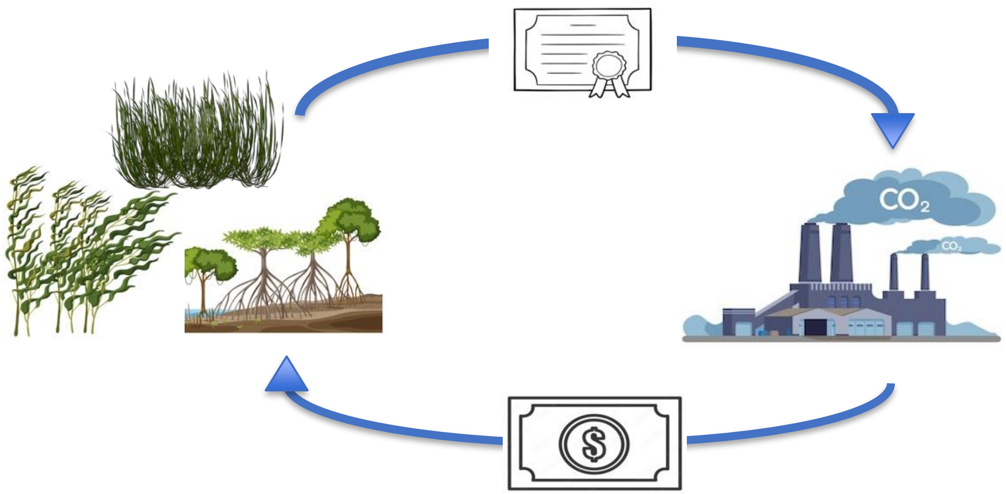
Participants and steps in the VCM

How are local beneficiaries/ communities involved?

Who verifies and issues the credits?

By what standard and methodology is the project conducted?

Who writes these methodologies?



How do companies/govts (etc.) find eligible carbon projects?

Who implements the project?

And many more…

Can all restoration projects benefit from carbon finance?

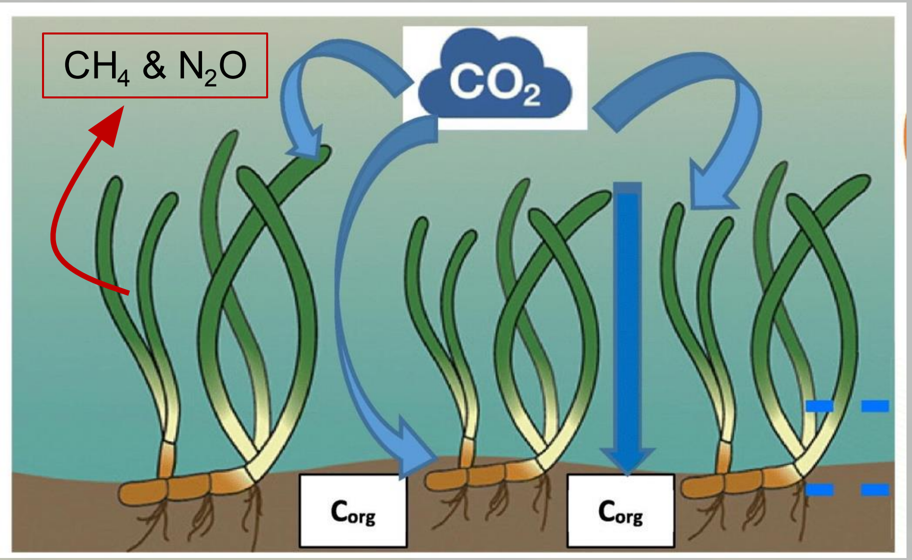
How much carbon can a seagrass meadow sequester annually?

Must account for:

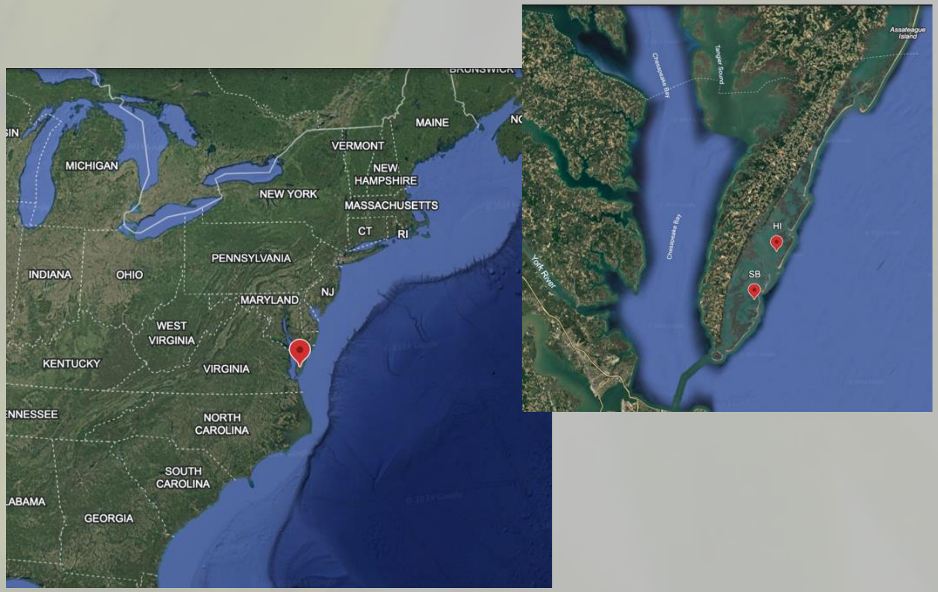
- OC sequestered in <u>sediment</u>
- OC is sequestered in <u>biomass</u> (net)
- <u>Nitrous oxide</u> and <u>methane</u> emissions
- (<u>CO_2 emissions</u> from project implementation)

This all must be considered *relative to a baseline or business-as-usual* scenario ($C_{net} = C_{MGMT} - C_{BAU}$).

For seagrass meadows, very few projects measure all these parameters relative to a baseline, and associated with restoration → Virginia Coast Reserve LTER



Adapted from Suwandhahannadi et al. 2024



Nature: Ocean Sustainably (Ward et al; In Press)

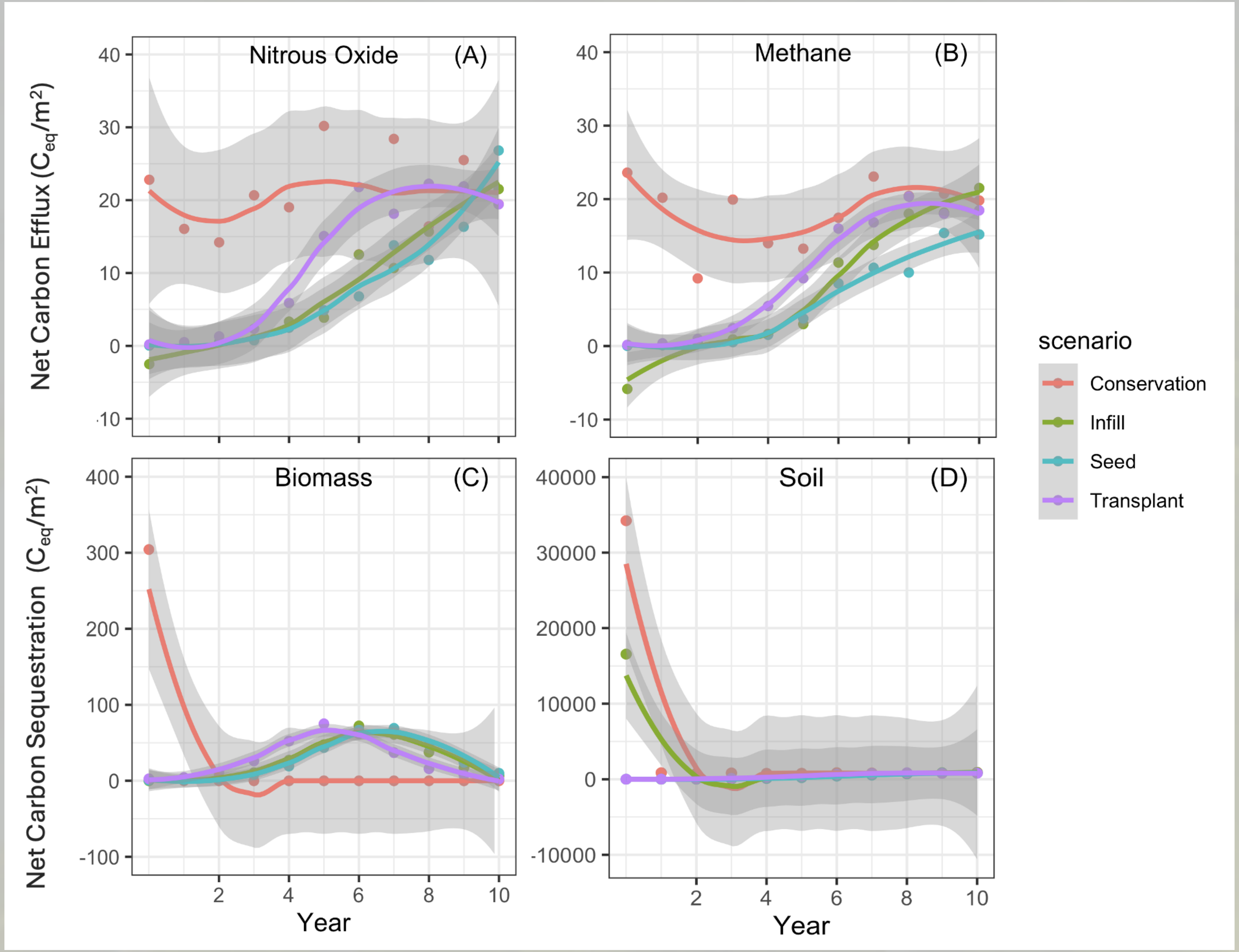
“Management Approach Matters: Meeting Seagrass Recovery and Carbon Mitigation Goals”

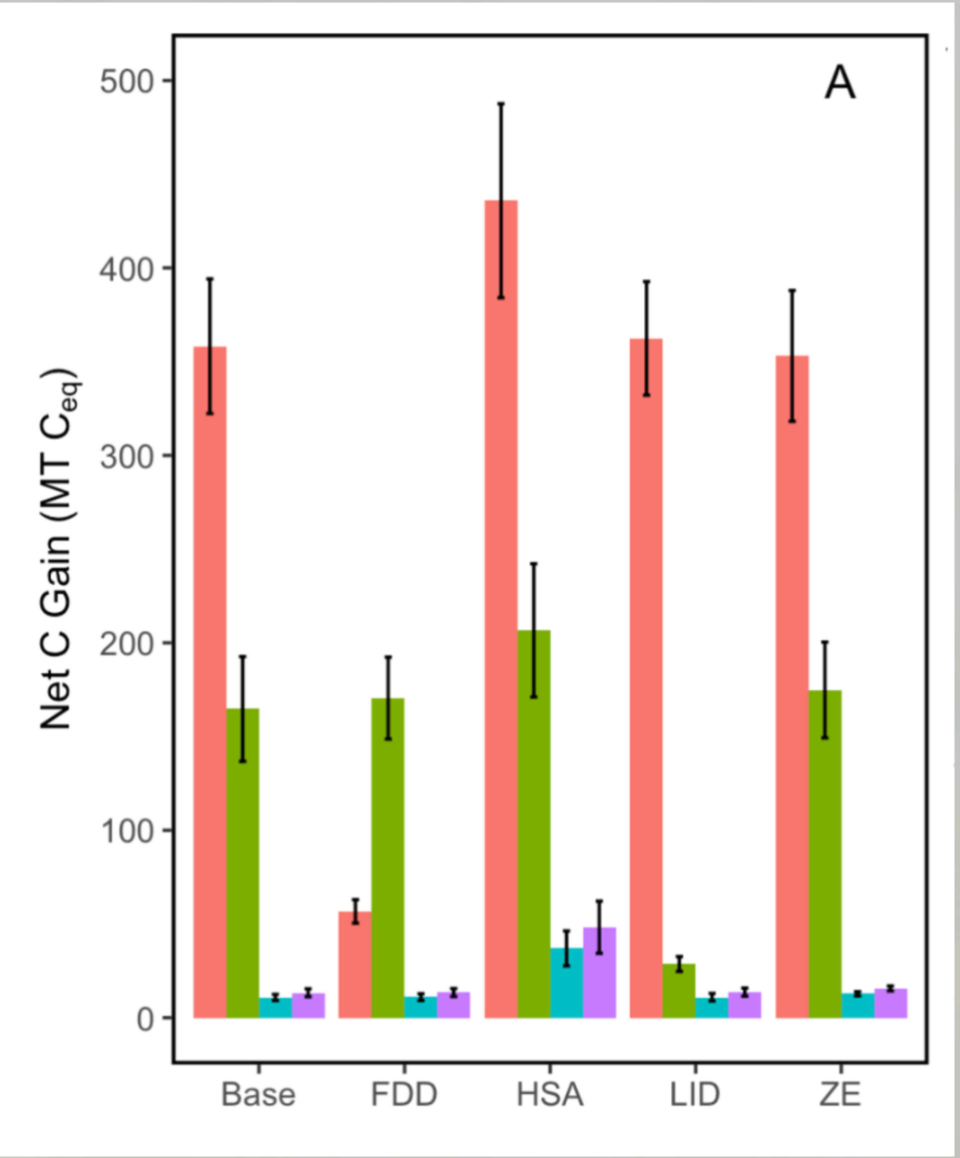
3) Alter key parameters to understand range of outcomes

Model simulation name	Input parameter changes
Base (B)	Virginia LTER
Zero Emissions (ZE)	C_{CH4} & C_{N2O} = 0 (No difference in CH_4 & N_2O emissions between vegetated and unvegetated sites.
High Sediment Accumulation (HSA)	$\rho_{veg} = 138 \pm 38$ g C m^{-2} yr^{-1}
Low Infill Depth (LID)	d_{infill} = 0.1m (apply a thinner layer of sediment addition)
Fishery Dredge Depth (FDD)	d_{dredge} = 0.1m (dredge to 0.1m, rather than 1m)

- CH_4 and N_2O emissions may be negligible
- Global sediment accumulation averages are higher than those recorded in Virginia
- Sediment placement and dredge/sediment loss depths can be highly variable

Results





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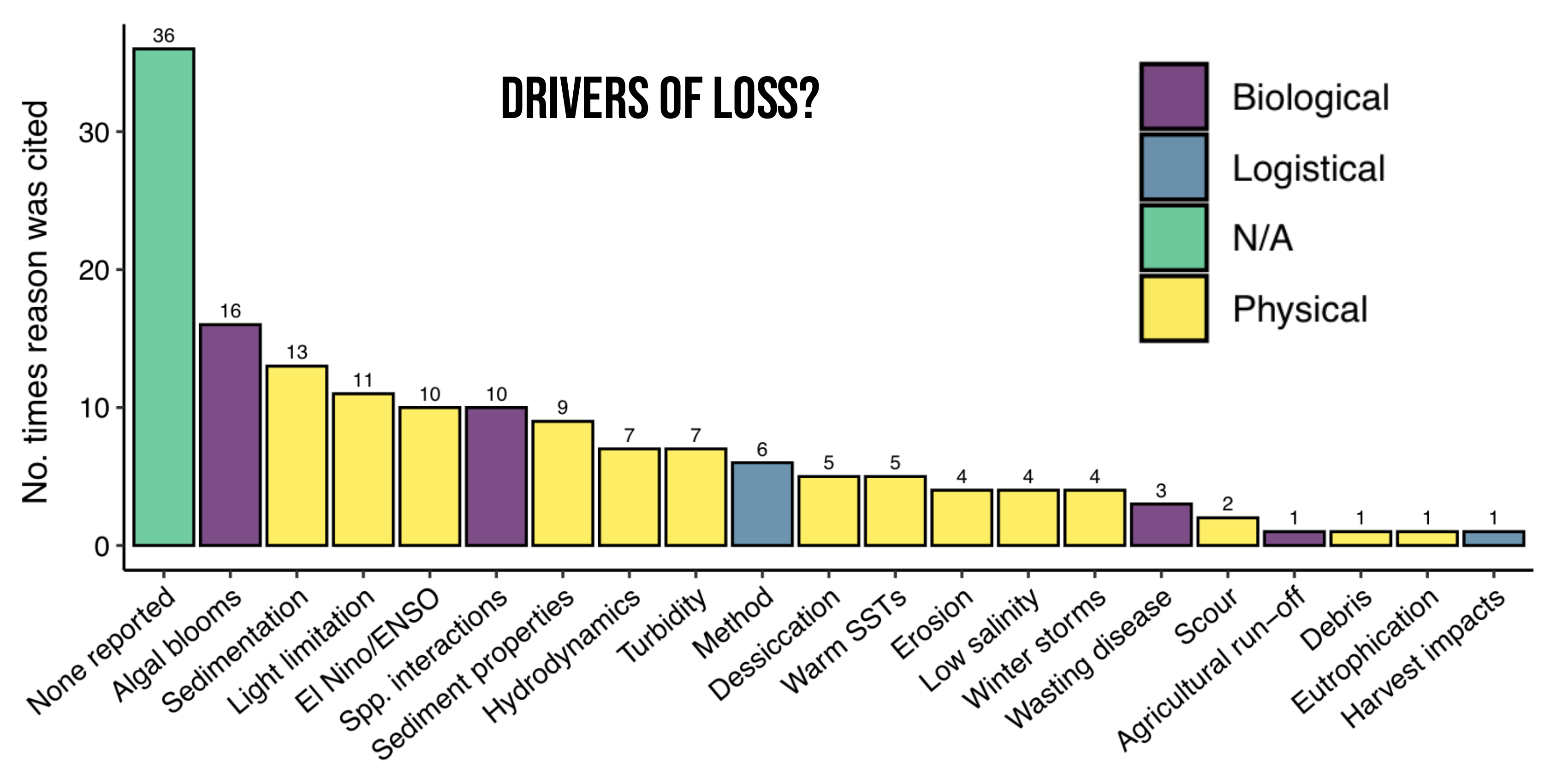
Base model input (Virginia LTER)

Parameter	Variable ID	Habitat Type	Mean	Error (SE)	Units	Data Source
Sediment (accumulation)	$\rho_{Sed,veg}$	Vegetated	36.68	2.79	g C_{eq} $m^{-2}yr^{-1}$	Greiner et al. 2013
Sediment (accumulation)	$\rho_{Sed,unveg}$	Unvegetated	0	0	g C_{eq} $m^{-2}yr^{-1}$	Greiner et al. 2013
[1]Sediment (stock)	$\delta_{Sed,veg}$	Vegetated	5578	454	g C_{eq} m^{-3}	McGlathery et al. 2012
[1]Sediment (stock)	$\delta_{Sed,unveg}$	Unvegetated	2774	404	g C_{eq} m^{-3}	McGlathery et al. 2012
Biomass	$\rho_{Biomass,veg}$	Vegetated	49.4	12.21	g C_{eq} m^{-2}	McGlathery et al. 2012
Biomass	$\rho_{Biomass,unveg}$	Unvegetated	0	0	g C_{eq} m^{-2}	McGlathery et al. 2012
Methane	$\rho_{CH4,veg}$	Vegetated	4.58	3.03	g C_{eq} $m^{-2}yr^{-1}$	Oreska et al. 2020
Methane	$\rho_{CH4,unveg}$	Unvegetated	0.57	0.40	g C_{eq} $m^{-2}yr^{-1}$	Oreska et al. 2020
N_2O	$\rho_{N2O,veg}$	Vegetated	5.07	3.38	g C_{eq} $m^{-2}yr^{-1}$	Oreska et al. 2020
N_2O	$\rho_{N2O,unveg}$	Unvegetated	1.69	0.85	g C_{eq} $m^{-2}yr^{-1}$	Oreska et al. 2020
Dredge depth	d_{dredge}	Vegetated	-1	NA	m	Van Maren et al. 2015; Howarth and Stewart, 2014.
Sediment layer depth	d_{infill}	Unvegetated	1	NA	m	Merkel, 2010; Flindt et al. 2022
Remineralization (%)	r_{remin}	Unvegetated	50	NA	%	De Borger et al. 2021; Graca et al. 2004

Site selection likely more important than restoration method: choose wisely



Algal blooms (n=16), sedimentation (n=13), and light (n=13)
are key drivers of loss
(stressors can be intertwined)

Mixed results of seagrass restoration success: 32%–60% of restored plots failed by project end

Varying definitions of 'success'

- Practitioner-defined success
  → 65% of plots had no definition of success
  → Of those that did, 51%–58% succeeded

- Final shoot density ≥ transplanted shoot density
  → 68% of plots were successful

- Final plot area ≥ transplanted plot area
  → Couldn't be evaluated in 64% of plots (no final area)
  → 40% of plots were successful

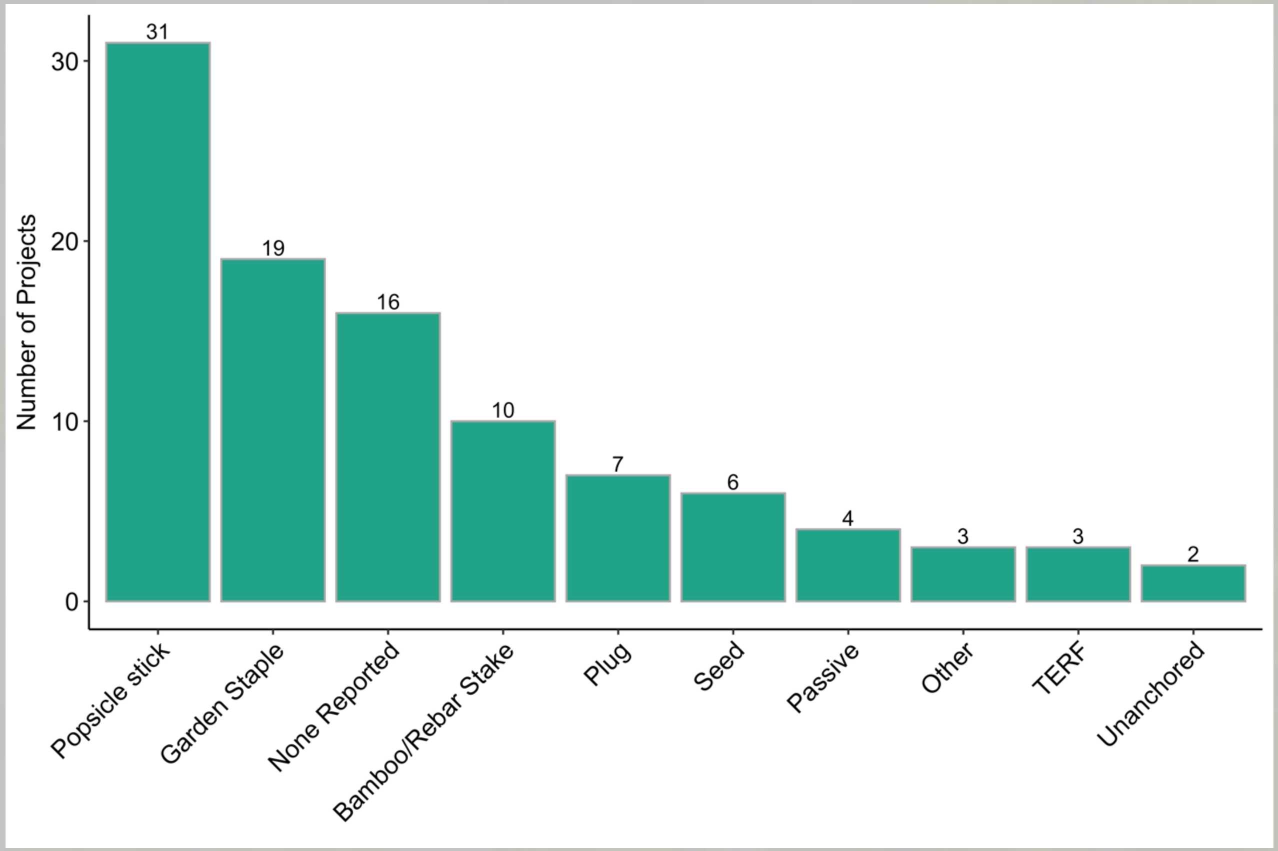
CAN WE USE THIS HISTORY TO REACH TARGETS AND RECOVERY GOALS?

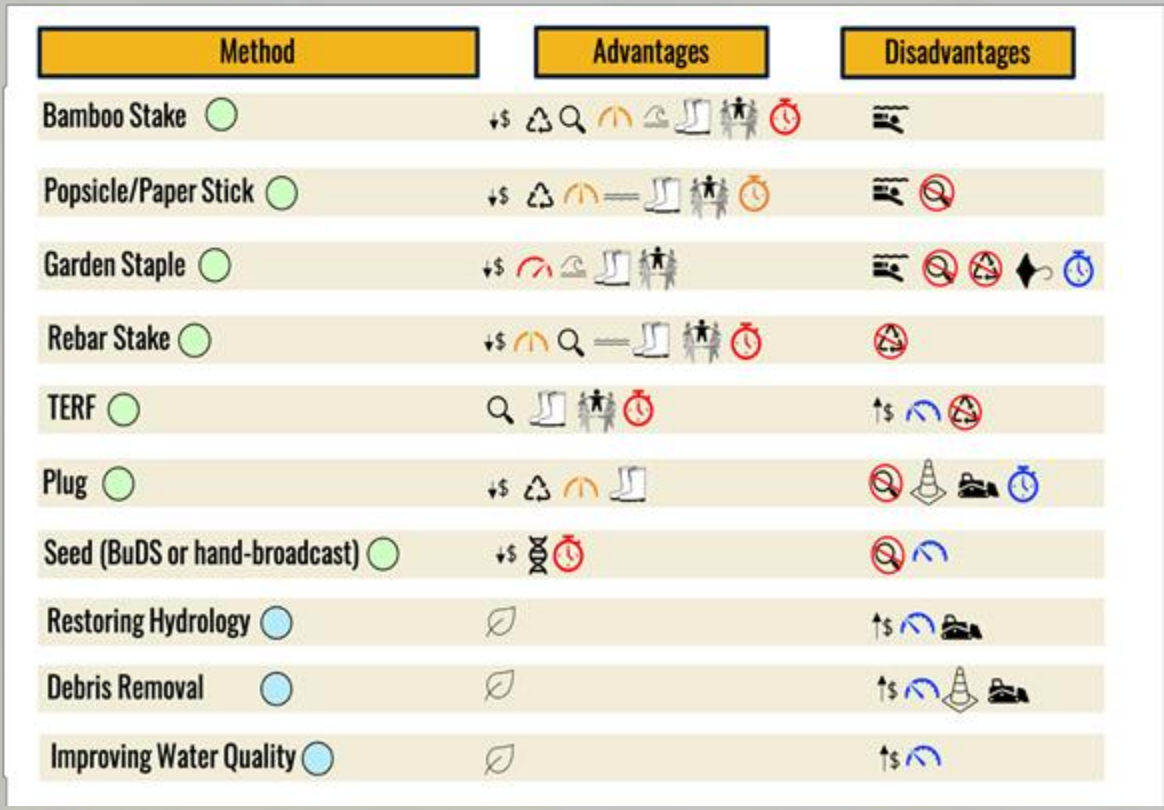
- Mixed reviews of success from West coast; regional losses? (Merkel (1998); Stamey (2004); Thom (1990); Fonseca (1998)
- Technical reports (not peer reviewed)
- Thom (1990): need a "clearinghouse" of eelgrass restoration results and standardization of techniques
- Thom et al. (2008): nearly identical needs— a review of existing projects, lessons learned, recommendations for standardization

Meta-analysis goals:

1. Summarize applied restoration approaches and attributes (e.g., methods, mitigation ratios, monitoring)
2. Define and evaluate restoration success
3. Lessons learned from these efforts to improve future seagrass restoration

HOW IS RESTORATION BEING CONDUCTED?





DIRECT TRANSPLANT USING SHOOT ANCHORING TECHNIQUES ARE MOST COMMON

MITIGATION PROJECTS ARE MONITORED LONGER & TRANSPLANTED AT LOWER DENSITIES

- PROJECT LENGTH
  - MITIGATION (N=60): 4.5 (±0.7) YEARS
  - NON-MITIGATION (N=22): 1.5 (±0.4) YEARS
- TRANSPLANT DENSITY:
  - MITIGATION: 16.5 (±3.4) SHOOTS/M^2
  - NON-MITIGATION: 53 (±10) SHOOTS/M^2
- AVG. APPLIED MITIGATION RATIO OF 3:1 (ABOVE TYPICALLY REQUIRED RATIO)

WHAT CAN WE LEARN FROM THIS?

→ MITIGATION REQUIREMENTS HELP ENSURE LONG-TERM (~5 YR.) MONITORING

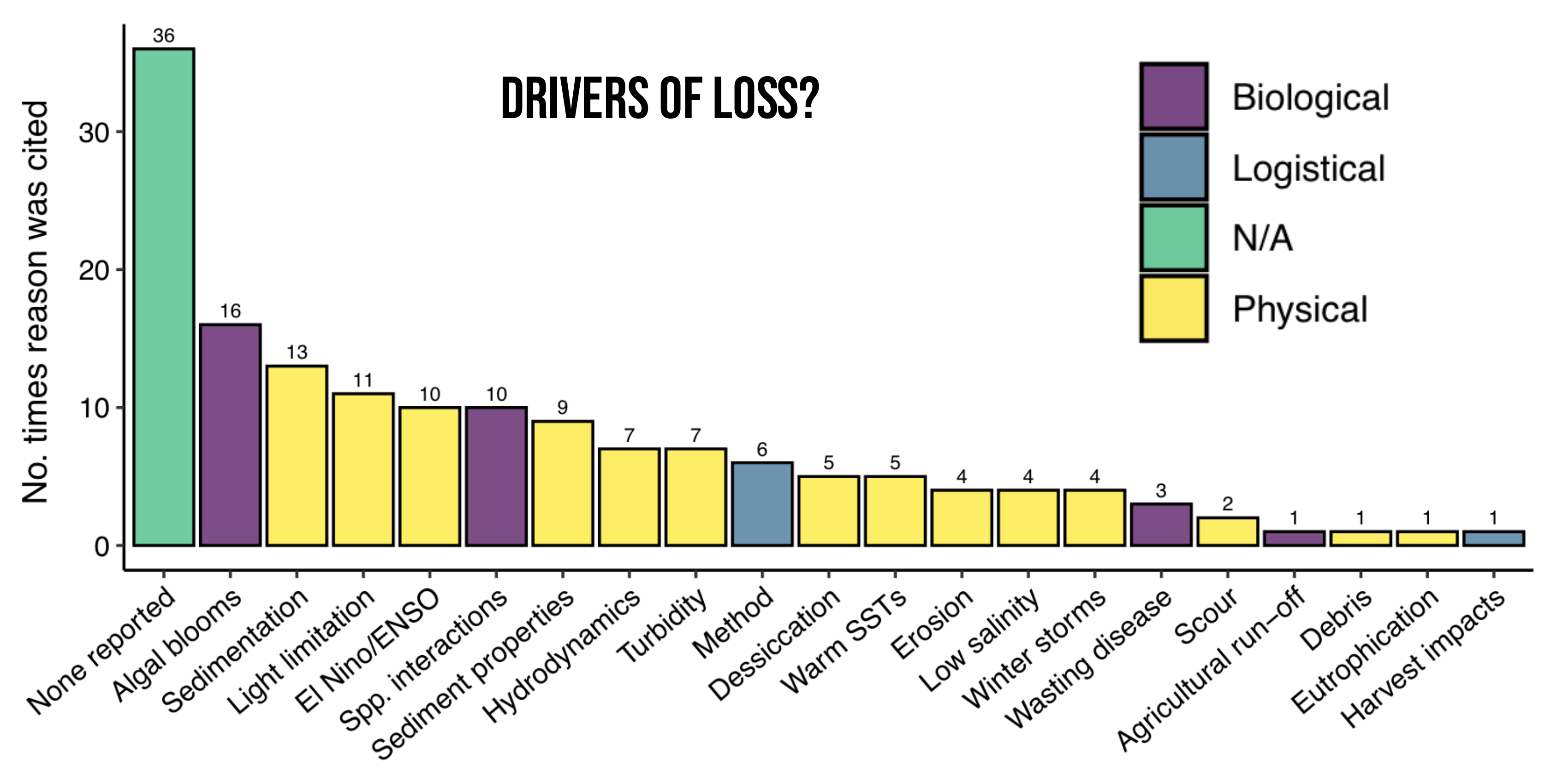
→ IMPLICATIONS OF A 'HIGHER THAN REQUIRED' RATIO?

→ WHAT SHOOT DENSITIES SHOULD BE APPLIED?

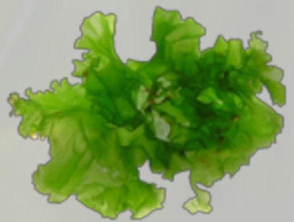
EFFECT OF TRANSPLANTING AT HIGHER RELATIVE DENSITIES LASTS ~6 MONTHS (BUT NOT LONGER).

Photo: K. Beheshti

SITE SELECTION LIKELY MORE IMPORTANT THAN RESTORATION METHOD: CHOOSE WISELY



ALGAL BLOOMS (N=16), SEDIMENTATION (N=13), AND LIGHT (N=13)
ARE KEY DRIVERS OF LOSS
(STRESSORS CAN BE INTERTWINED)



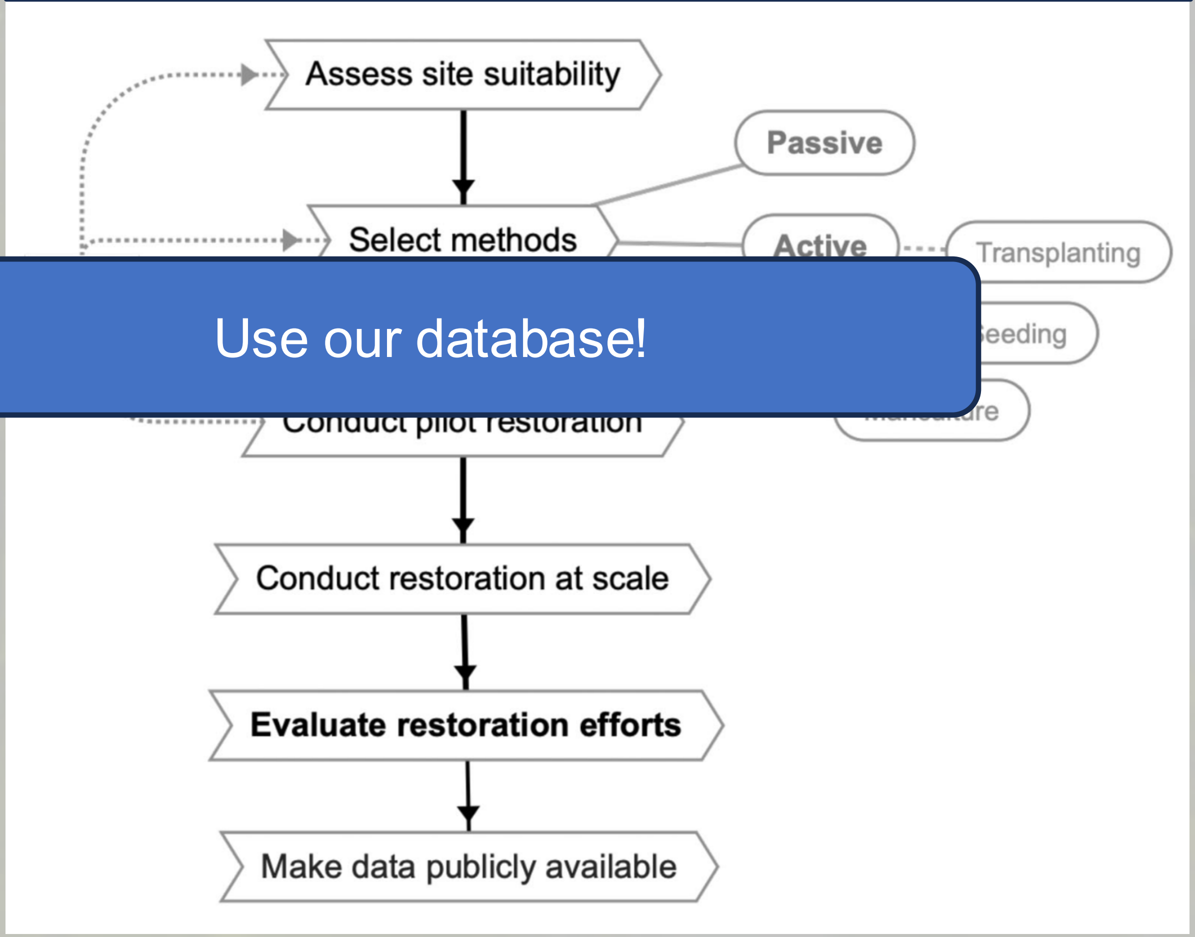
FAILING FORWARD: IMPROVING WEST COAST RESTORATION

1) Use standard, best-practice approaches to restoration – including sharing and publishing data/outcomes

2) Consider functional recovery

3) Consider the role of policies and cohesive monitoring in a future climate - how we will track and respond to non-point source stressors?

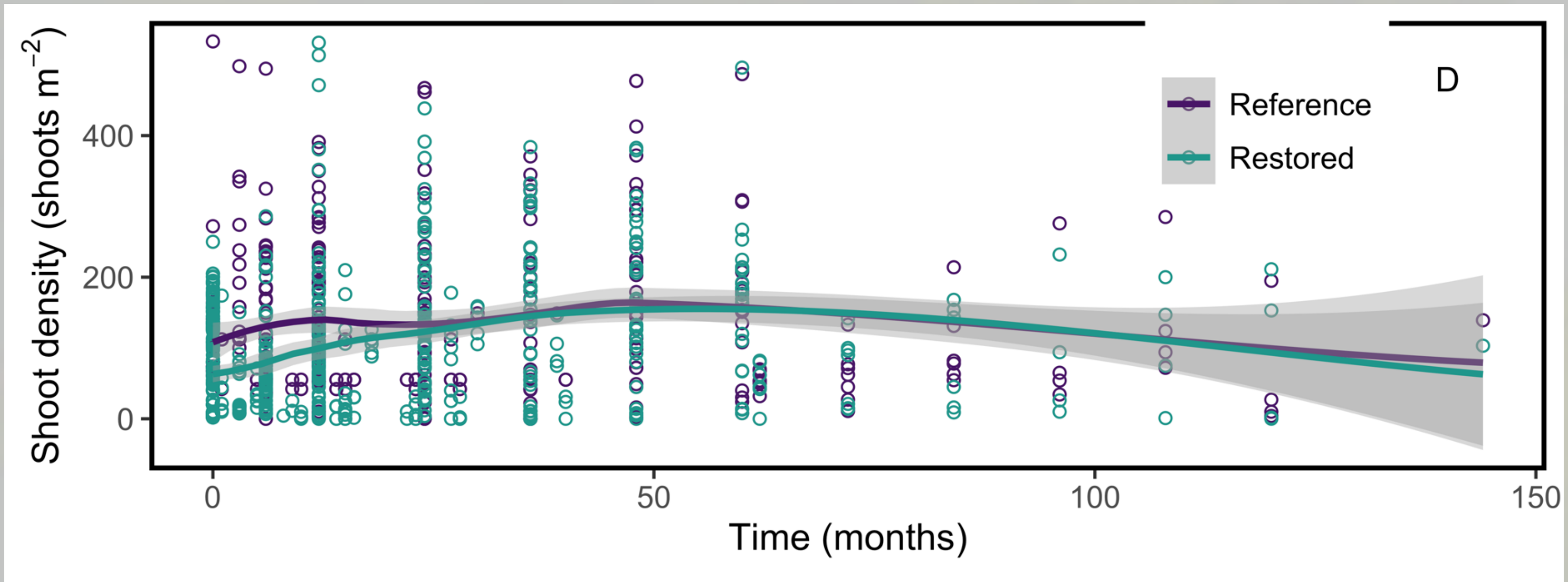
Recommended Approach

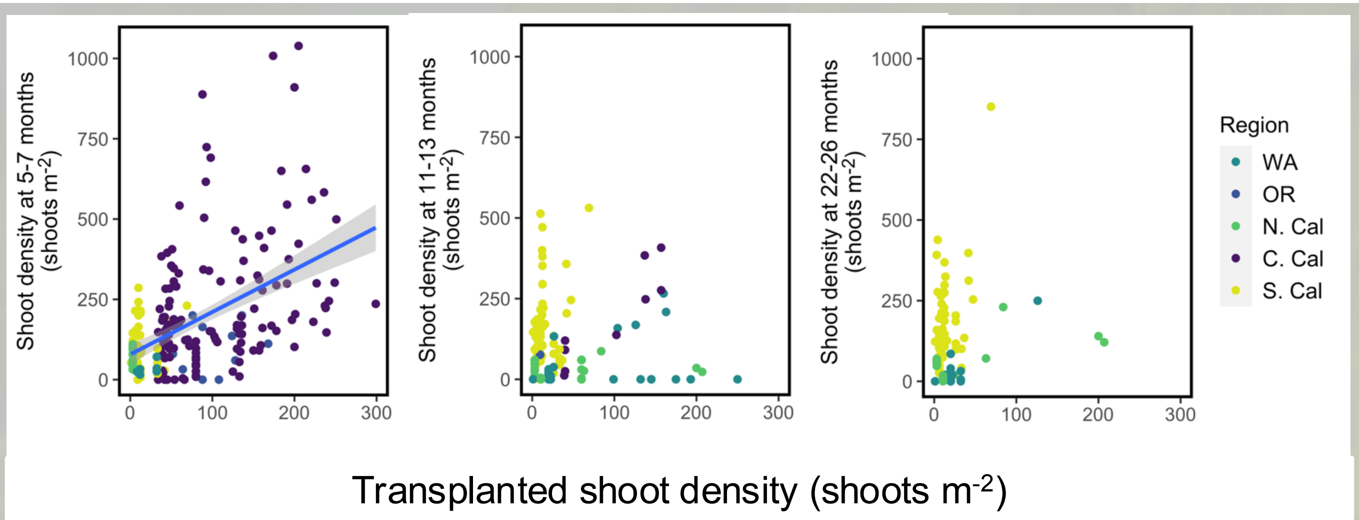


Use our database!

WITH ASPIRATIONAL HABITAT GOALS, AND AN INCREASING NEED FOR RESILIENCE, FAILURE IS COSTLY.

EFFECT OF TRANSPLANTING AT HIGHER RELATIVE DENSITIES LASTS ~6 MONTHS





DOES TRANSPLANTING AT HIGHER SHOOT DENSITIES LEAD TO GREATER SHOOT DENSITIES 6, 12, OR 24 MONTHS AFTER RESTORATION? → GENERALIZED LINEAR MODEL

<u>IMPLICATIONS:</u>

- CONSIDER TIMESCALE OF RESTORATION MONITORING (BEYOND 6 MONTHS)
- CONSIDER INVESTMENT/ENERGY AND IMPACT TO DONOR MEADOWS

Photo: K. Beheshti