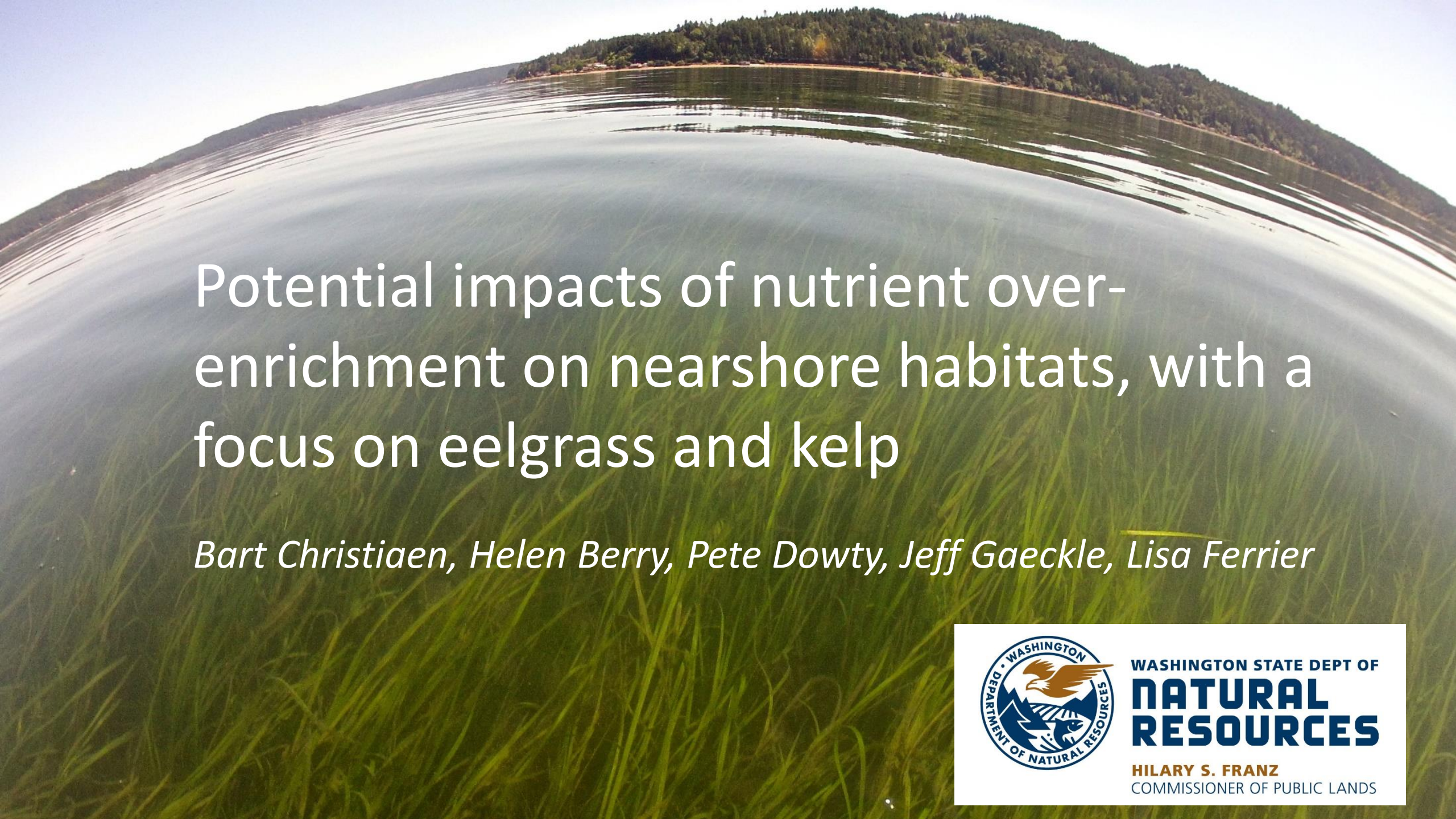
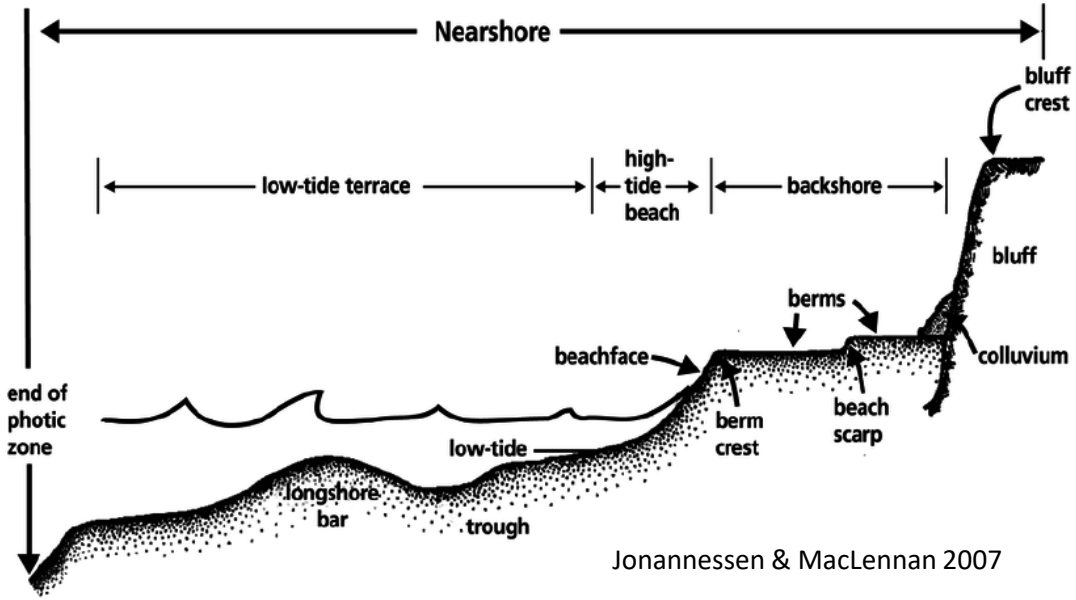


Potential impacts of nutrient over-enrichment on nearshore habitats, with a focus on eelgrass and kelp

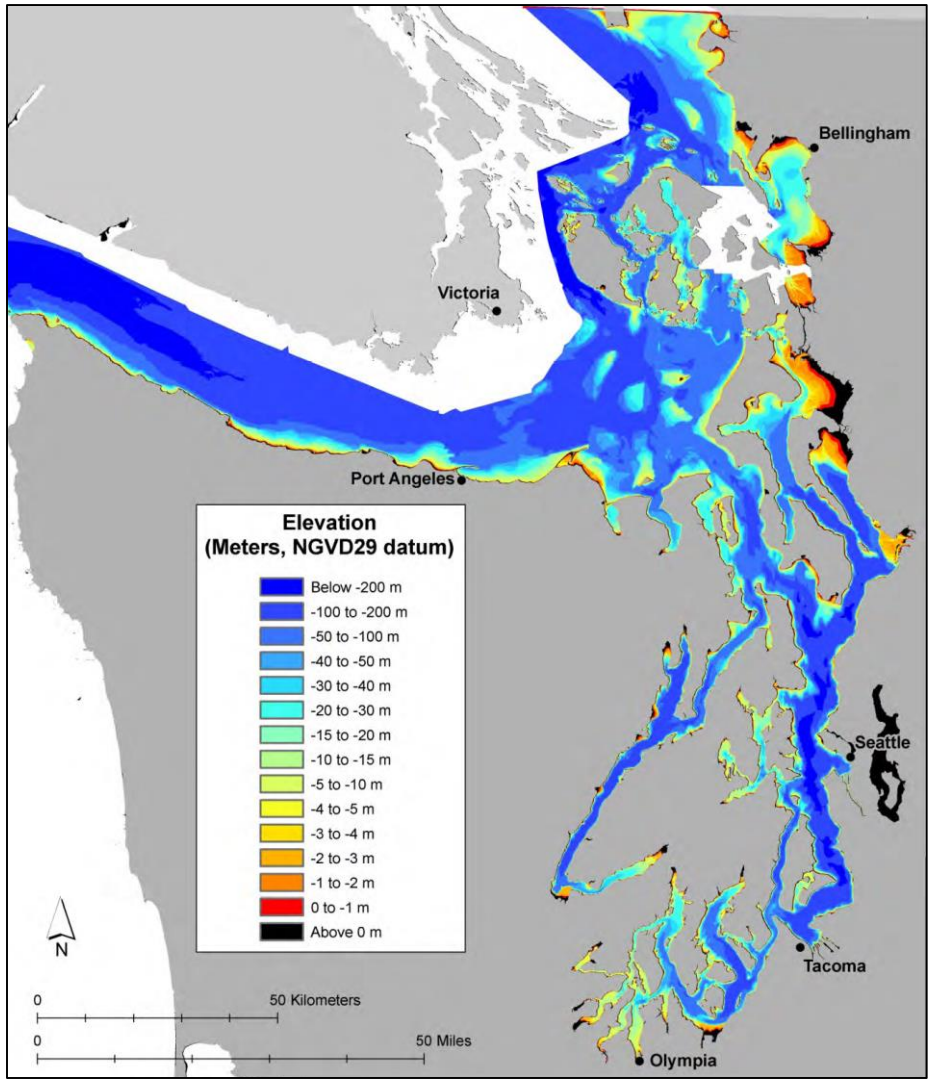
Bart Christiaen, Helen Berry, Pete Dowty, Jeff Gaeckle, Lisa Ferrier

WASHINGTON STATE DEPT OF
NATURAL RESOURCES
HILARY S. FRANZ
COMMISSIONER OF PUBLIC LANDS

The nearshore environment



Jonannessen & MacLennan 2007

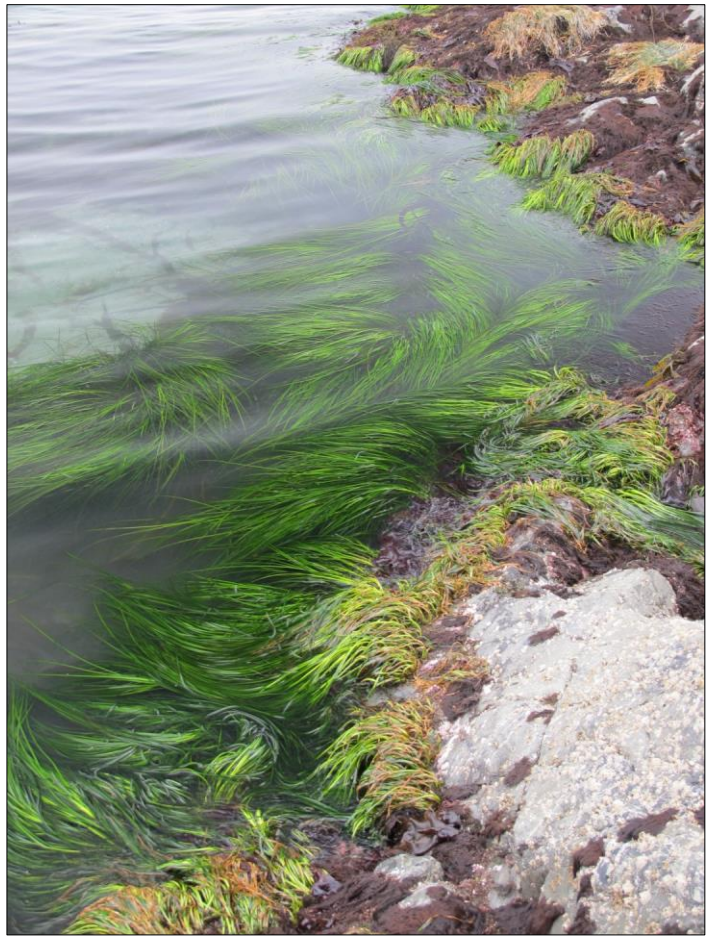


- High tide line to end of photic zone
- Most of Puget Sound: narrow band
- Diverse community of plants and algae

Diversity

Seagrass species in Washington State

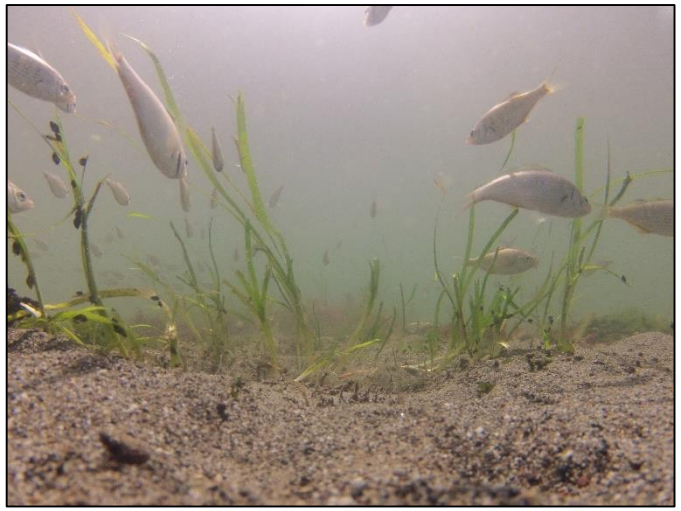
Eelgrass (*Zostera*)



Surfgrass (*Phyllospadix*)

Importance

Important but vulnerable



- Habitat for a wide range of organisms
- Fuels the detrital foodweb
- Sensitive to nutrient over enrichment

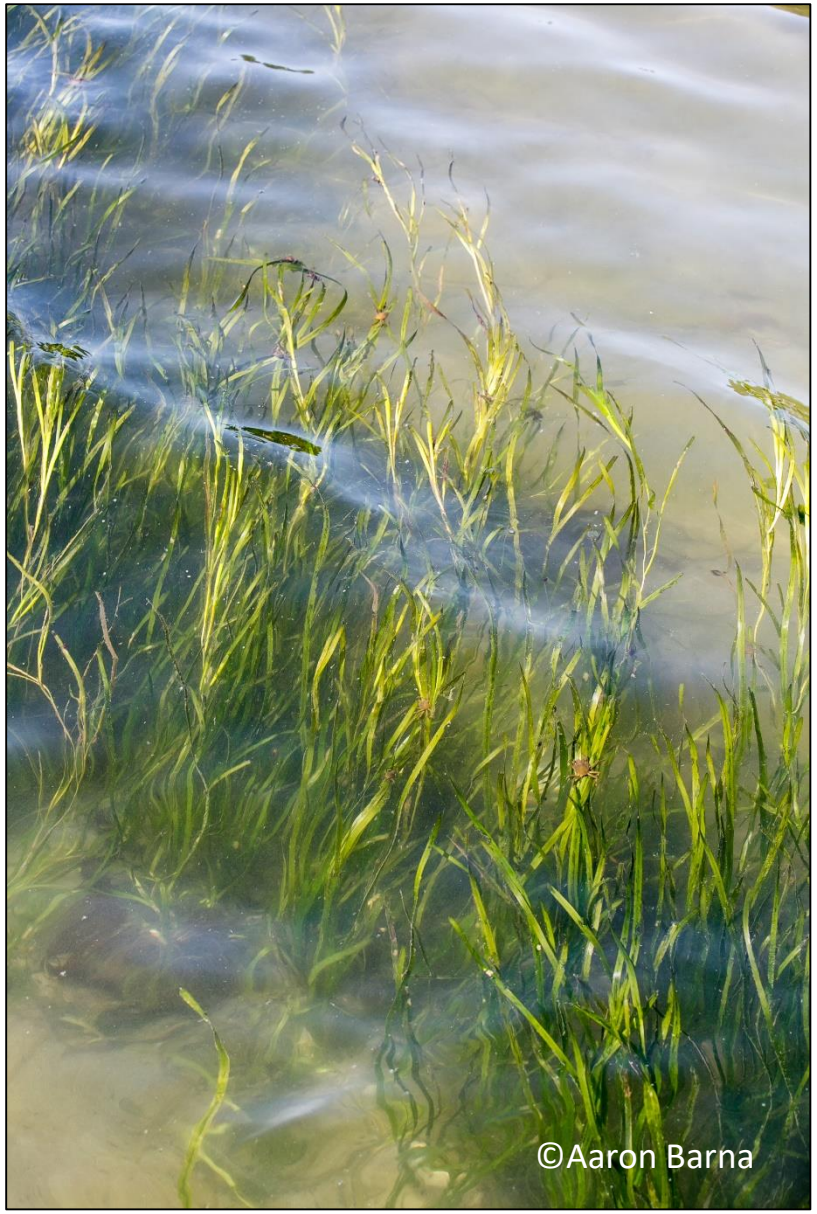
Physiological response to high water column NO_3^-

Zostera marina evolved in N poor conditions: no product inhibition feedback for nitrate uptake and assimilation

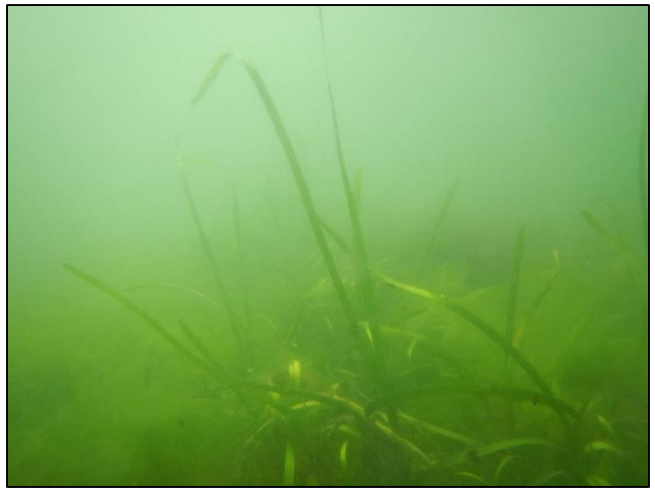
NO_3^- assimilation to amino acids is metabolically "expensive".

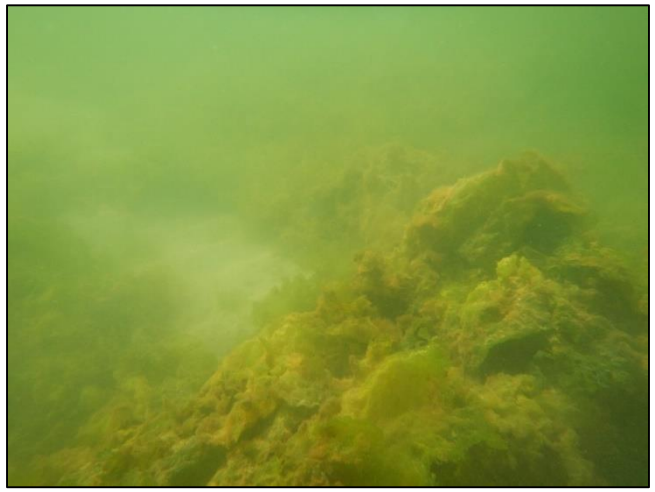
High water NO_3^- concentrations over extended periods of time: eelgrass becomes internally C-limited

Lower productivity and survival



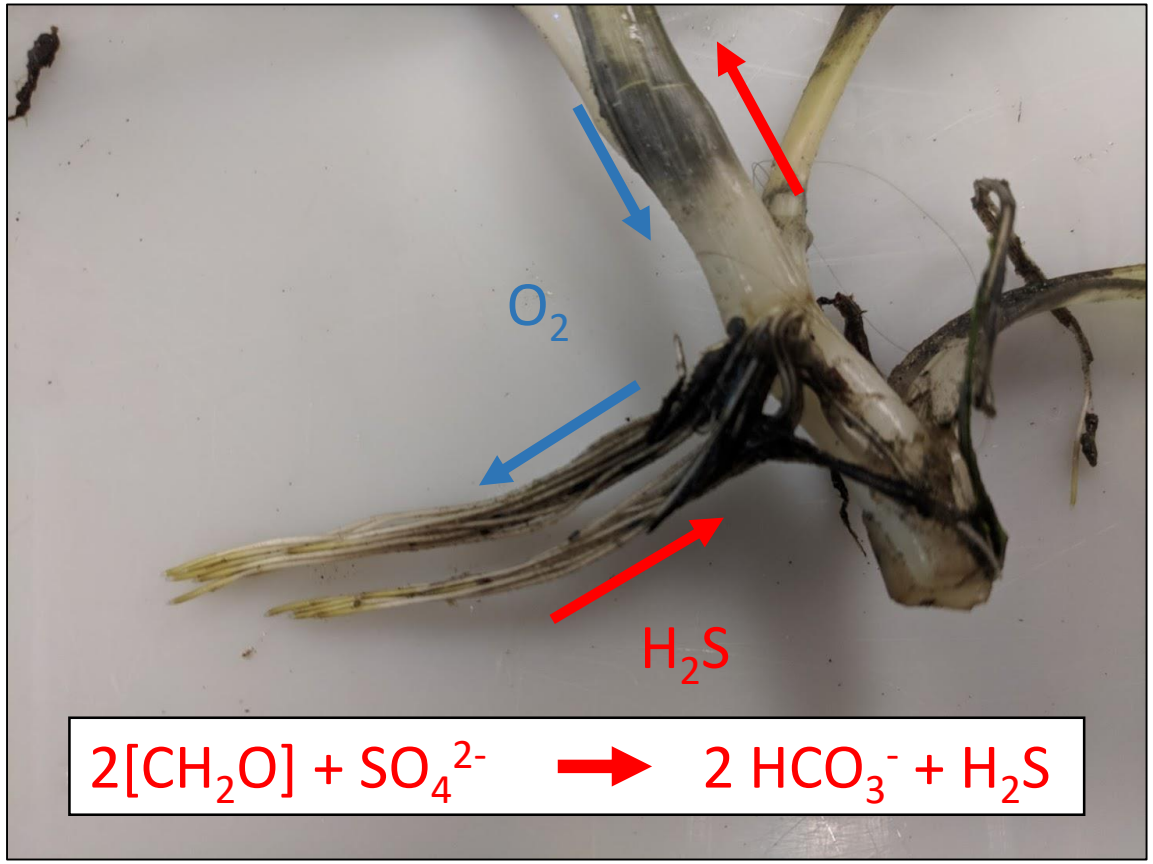
Competitive interactions under increased N load





- Higher incidence of phytoplankton blooms, epiphytes or overgrowth by green algae
- Lower light availability
- Lower shoot density, reduces max depth of seagrass beds

Increased sulfide intrusion in rhizosphere



Microbial respiration of organic matter in anoxic sediments: sulfate reduction

Sulfide is common in marine sediments and *Zostera marina* is adapted to moderate sulfide concentrations

Increased sulfide intrusion under certain conditions becomes toxic for the plants:

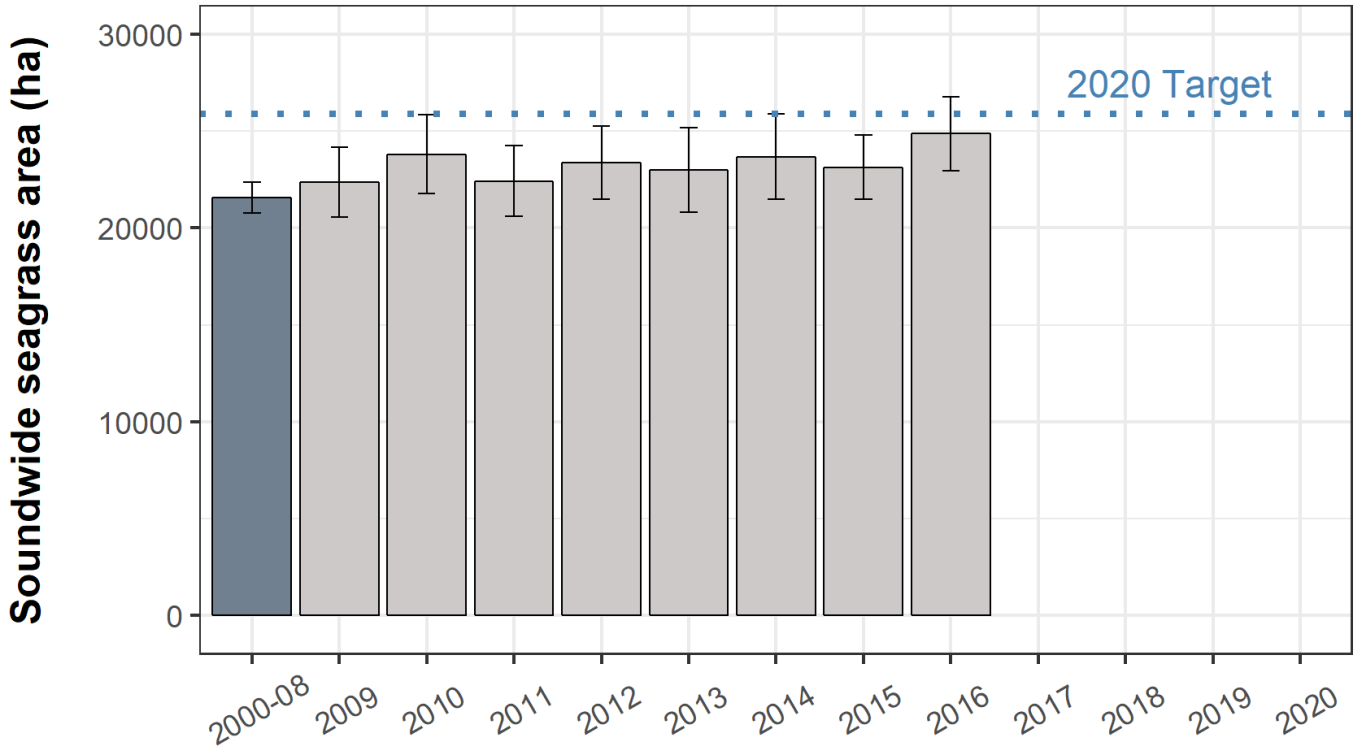
- High sediment organic matter
- Algae cover
- Oxygen depletion
- Increased temperature
- Light reduction

Puget Sound

What about Puget Sound

- Declines in eelgrass?
- Spatial patterns in eelgrass distribution
- Spatial pattern in depth limits of eelgrass beds in greater Puget Sound?

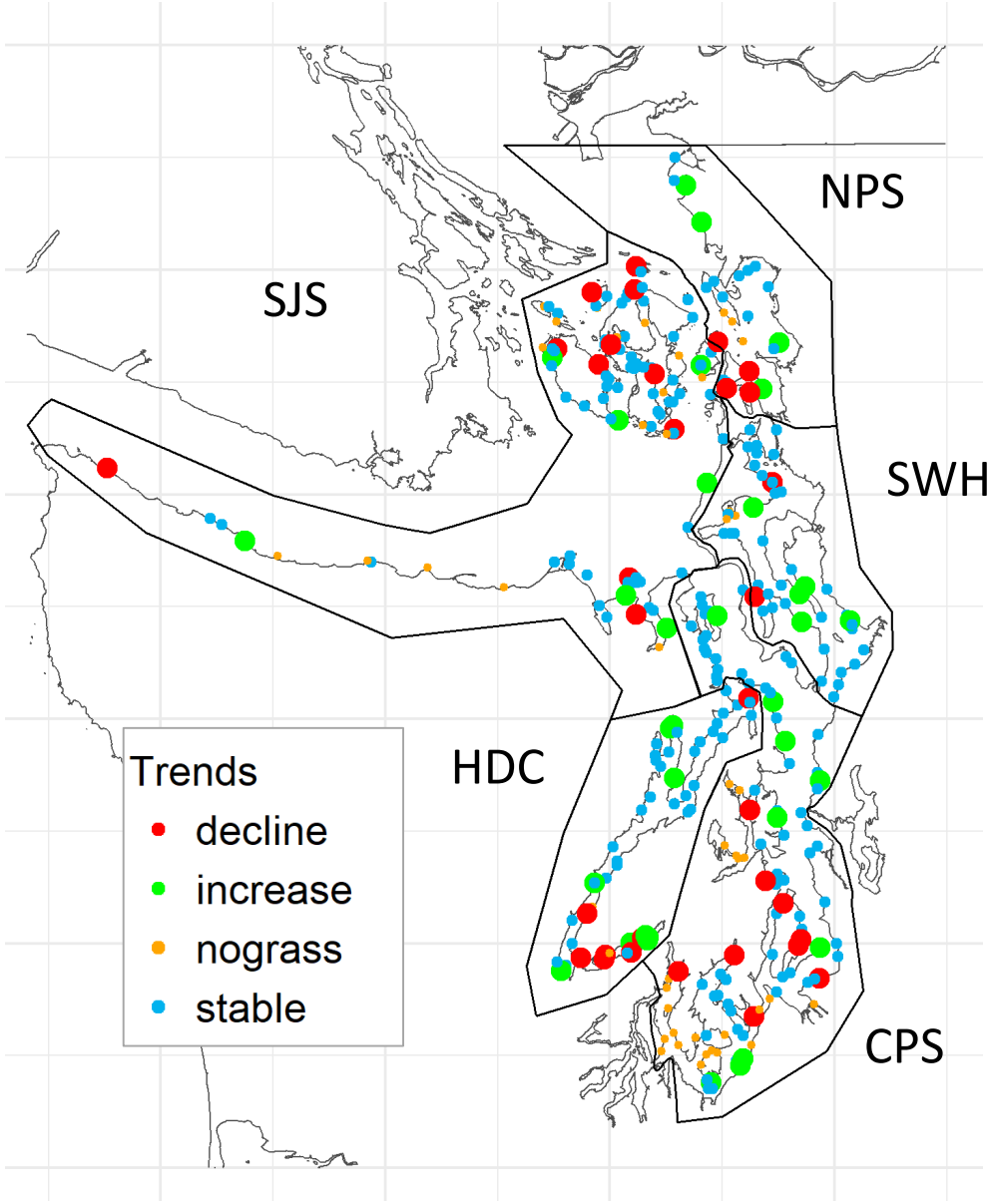
Soundwide trends



On a soundwide scale: eelgrass area relatively stable since 2000 (DNR – SVMP)

No major declines in eelgrass in herring spawn areas in Puget Sound over the last 40 years (Shelton et al. 2016)

Site-level trends 2000 - 2016



Increases/declines in eelgrass cover when looking on a smaller spatial scale

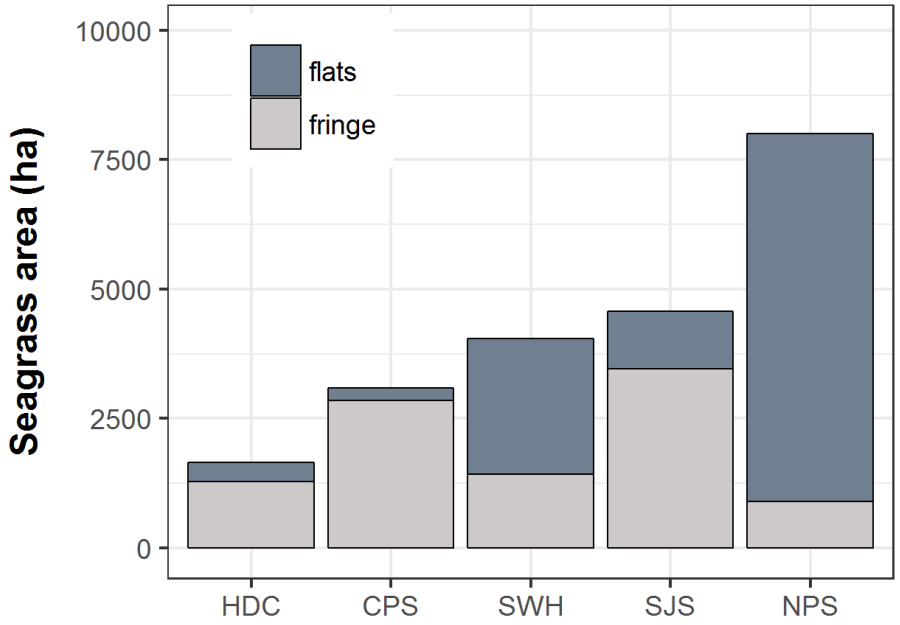
~ same number of increases and declines

Several eelgrass declines at the end of inlets & areas with longer residence times:

- Westcott Bay
- Quartermaster Harbor
- Port Orchard
- Fidalgo Bay
- Case Inlet and Carr Inlet

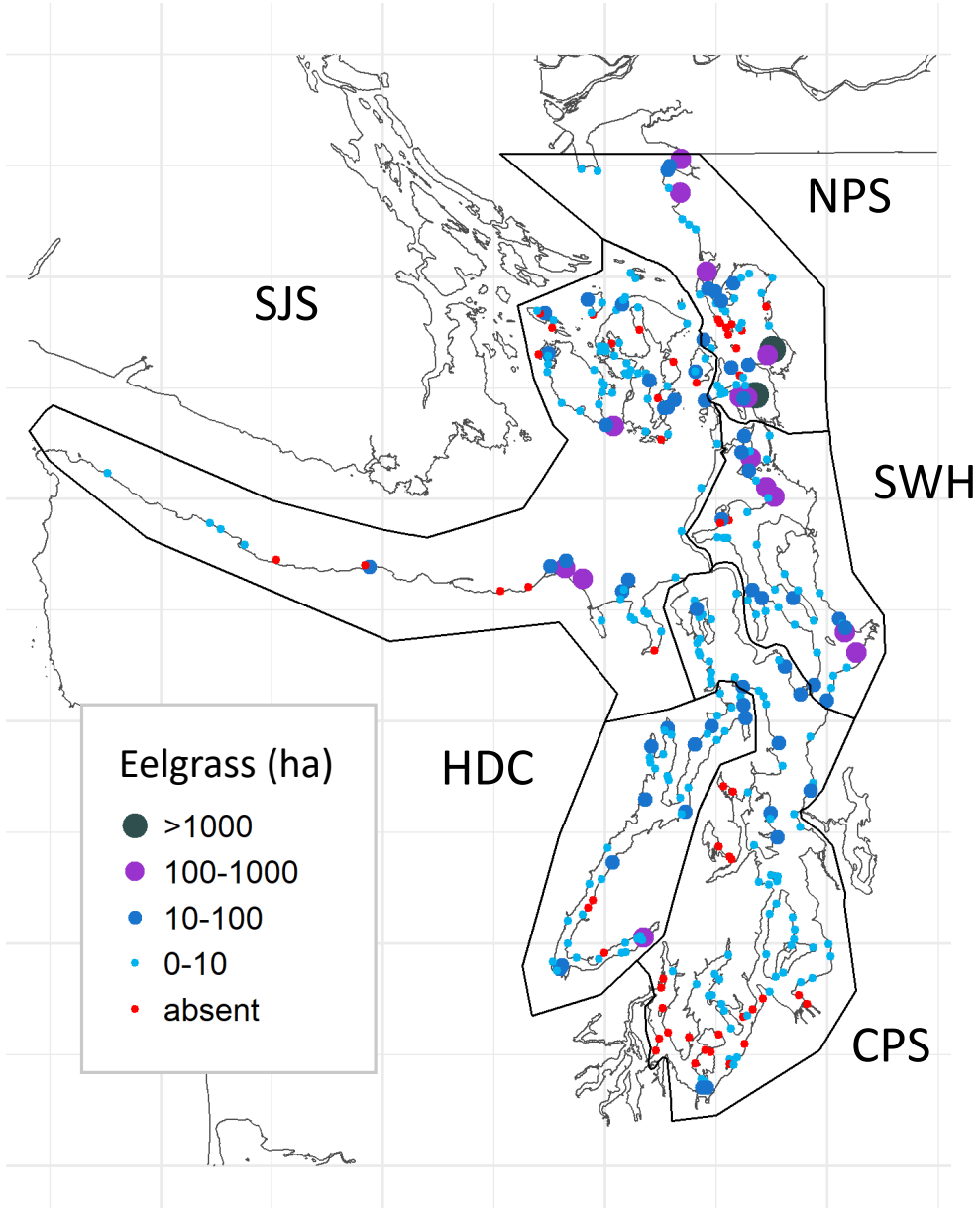
Associated with water quality?

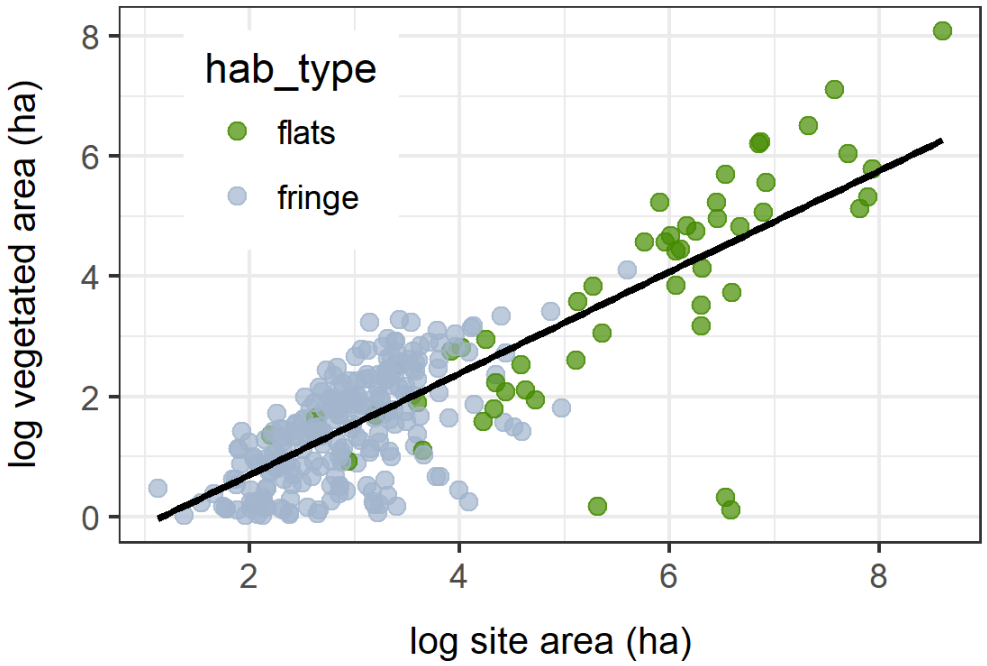
Spatial patterns in eelgrass distribution



- Approximately 23,000 ha of eelgrass in greater Puget Sound
- ~ 50% of eelgrass on tidal flats (74 sites total)
- Distribution different in each region

Spatial patterns in eelgrass distribution



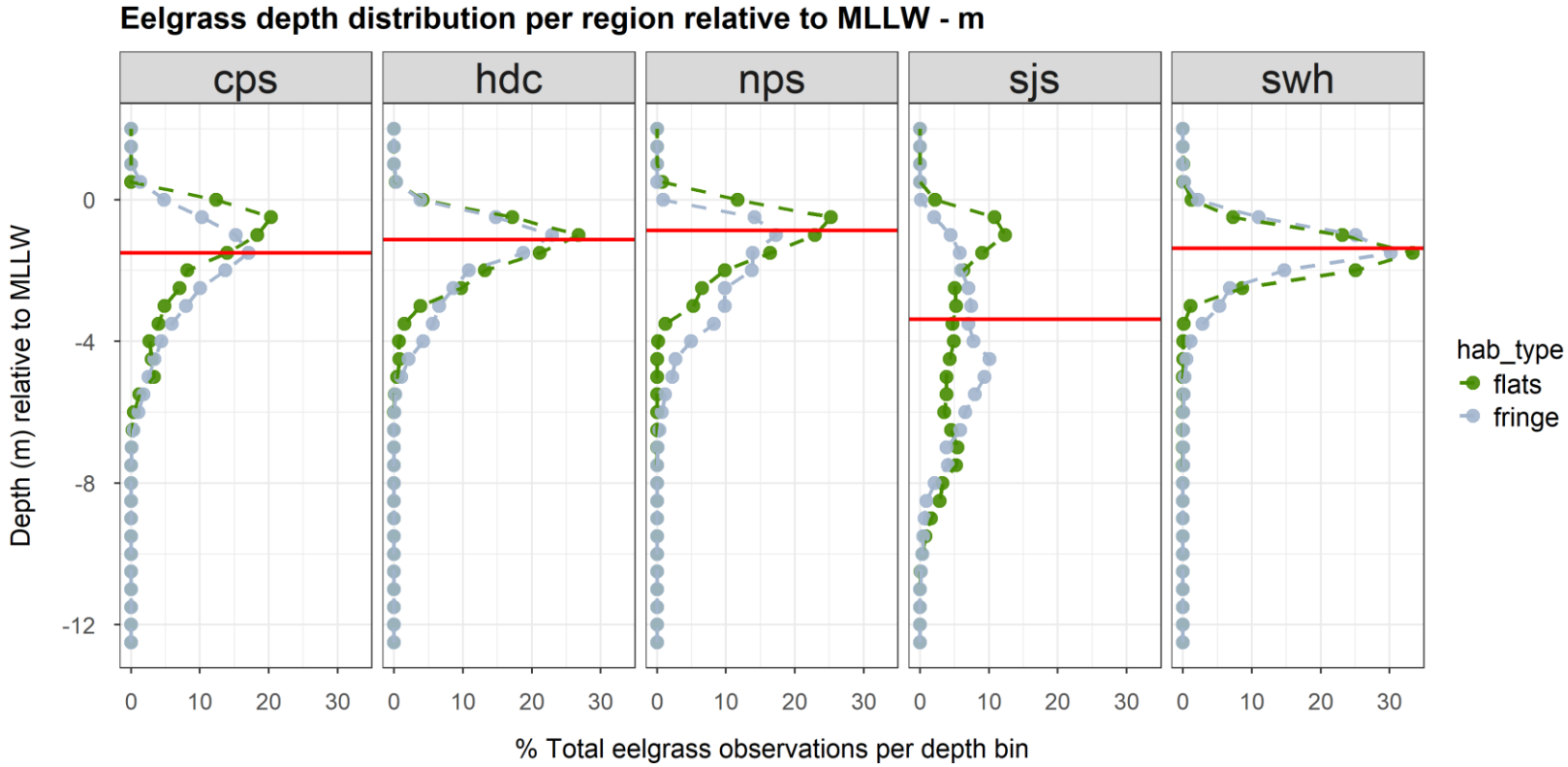


Spatial patterns in eelgrass area in part determined by available substrate

No eelgrass in southernmost part of Puget Sound, and in Dyes Inlet and Liberty Bay

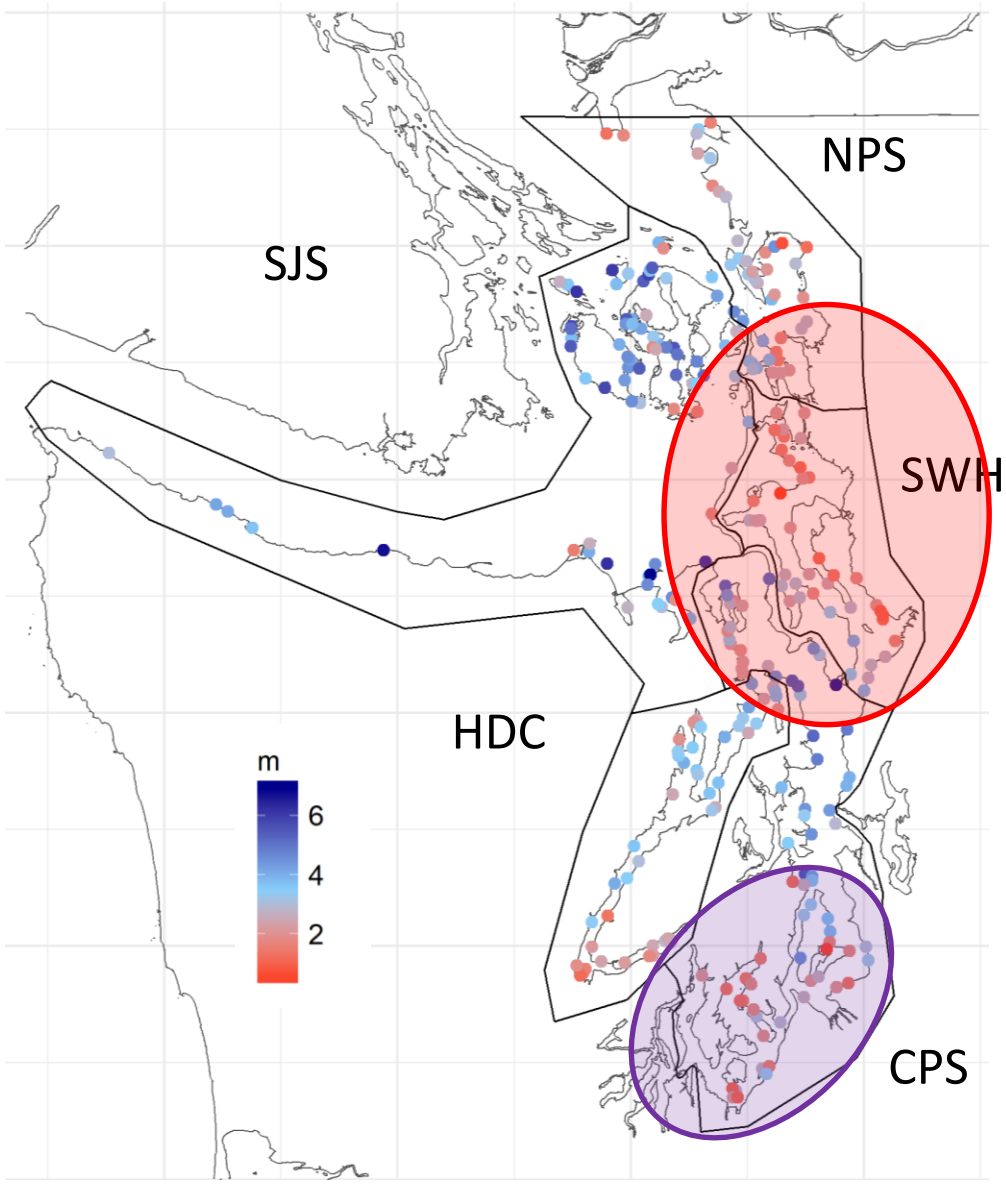
Status and trends

Spatial patterns in depth distribution



- Eelgrass grows between +1.4 and -12 m (MLLW)
- Optimal depth range appears to be between 0 and -4 m (MLLW)
- Different depth distribution regions / flats vs fringe

Spatial patterns in eelgrass depth range



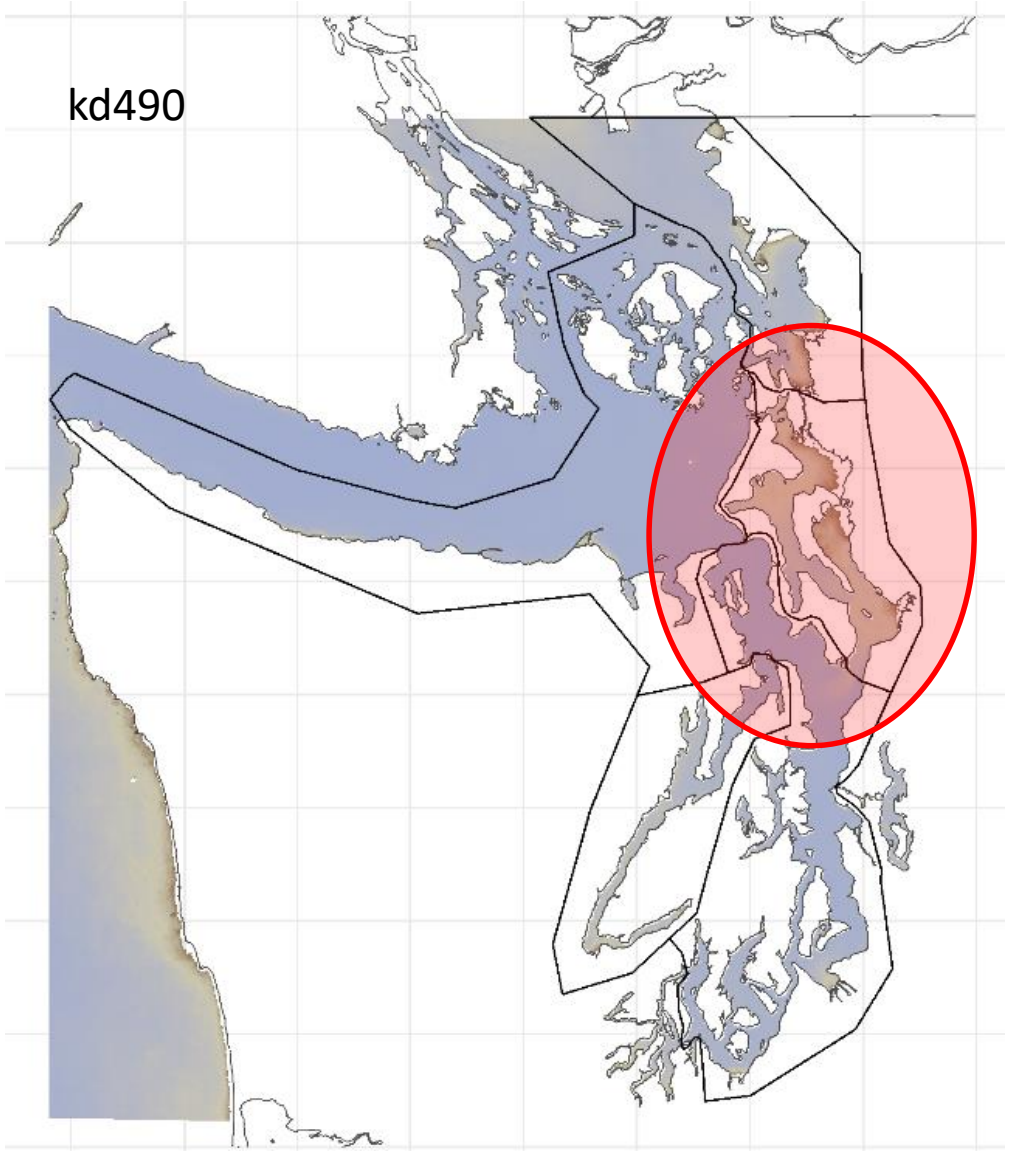
Eelgrass: depth difference between shallow and deep edge of seagrass beds at individual sites

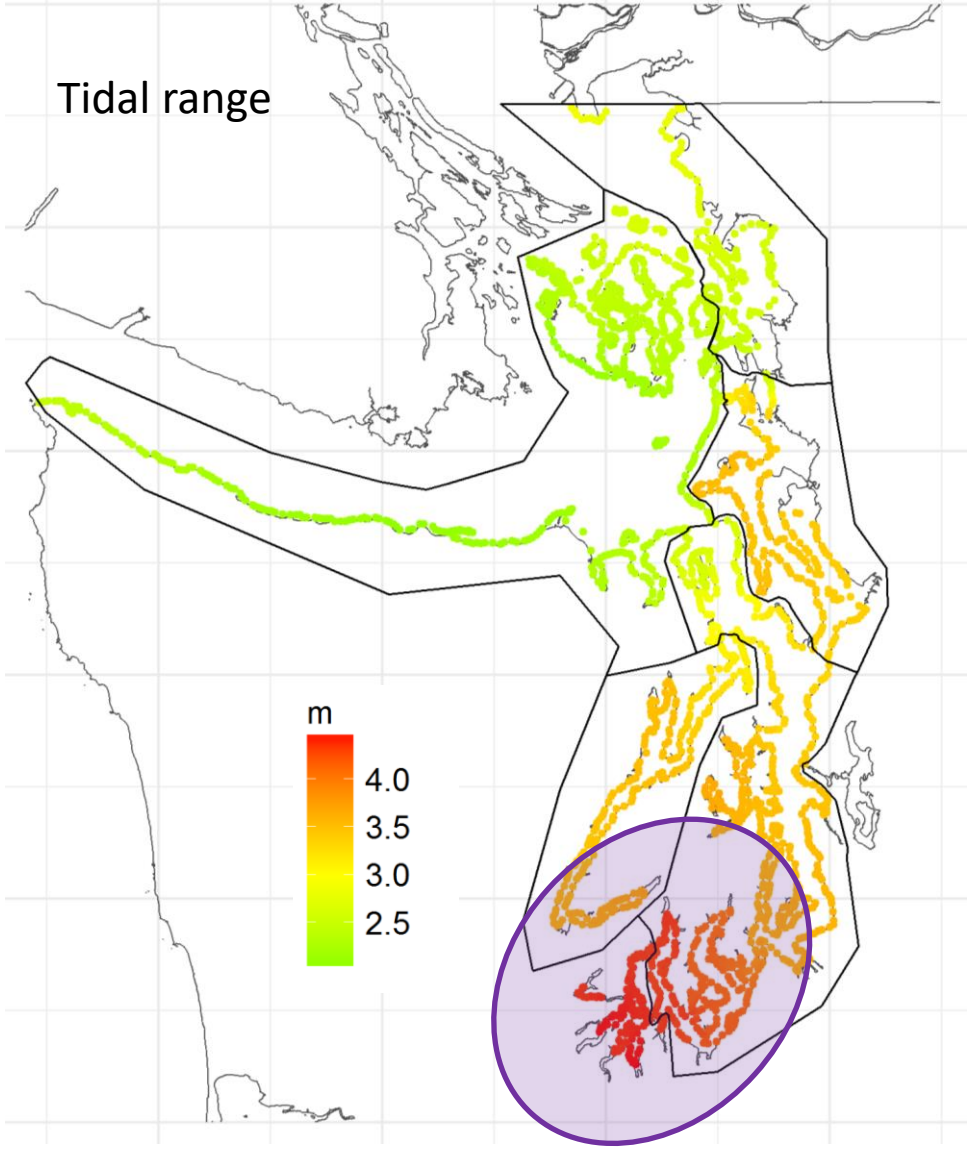
Eelgrass depth range varies from more than 6m in the San Juan Islands and the Strait, to less than 2 m in the Saratoga Whitbey Basin and South Puget Sound.

Gradient from North to South in Central Puget Sound and Hood Canal.

Hypothesis: areas of concern, smaller depth range = eelgrass more sensitive to disturbance?

Potential drivers: water clarity and tidal range

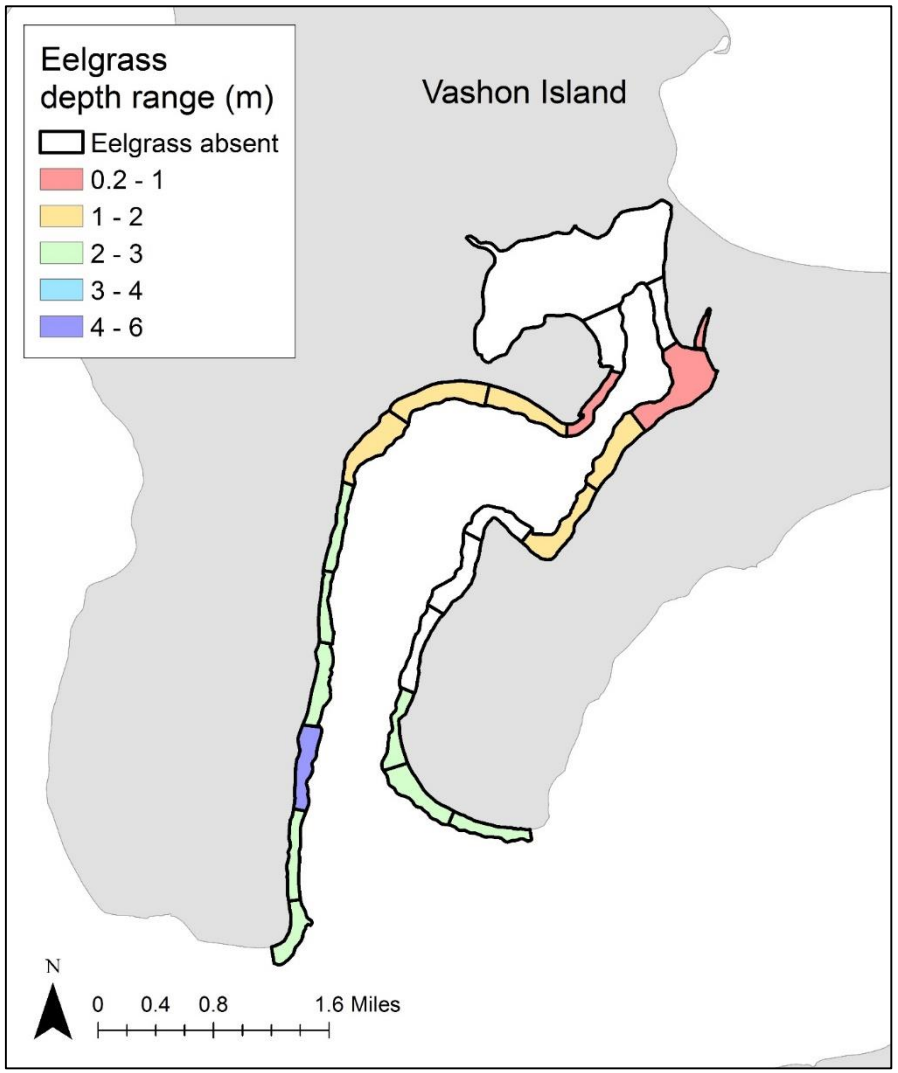


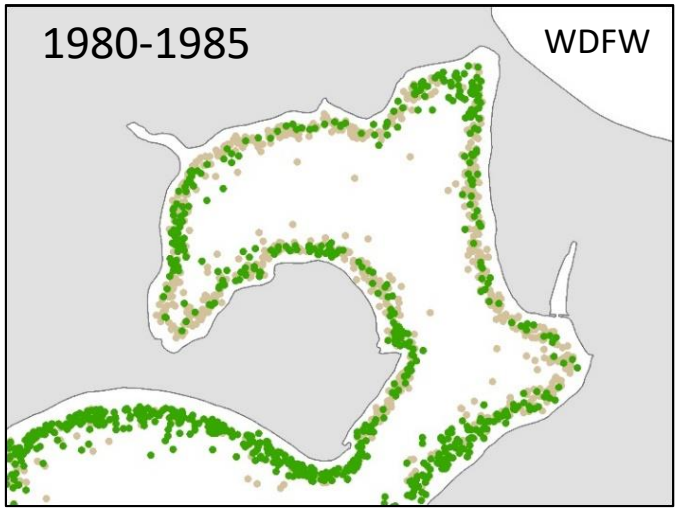


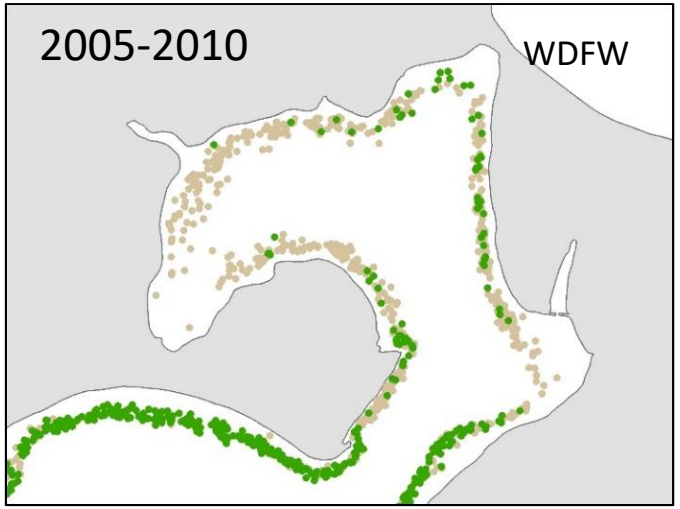
Satellite data by Brandon Sackmann, Integral Consulting

Case study

Case study: Quartermaster Harbor







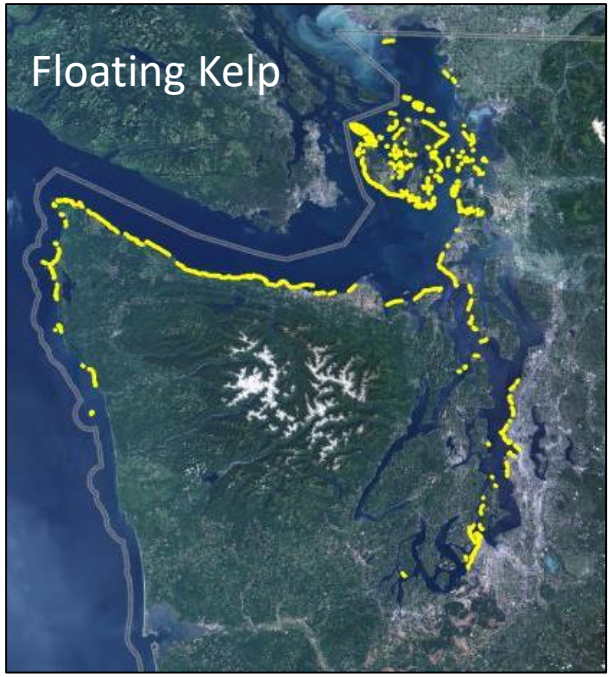
- Gradient in eelgrass depth range from the mouth to the head of Quartermaster Harbor
- Loss of eelgrass in inner part of Quartermaster Harbor over last 40 years
- Currently no eelgrass left in inner harbor

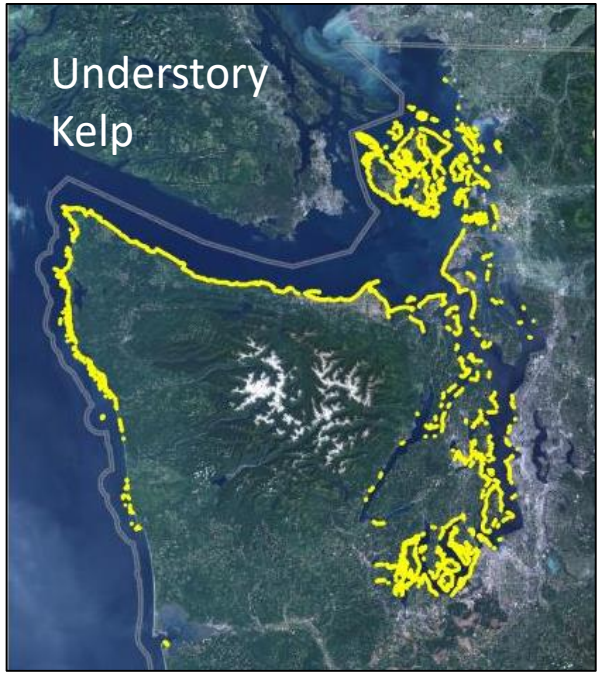
Diversity

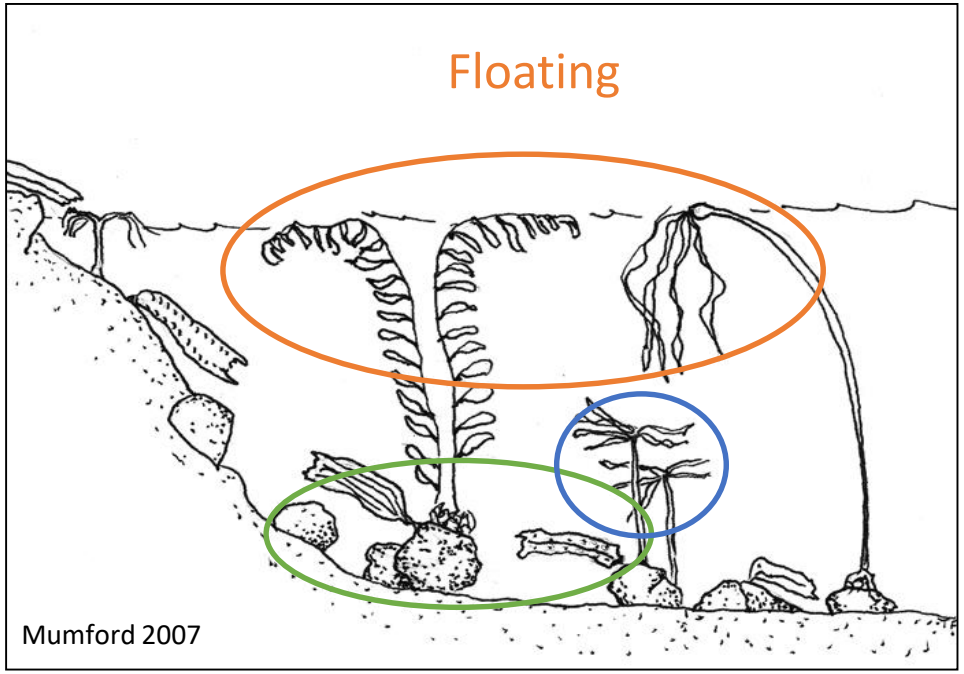
Macroalgal communities in Washington State

- 625 species of seaweeds (red, brown, green)
- Kelp = brown algae from order Laminariales
- 23 species of kelp = one of the most diverse kelp communities in the world!

Kelp in greater Puget Sound







Floating kelp:
11% of shoreline

Understory kelp:
31% of shoreline

Prostrate

Stalked

Understory kelp is more abundant than floating kelp in greater Puget Sound!

Diversity

Family	Native Kelp Species in Puget Sound	Strait & Western Whidbey Is.	San Juan Arch. & North	CPS & SPS	Type
Agaraceae	*Agarum clathratum*		✓		Perennial, prostrate
	Neoagarum fimbriatum	✓	✓	✓	Perennial, prostrate
	Costaria costata	✓	✓	✓	Annual, prostrate
Alariaceae	*Alaria marginata*	✓	✓	✓	Annual, prostrate
	Lessoniopsis littoralis		✓		Perennial, stalked
	Pleurophycus gardneri	✓	✓		Annual, prostrate
	Pterygophora californica	✓	✓	✓	Perennial, stalked
Laminariaceae	*Cymathaere triplicata*	✓	✓		Annual, prostrate
	Laminaria ephemera	✓	✓	✓	Annual, prostrate
	Laminaria longipes	?	✓		Perennial, prostrate
	Laminaria setchellii	✓	✓		Perennial, stalked
	Laminaria sinclairii	?			Perennial, prostrate
	Nereocystis luetkeana	✓	✓	✓	Annual, floating
	Saccharina complanata		✓	✓	Perennial, stalked
	Saccharina latissima	✓	✓	✓	Annual, prostrate
	Saccharina nigripes	✓	✓	✓	Annual, prostrate
	Saccharina sessilis	✓	✓		Perennial, prostrate
Less.	*Egregia menziesii*	✓	✓		Perennial, floating

✓ Common

✓ Uncommon

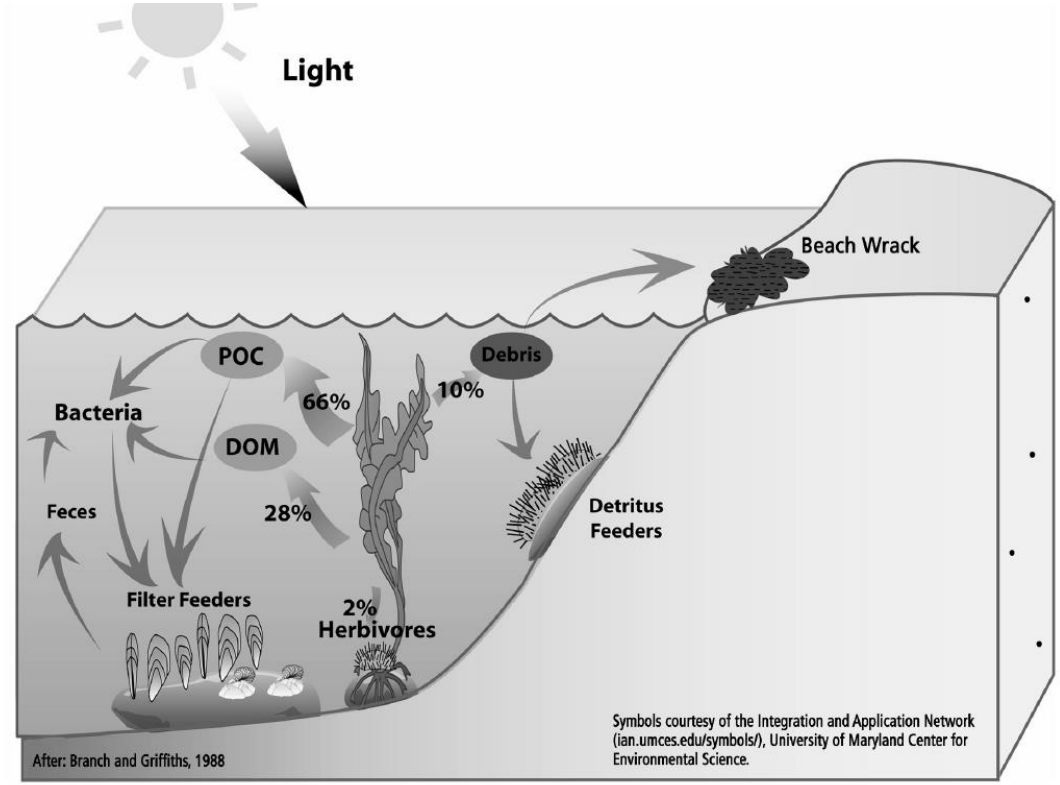
Sources:

Mumford 2007, individual studies

Diversity

Importance

Important but vulnerable

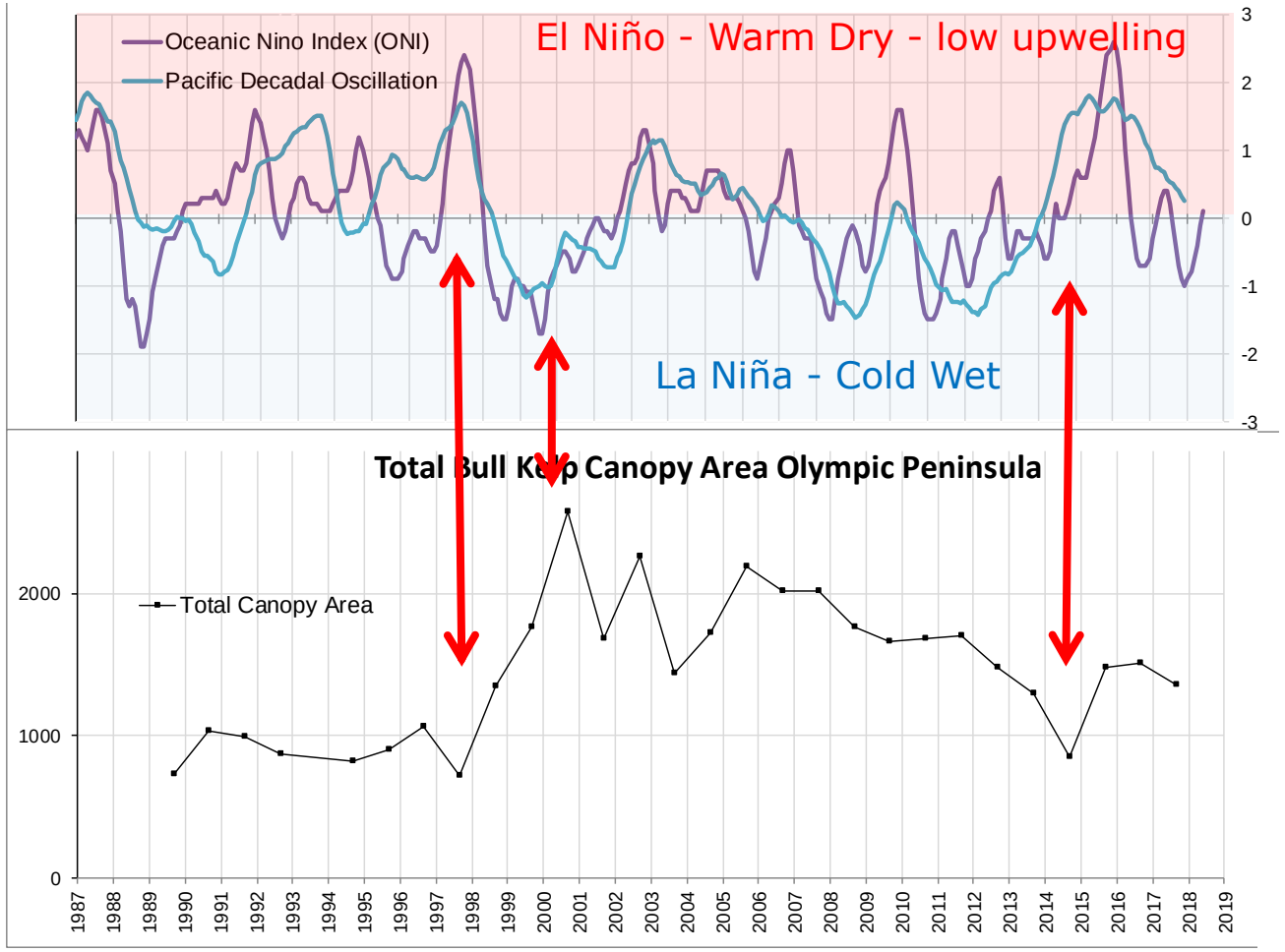


Mumford 2007

- Provide habitat for a wide variety of species
- Kelp and eelgrass fuel the detrital food web
- Export of particulate and dissolved organic matter

Stressors

Climate



Significant correlations

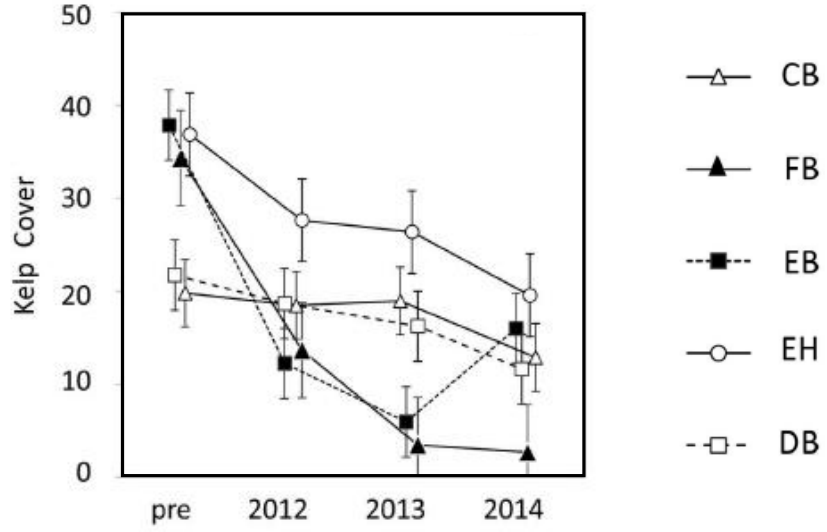
- – Oceanic Nino Index (ONI)
- – Pacific Decadal Oscillation (PDO)
- \+ North Pacific Gyre Oscillation (NPGO)

Grazing

- Classic example of trophic cascade: otters – urchins – floating kelp
- Low urchin densities along Washington State (otters present on outer coast, urchin fisheries in Puget Sound) = no overgrazing on kelp
- High abundance of kelp crabs in Puget Sound. Feeding preference for bull kelp

Light limitation and sedimentation

- Extreme example: kelp cover plummets after Elwha dam removal
- Kelp bed limited by light, declines were more pronounced at depth
- Gametophyte sensitive to siltation



Rubin et al. 2017, Plos One

Competitive interactions with other algae

- High nutrient loads: reduction in diversity of the macroalgal community + dominance of early successive species and free floating macroalgae (often green algae)
- Puget Sound: competitive interaction between kelp species and the invasive *Sargassum muticum*

Stressors

Global scale: increased competition with turf algae

KELP FOREST
- Shading
- Low sedimentation
- High kelp spore supply

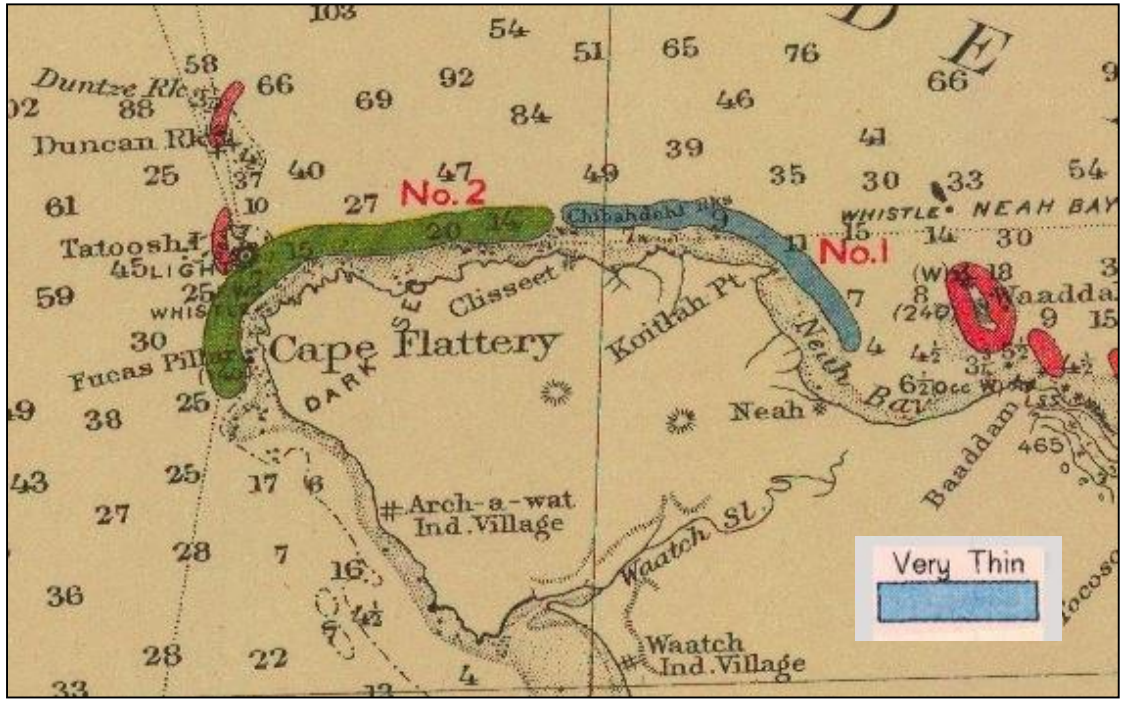
TURF ALGAE REEF
- High sedimentation
- Low kelp spore supply
- More access for grazers

Warming
Heat waves
Eutrophication
Competition
Herbivory

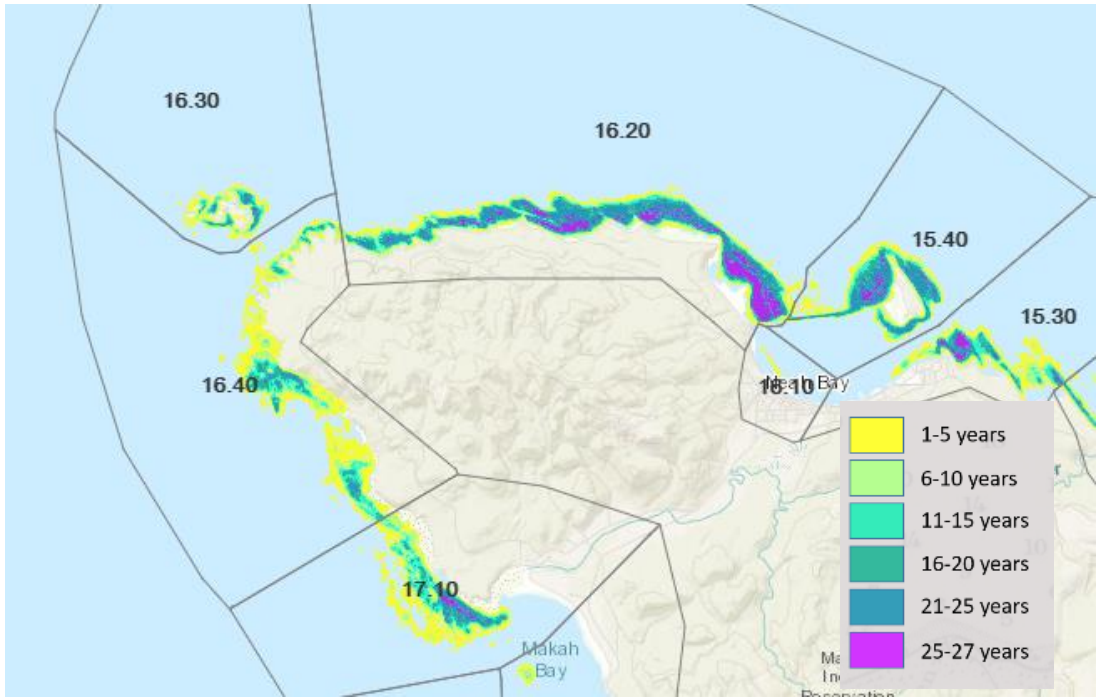
Felbee-Dexter & Wenberg 2018, BioScience

Puget Sound

What about Puget Sound?



Rigg 1911-12
Fertilizer Resources

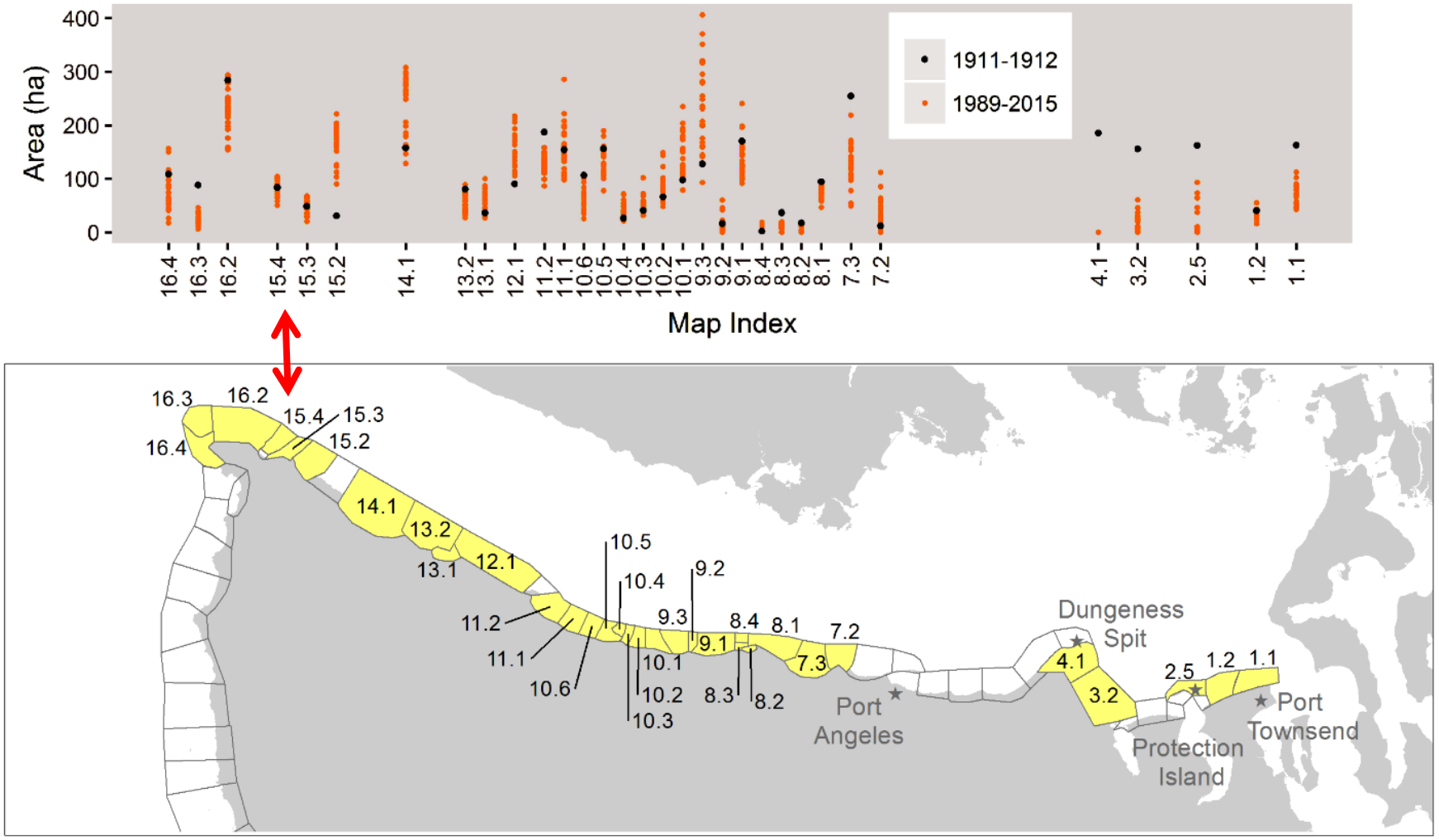


DNR 1989-2015
Annual Aerial Kelp Canopy Surveys

Explore the maps at geo.wa.gov - search for “kelp forests”

Status and trends

Floating Kelp relatively stable in Strait during last century

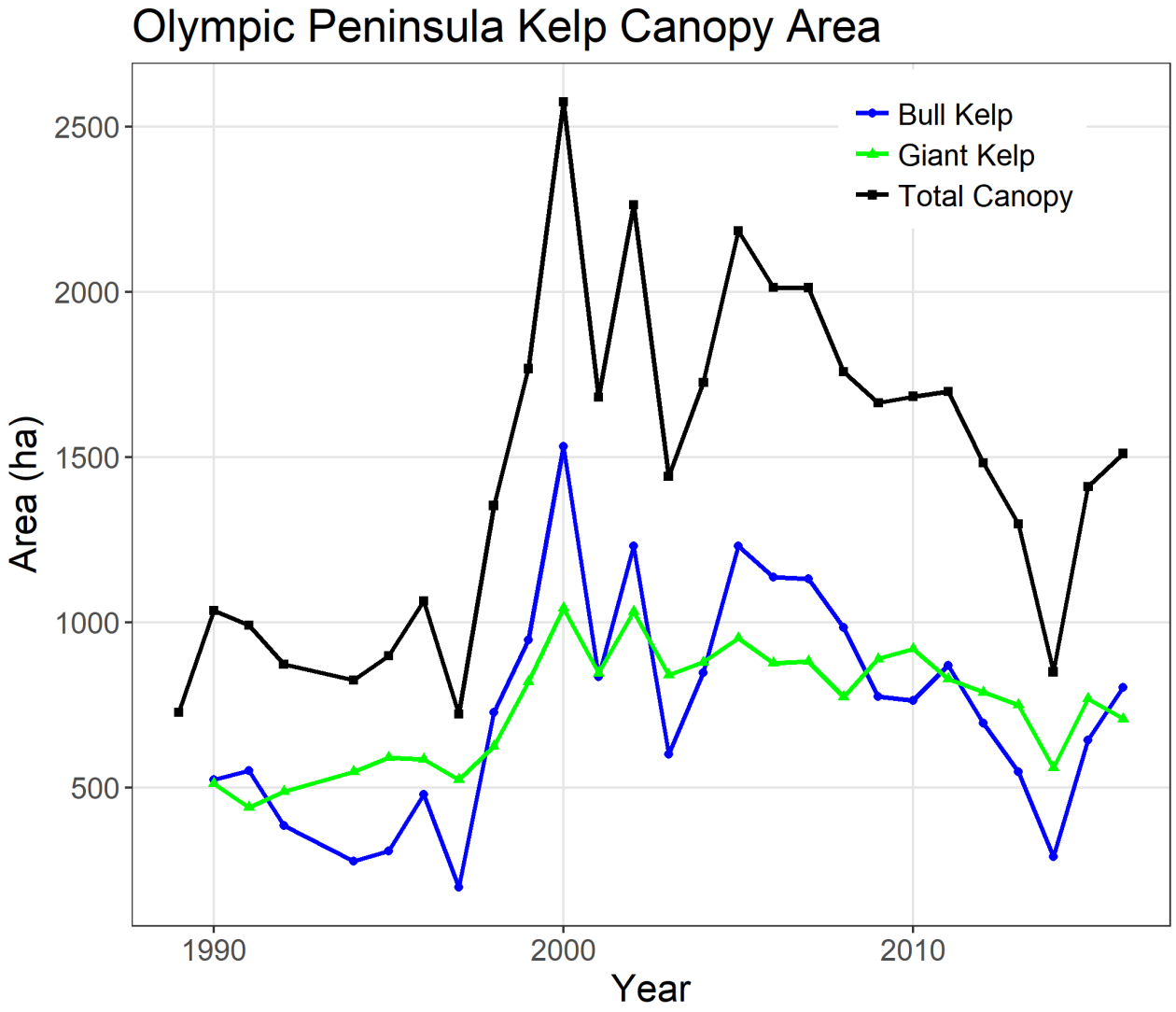


Pfister, Berry and Mumford, 2017. Journal of Ecology

Status and trends

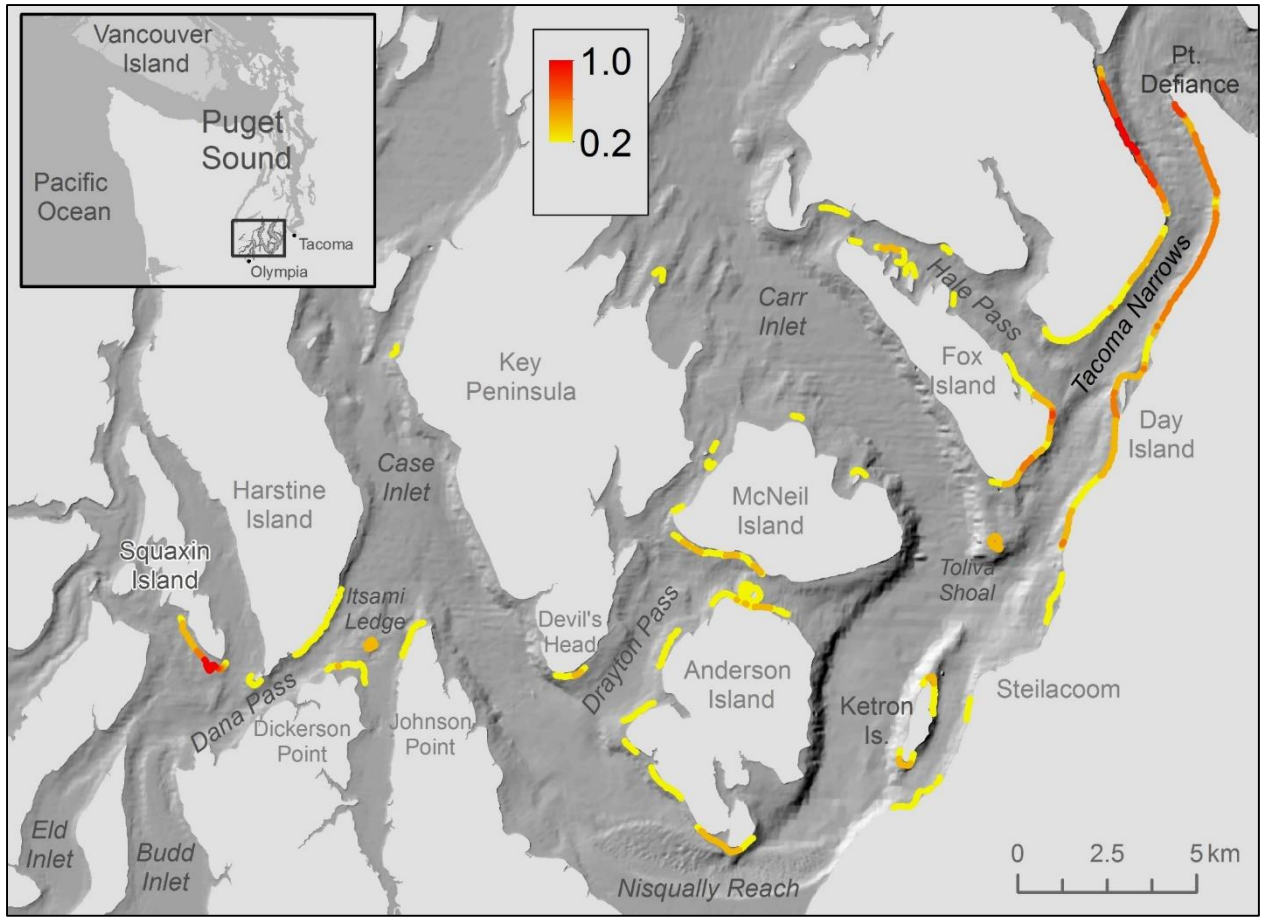
High inter-annual variability, linked with to climate

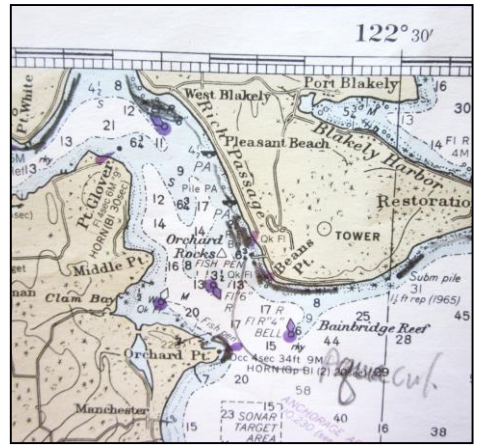
- Stable, yet high variability
- Abundance of two species positively correlated ($p < 0.001$)
- Extreme lows in kelp abundance during extreme high temperatures (1997 and 2014)



Status and trends

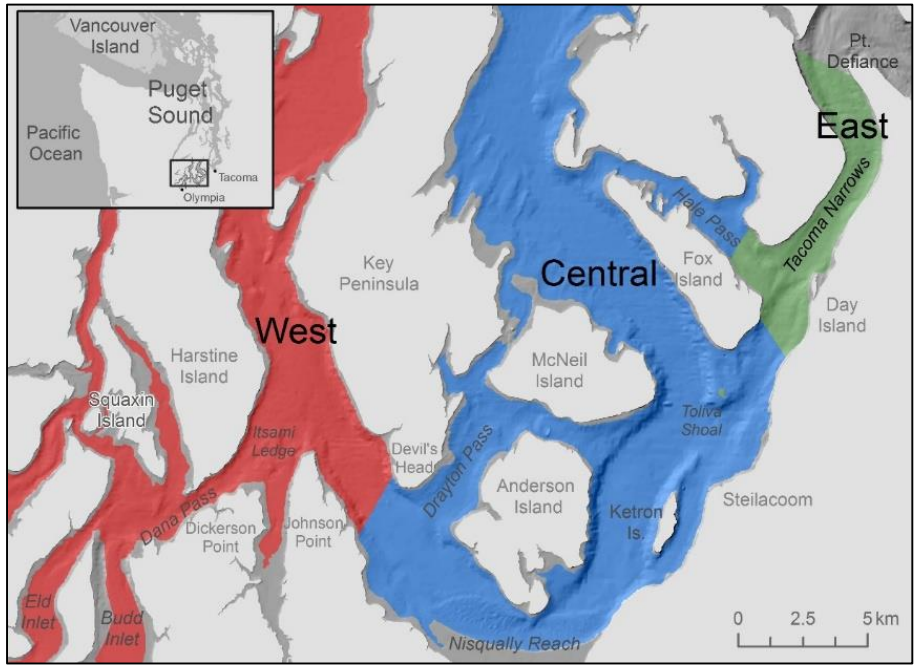
Bull kelp in South Puget Sound: declines since 1980

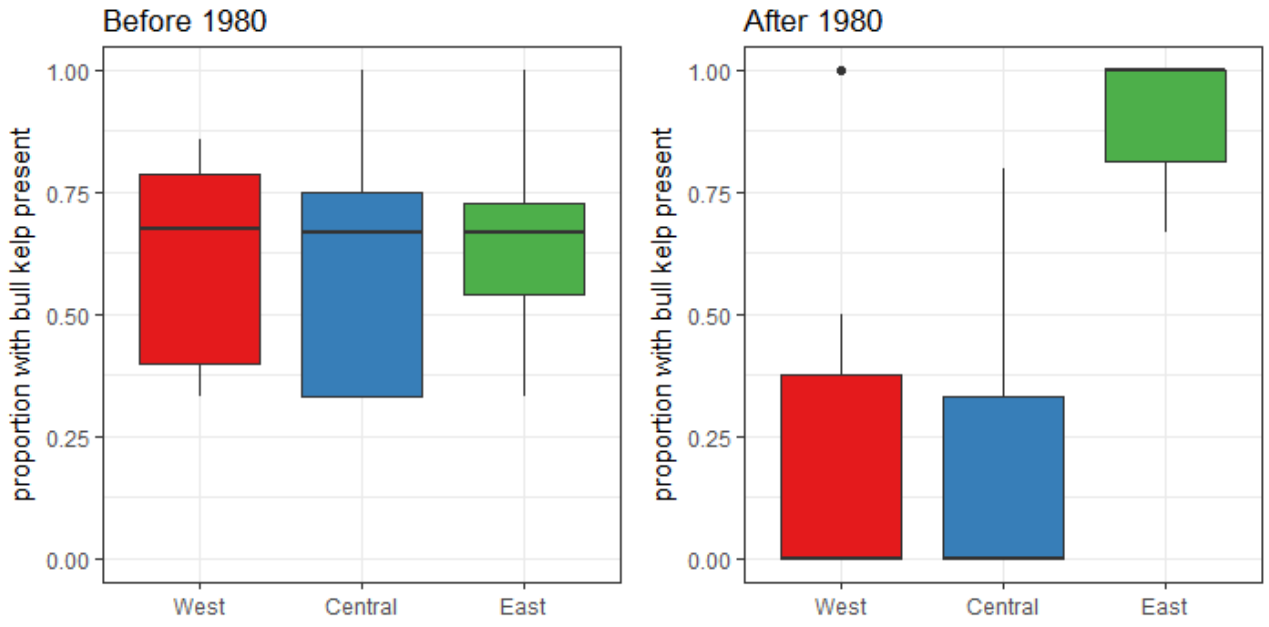




Status and trends

Bull kelp in South Puget Sound





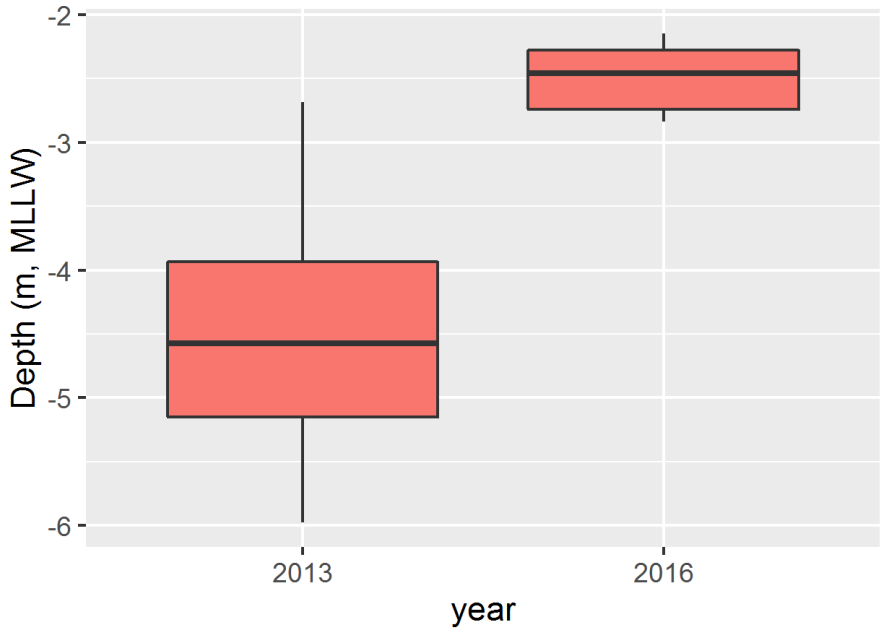
Large change in kelp distribution. Before 1980, proportion of observations with kelp nearly identical in all regions. After 1980 bull kelp almost disappeared from the west and central

Multiple stressors likely played a role, and may have changed over time (sedimentation, nutrients, changes in trophic structure, temperature, …)

Case study

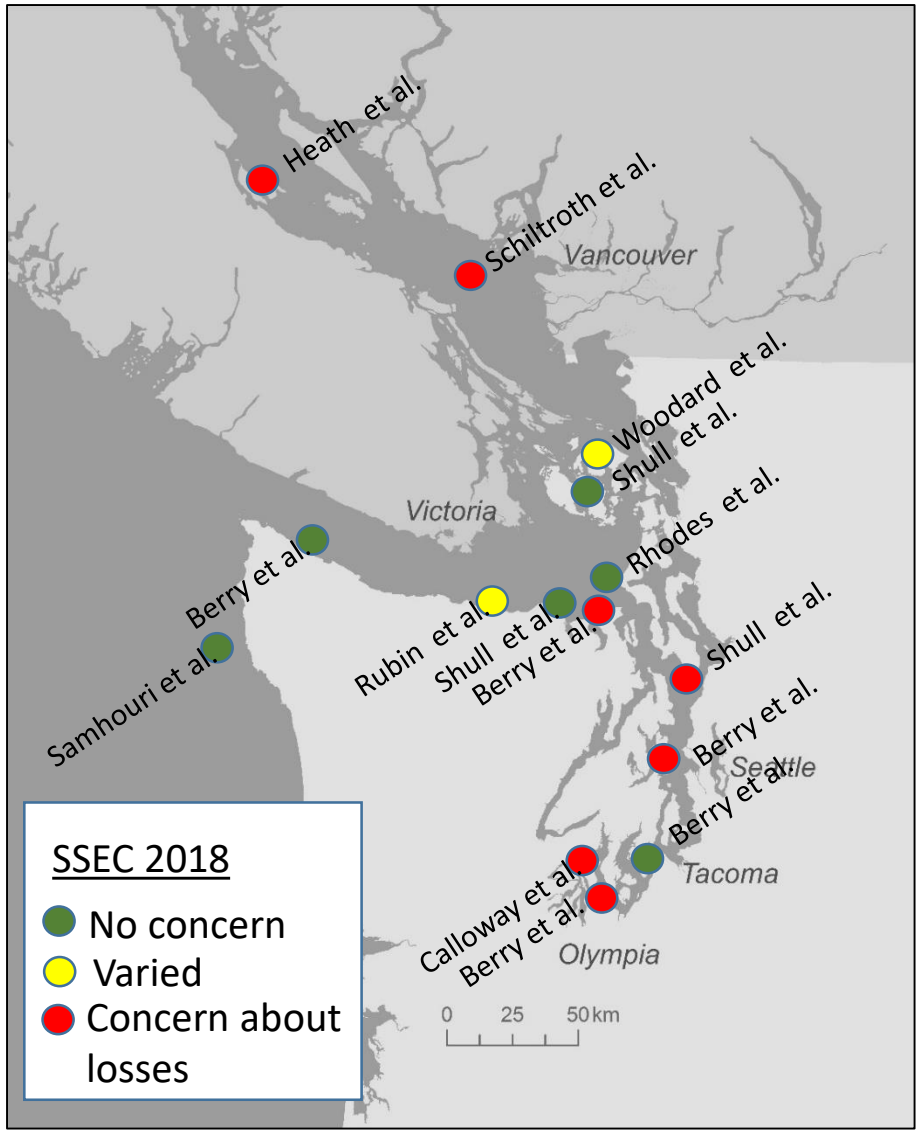
Ongoing declines at Squaxin Island (2013-2016)

year	area (ha)	% of 2013 area
2013	9.5	100%
2014	6.9	73%
2016	2.7	28%



Salish Sea

Similar declines at other locations in the Salish Sea



Kelp session of the 2018 Salish Sea Conference: concern about bull kelp losses at locations in the inner reaches of the Salish Sea

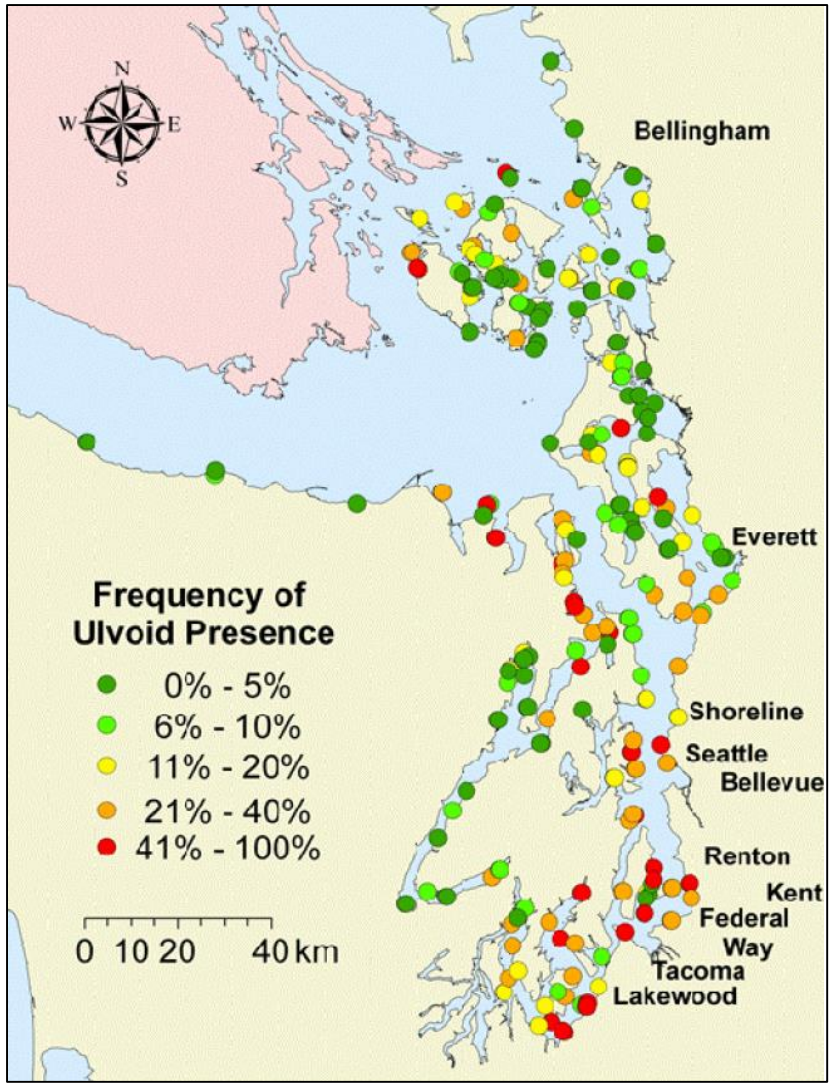
- Main recent concern: SST has exceeded thermal thresholds for kelp damage in the Strait of Georgia in Puget Sound
- Other candidate stressors include water quality, sedimentation, grazer damage (kelp crabs) and invasive algae (*Sargassum*)

Ulvoids

Blooms of green macro-algae

Eyes over Puget Sound July 16 2018, Publication No 18-03-037

Ulvoid algae in greater Puget Sound

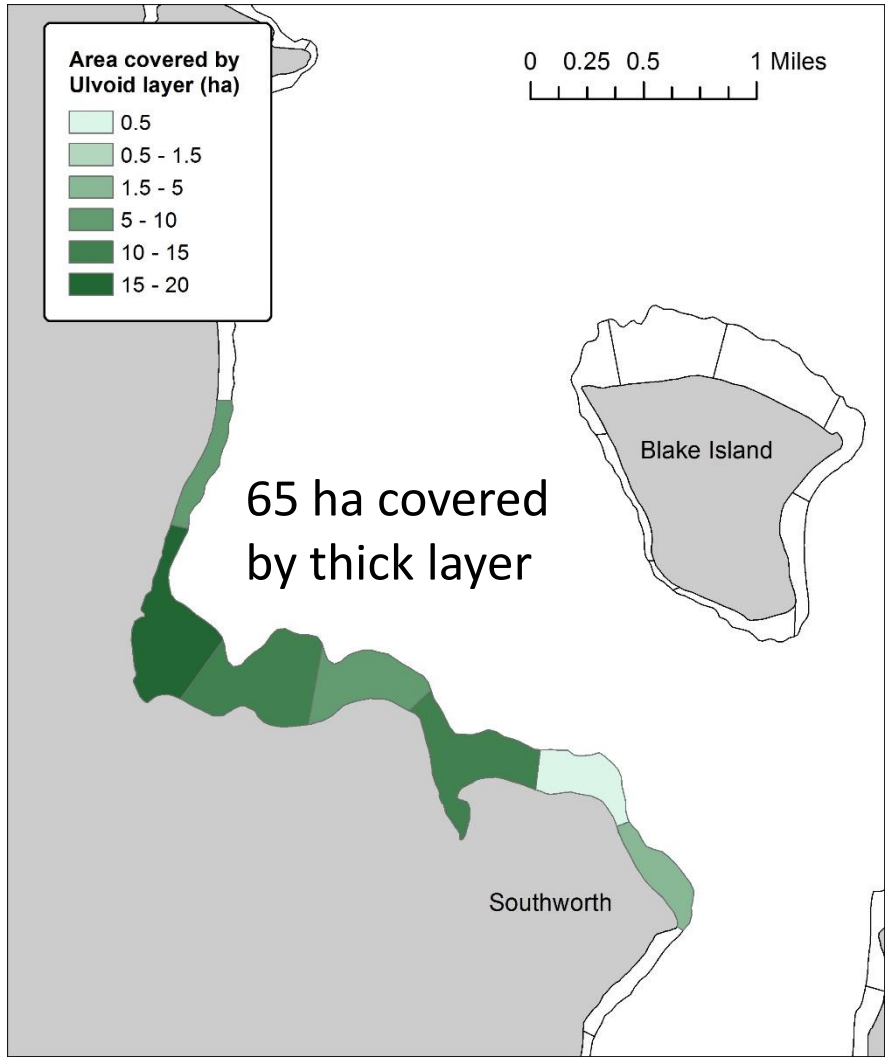


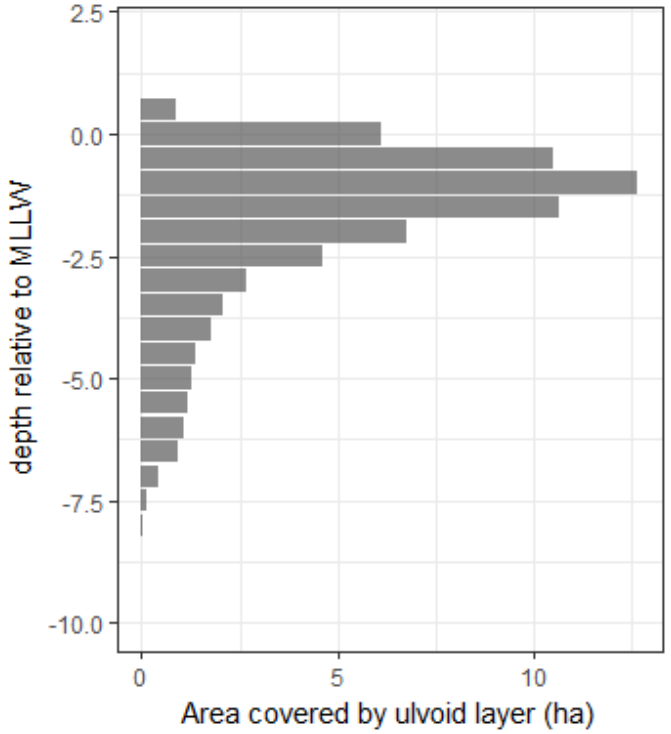
Nelson & Melton 2011

- High abundance of Ulvoids is often associated with ecosystems that are enriched in nitrogen
- Central & South Puget Sound have a higher frequency of occurrence

Ulvoids

Case study: South of Blake Island (Central Puget Sound)





- 65 ha total over 7 SVMP sites
- majority of ulvoid layer is in the subtidal
- Back of the envelope estimate ~ 500 – 1000 kg N

Accumulation of green algae due to tides and currents can lead to thick mats in both the intertidal and subtidal

Ulvoids

Conclusions

Research on worldwide declines show that excessive nutrients impact seagrass through

- Reduction of water clarity
- Changes in sediment biogeochemistry / substrate
- Competitive interactions with other algae

Eelgrass stable soundwide, but local increases and declines. Declines in enclosed embayments and areas with longer residence times. Potential effect of water quality?

Hypothesis: areas with limited eelgrass depth range: more sensitive to disturbance?

Long term declines in bull kelp in inner reaches of Salish Sea: Nutrients? Temperature? Grazing? Sedimentation?

Limited data on prevalence of green algae suggest ulvoids have high frequency of occurrence in Central and South Puget Sound. Blooms of green algae can indicate eutrophication.