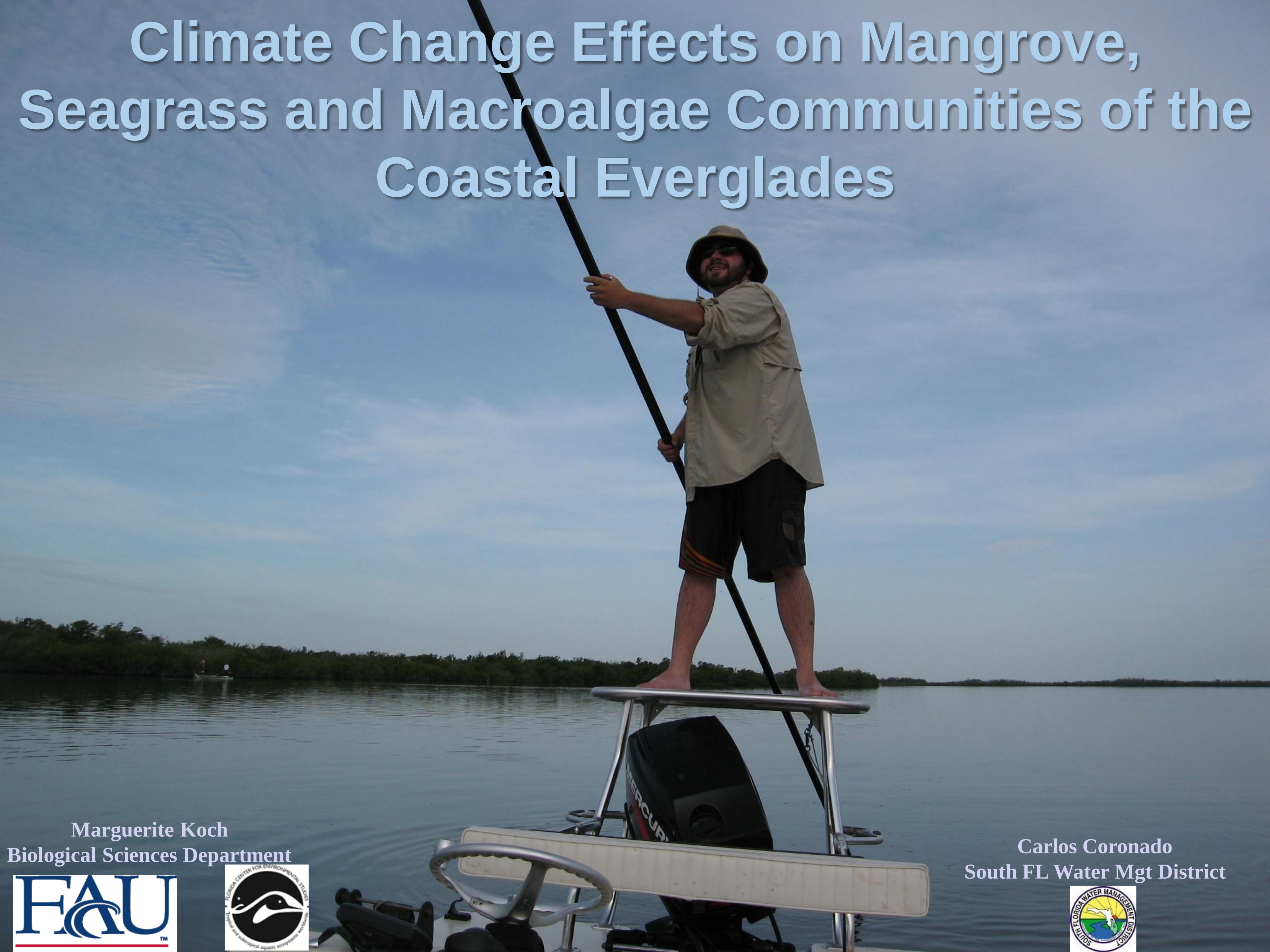
Climate Change Effects on Mangrove, Seagrass and Macroalgae Communities of the Coastal Everglades



Marguerite Koch
Biological Sciences Department

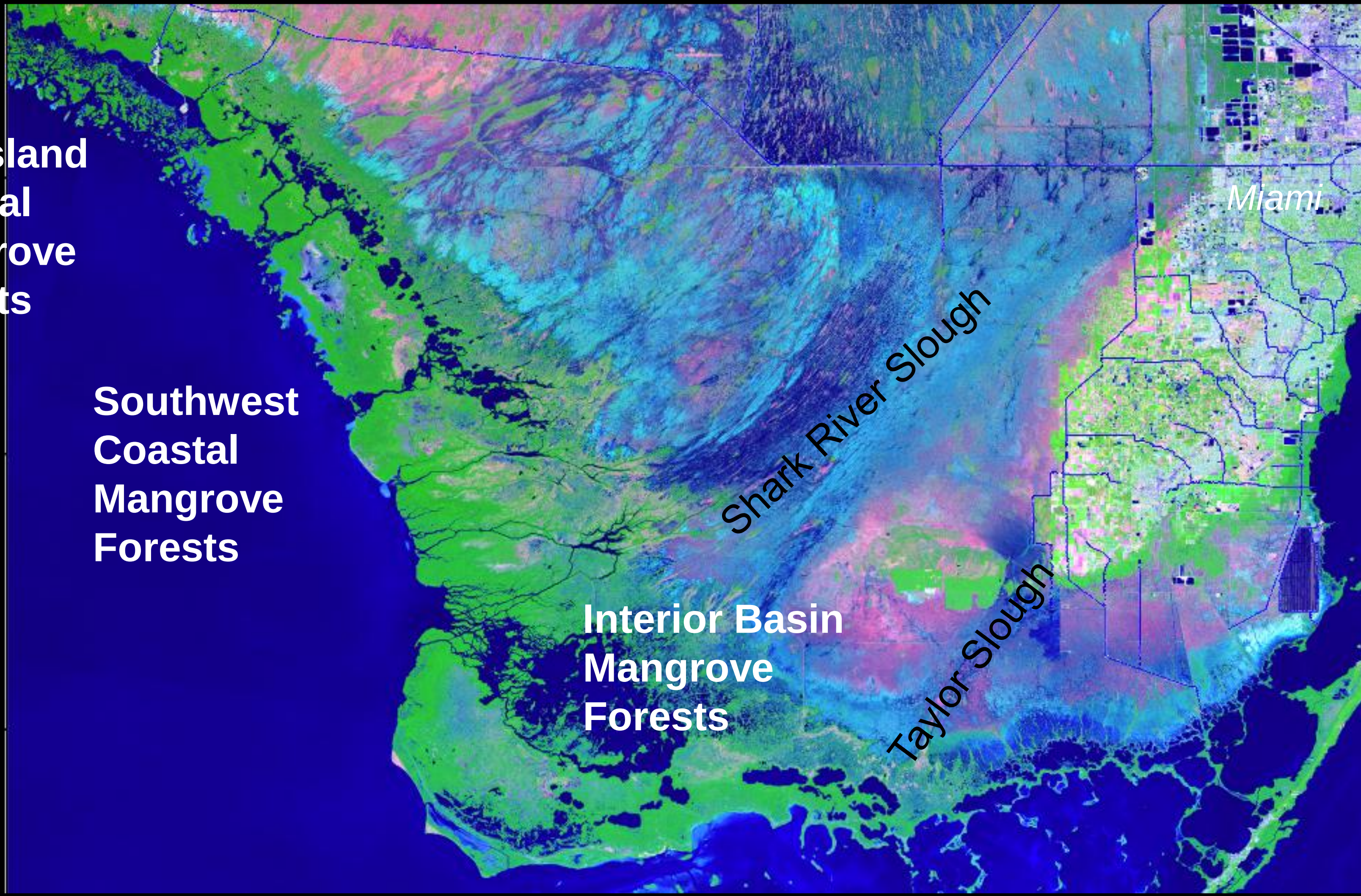
Carlos Coronado
South FL Water Mgt District

Specific Future Climate Scenarios (2060)

I. +1.5 ^{o}C Temperature Increase
II. 1.5 Foot SLR Increase (9.5 mm y^{-1})
III. +/- 10% Change in Precipitation
IV. 490 ppm CO_2

I) The Everglades Mangrove Community
(Diverse Forest Structure, Geomorphology and Biogeochemistry)

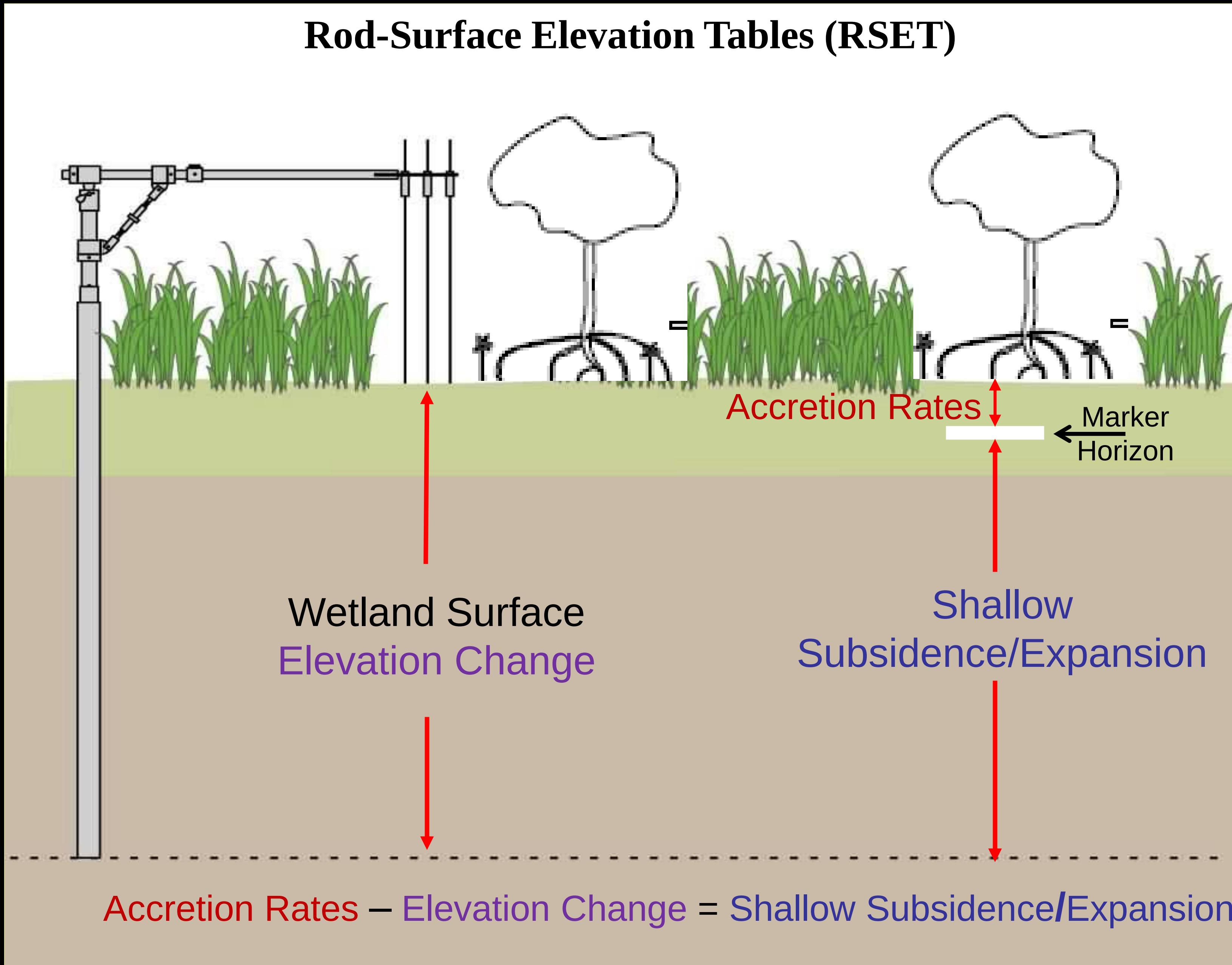
Mangrove Community Distribution in Everglades



Major Drivers of Everglades Mangrove Communities

1) Sea Level Rise Rates
2) Hurricane (Disturbance/Recovery)
3) Salinity/Temp/CO_2

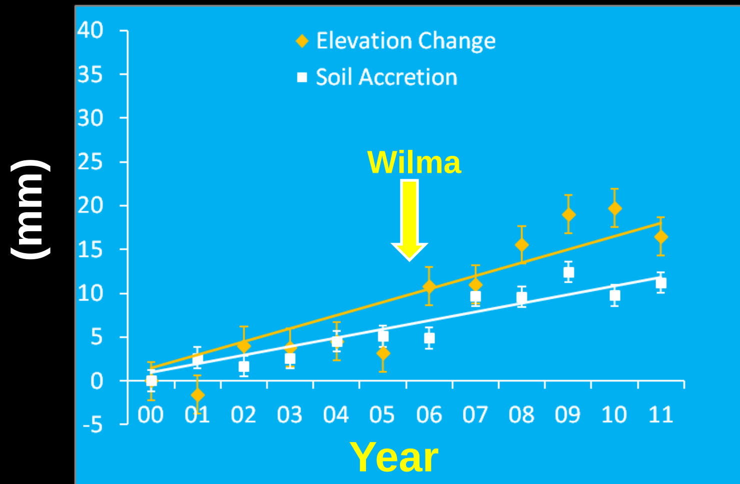
Measurements of Wetlands Keeping Pace with SLR



Rod-Surface Elevation Tables (RSET)

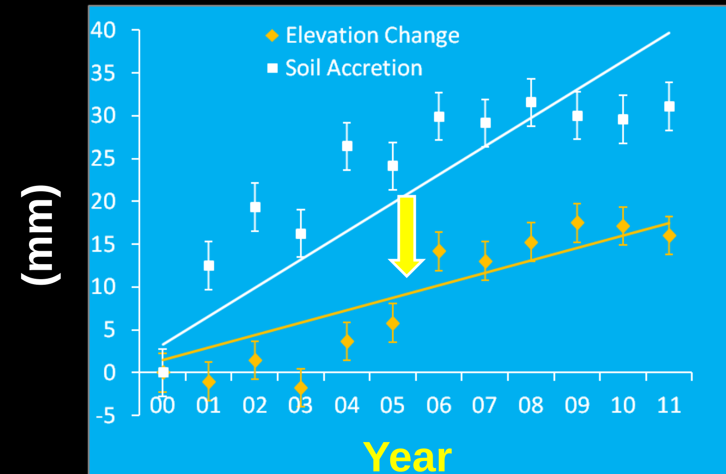
Northern Florida Bay Mangroves (Taylor Creek Basin) – Coronado/Sklar

Non-flooded Sites



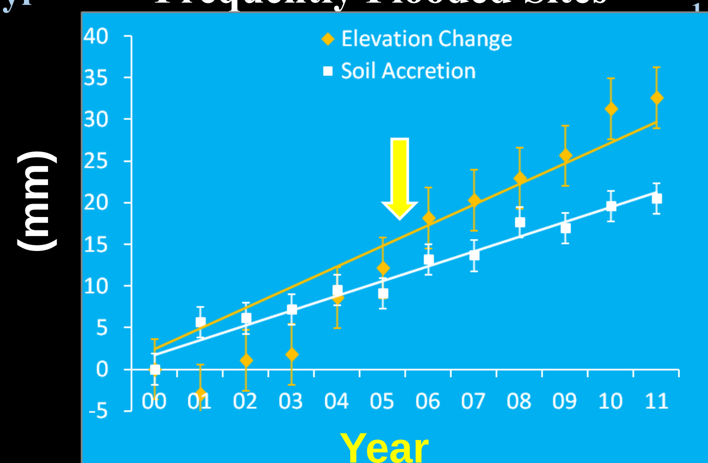
Elevation Change 1.5 mm yr^{-1}
Vertical Accretion 0.9 mm yr^{-1}
Soil Expansion 0.6 mm yr^{-1}

Permanent Flooded



Elevation Change 1.4 mm yr^{-1}
Vertical Accretion 3.3 mm yr^{-1}
Shallow Subsidence -1.9 mm yr^{-1}

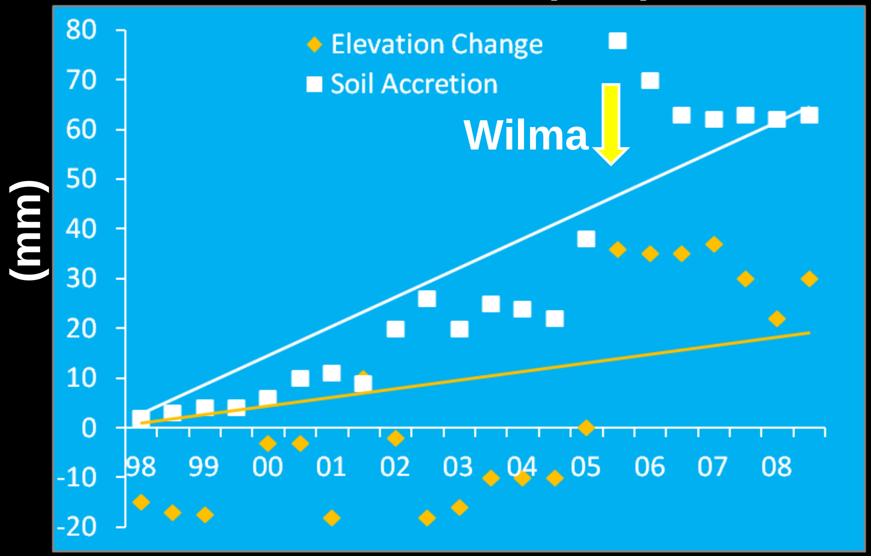
Frequently Flooded Sites



Elevation Change 2.5 mm yr^{-1}
Vertical Accretion 1.8 mm yr^{-1}
Soil Expansion 0.7 mm yr^{-1}

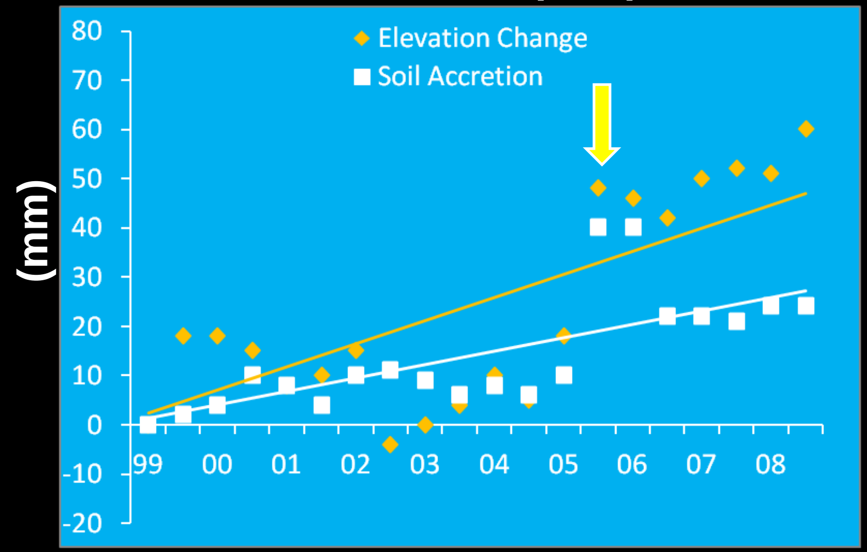
Southwest Florida (Shark River Region) – Tom Smith

Shark River (SH3)



Elevation Change 0.87 mm yr^{-1}
Vertical Accretion 2.9 mm yr^{-1}
Soil Subsidence -2.0 mm yr^{-1}

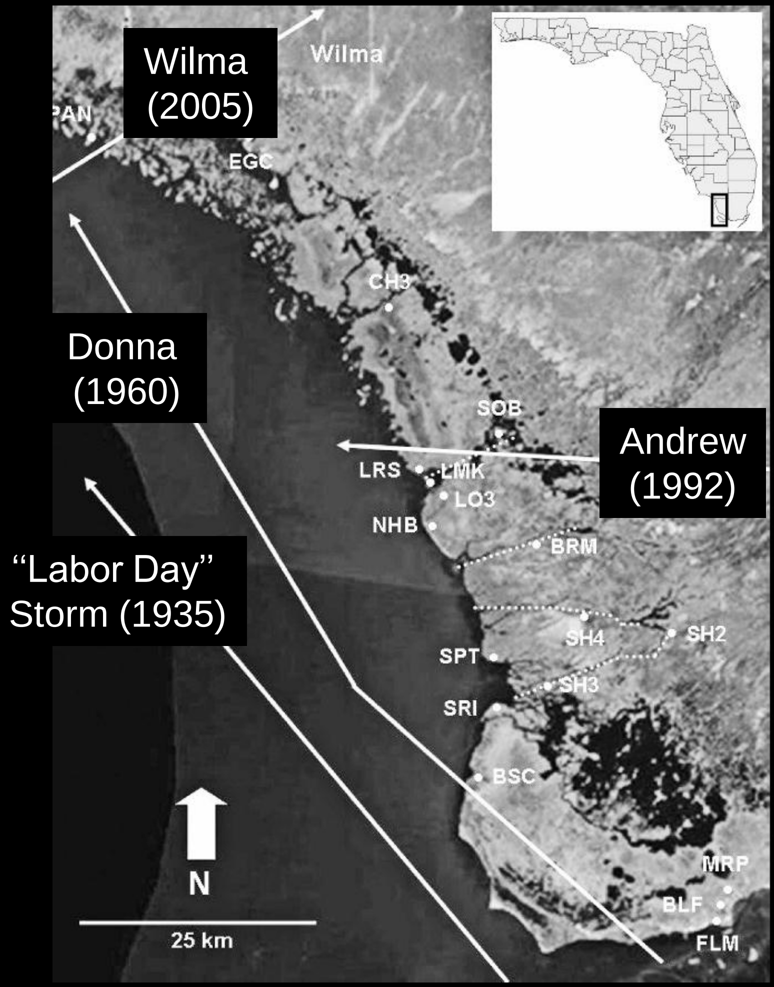
Lostman River (LO3)



Elevation Change 2.4 mm yr^{-1}
Vertical Accretion 1.4 mm yr^{-1}
Soil Expansion 1.0 mm yr^{-1}

Modified by Coronado from T. Smith et al 2009*

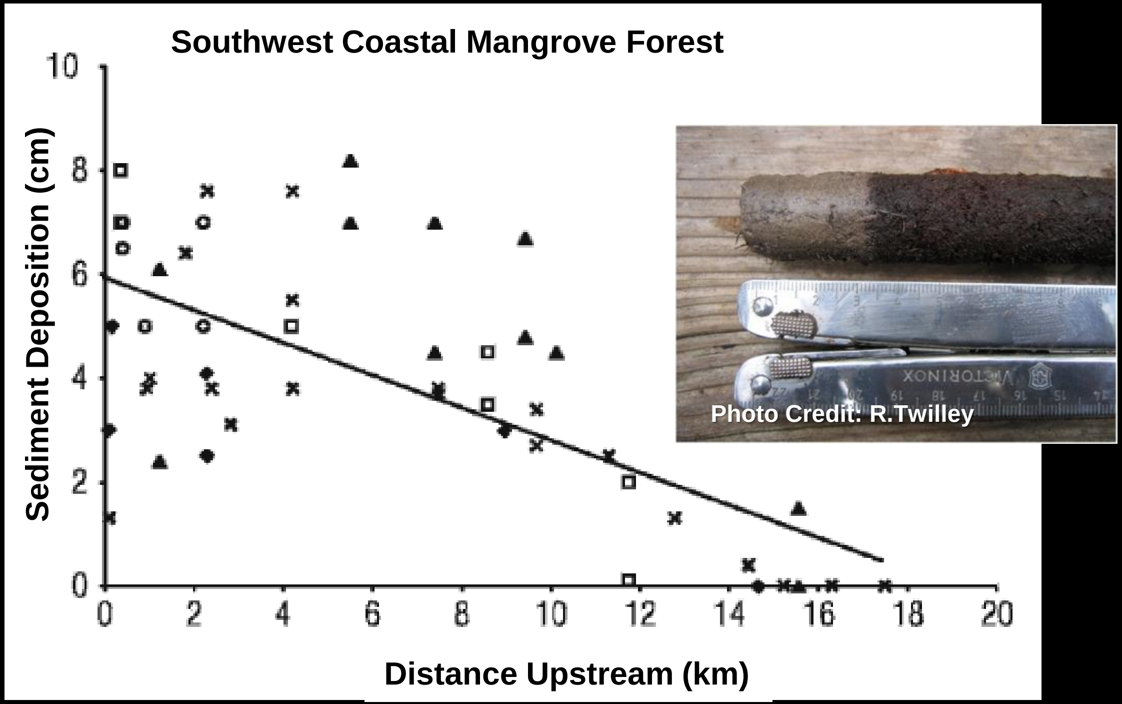
Mangrove Communities "state change" by Hurricanes



Smith et al. 2009

- **Transport propagules inland (recruitment)**
- **Influx sediment, nutrients (accretion)**
- **Scour coastline (erosion/peat collapse)**

Coastal Forests - Rapid Sediment Deposition
(10-80 mm pulsed event)

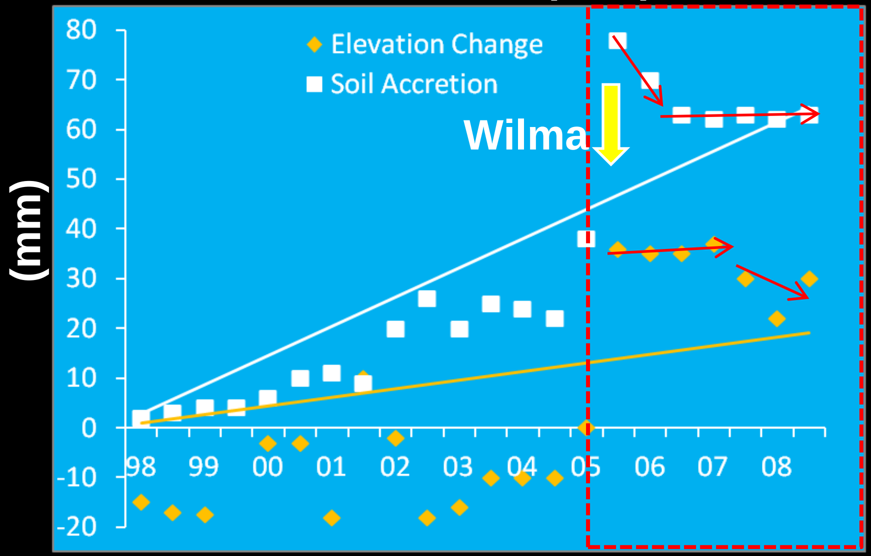


Smith et al. 2009

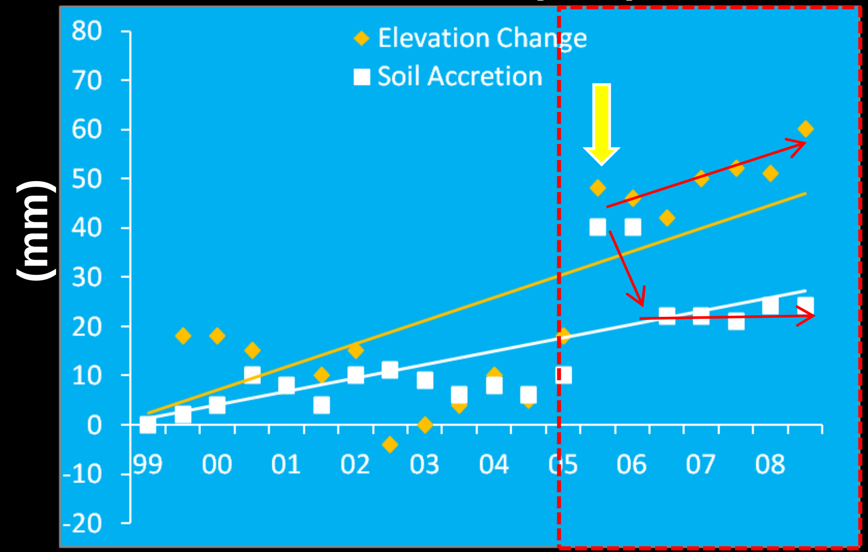
Efflux of Sediments and Compaction (1 m tides along Gulf of Mexico)

Long-Term Post Hurricane Sediment Elevation Change and Accretion Rates Southwest Florida (Shark River Region)

Shark River (SH3)



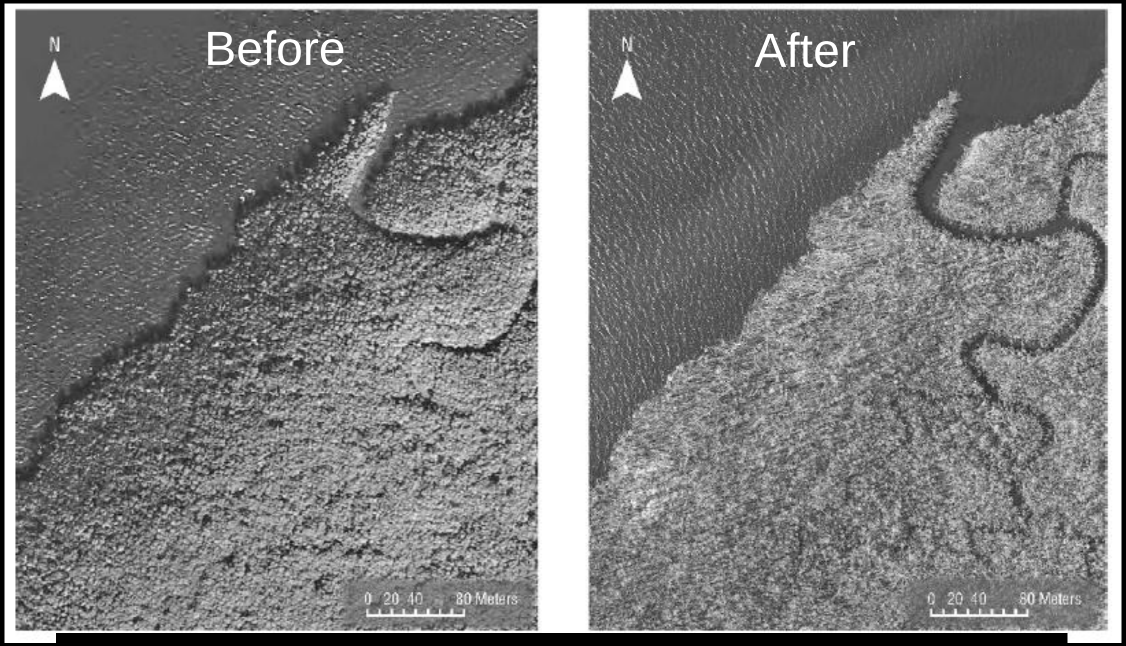
Lostman River (LO3)



Modified by Coronado from T. Smith et al 2009

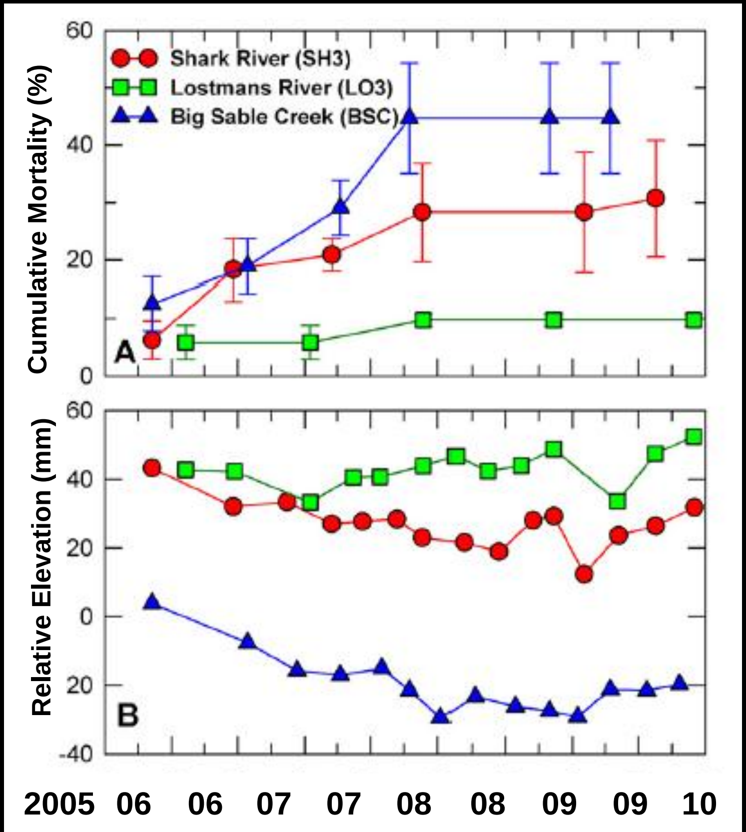
Loss of Forest and Belowground Structure

- Erosion of Surficial Peat – Delayed Tree Mortality
- Peat Oxidation
- Peat Collapse



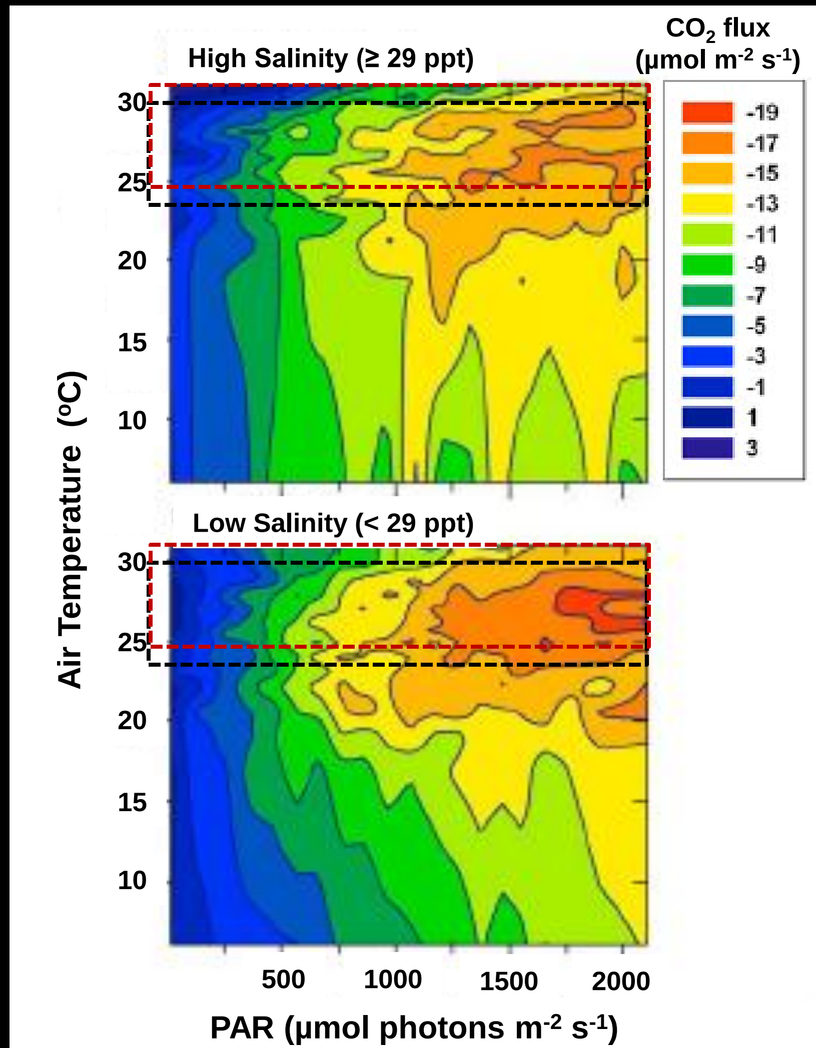
Little Shark Island-West Coast after Wilma 2005

Smith et al. 2009



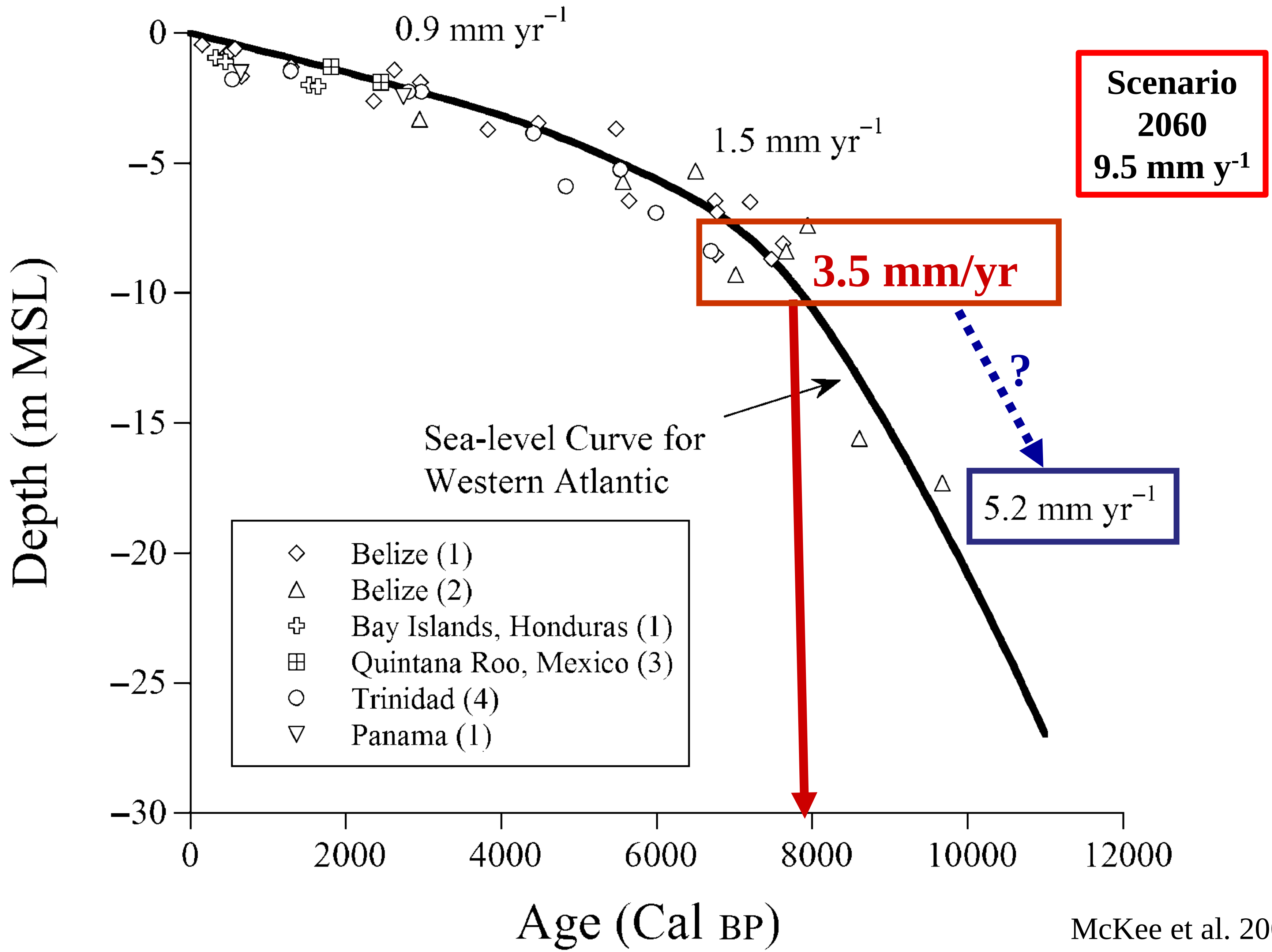
Barr et al. 2012

Temperature, Salinity and Elevated CO_2 Effects Mangroves (Eddy Covariance 30 m Towers – Mouth of Shark River)



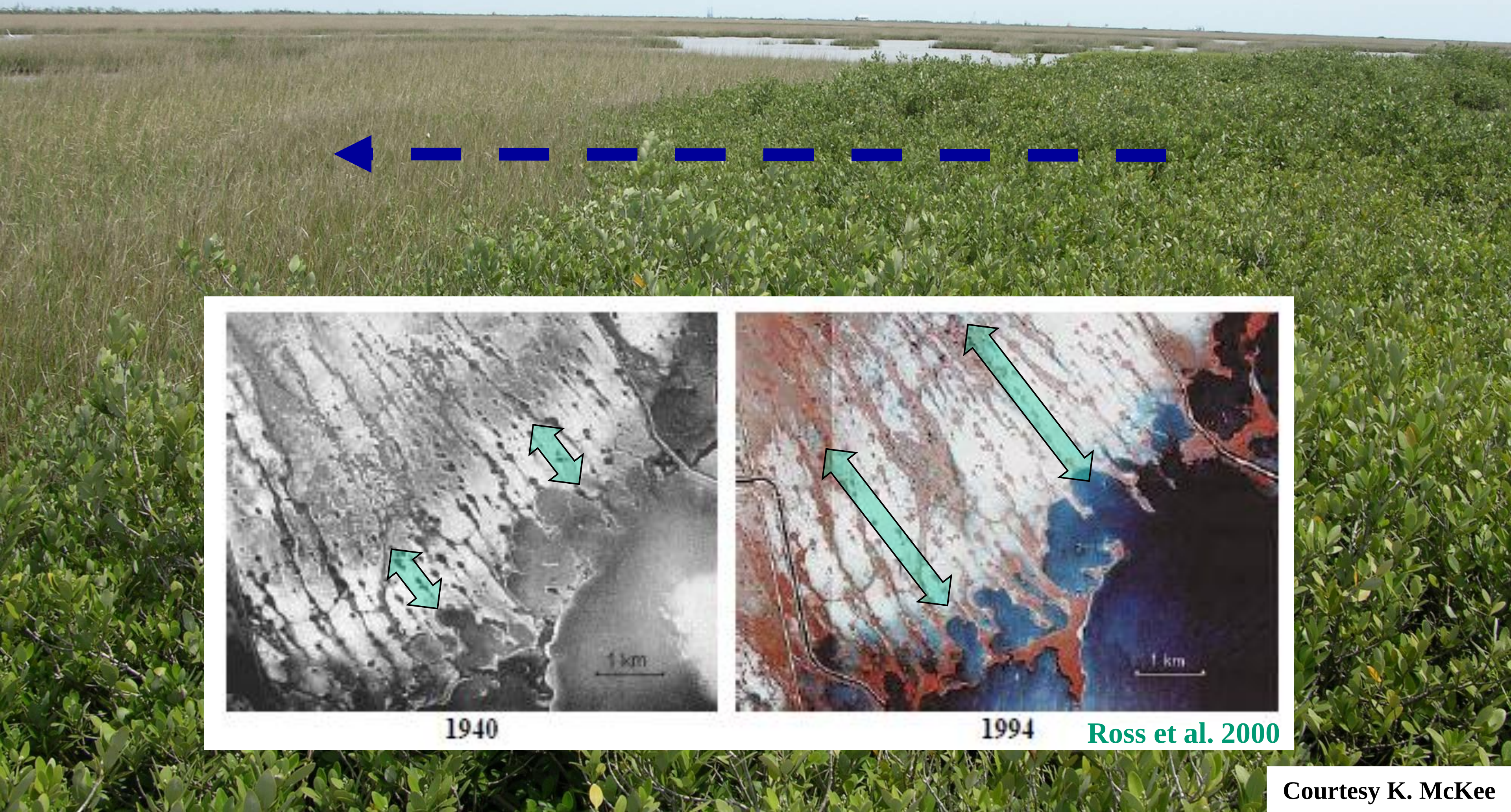
Barr et al. 2010

Rate of Mangrove Peat Accumulation-Caribbean



McKee et al. 2007

March of the Mangroves
(Latitudinal Shifts Community)



Ross et al. 2000

Courtesy K. McKee

Conclusions

•Using a 9.5 mm y^{-1} scenario for sea level rise (SLR) coastal mangrove forests would be overwhelmed and not likely keep pace with SLR

•Rates of elevation change long-term are ~1-2.5 mm y^{-1} with reliance on belowground biomass and autochthonous processes to maintain elevation- highly vulnerable to SLR.

•Storm surges can deposit 10-80 mm along SW coast and ~5 mm Florida Bay some of which is subsequently lost back to tide

•Storms can also destabilize sediments with high forest mortality causing erosion (20-30 mm) and peat collapse-with ~3yr lag phase

•Reduced freshwater flows and marine transgression with SLR will move the mangrove community into marsh habitat

•Mangrove community productivity is enhanced under polyhaline conditions (<29 ppt) and temperatures below 30ºC

Scientific Needs

- Regional measurements and estimates of SLR
- Higher resolution Elevation Maps in Mangrove zone
- Role physiochemical processes, forest type and pulsed events on Mangrove sediment elevation change
- Sediment "Erodibility" Index Maps – Nutrient Content
- Mangrove Island SET studies in Florida Bay
- Modelling scenarios integrating drivers of various time scales

Future Management Scientific Needs

- Develop models that can assist in determining if freshwater input into Florida Bay (as part of CERP) could slow down the inland expansion of mangrove into the Everglades?
- Will freshwater inputs increase above and belowground mangrove productivity and long-term elevation changes keep pace with SLR?
- Will rising CO_2 increase productivity at higher salinity levels and enhance above and below-ground productivity?

II. The Greater Everglades Seagrass and SAV Community (Oligohaline to Marine Species: Ecotone to FL Reef Tract)

Marine SAV Community Distribution in Everglades

Why are Marine Macroalgae & Seagrasses Important?


- Habitat - Foundation
- Base Foodwebs
- Sediment Stabilization
- Sediment Generation Tropics
- Settlement Sites Corals
- Nutrient Cycling
- Competitors (Nuisance spp)
- Substrates - Epiphytes





Global Change Biology

Global Change Biology (2013) 19, 103–132, doi: 10.1111/j.1365-2486.2012.02791.x

REVIEW

Climate change and ocean acidification effects on seagrasses and marine macroalgae

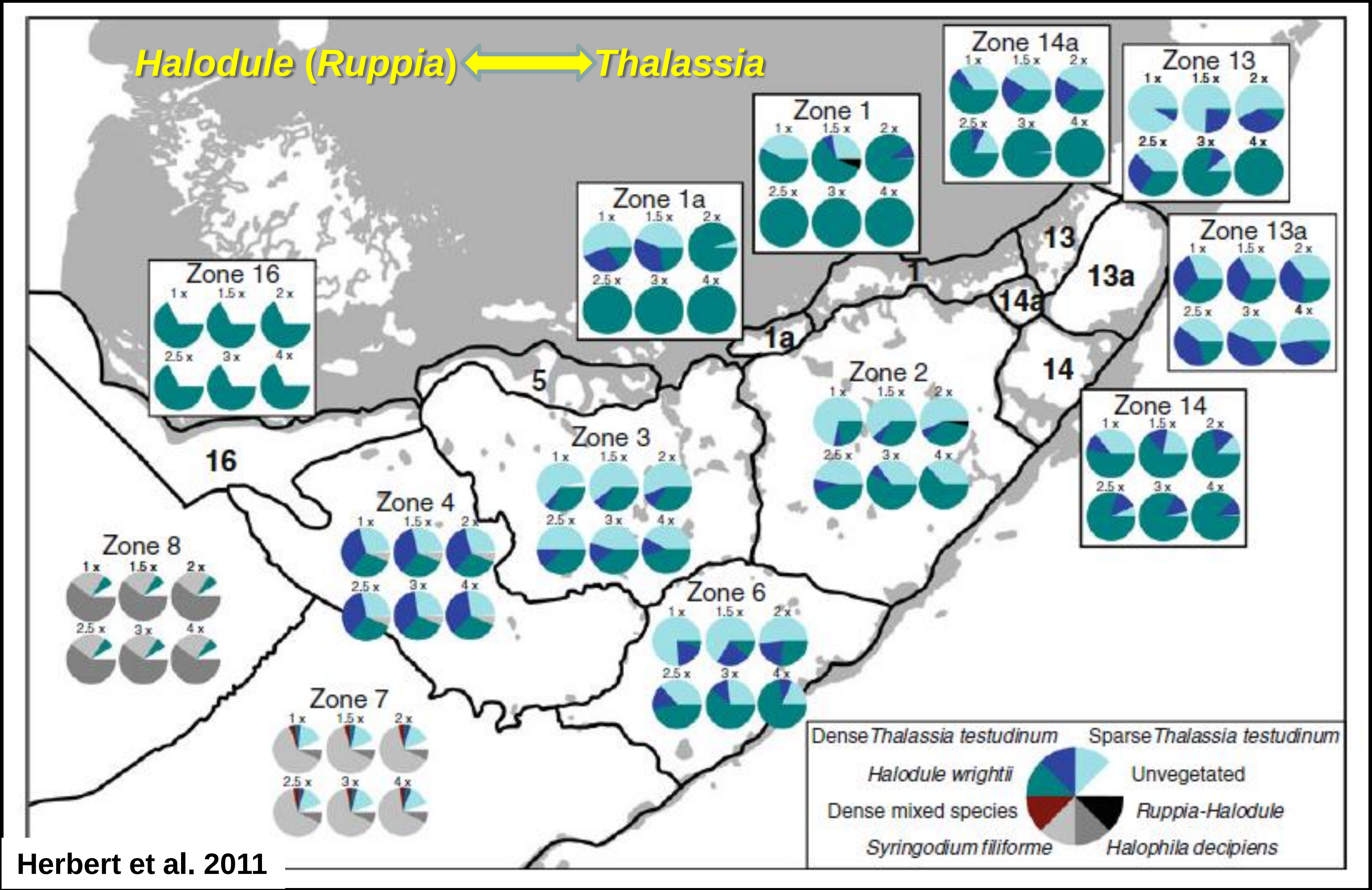
MARGUERITE KOCH*§, GEORGE BOWES†, CLIFF ROSS‡ and XING-HAI ZHANG§

Major Drivers of Greater Everglades Marine SAV Communities

1) Salinity
2) Nutrients
3) Light
4) Grazing/Competition (CO_2 Enrichment)

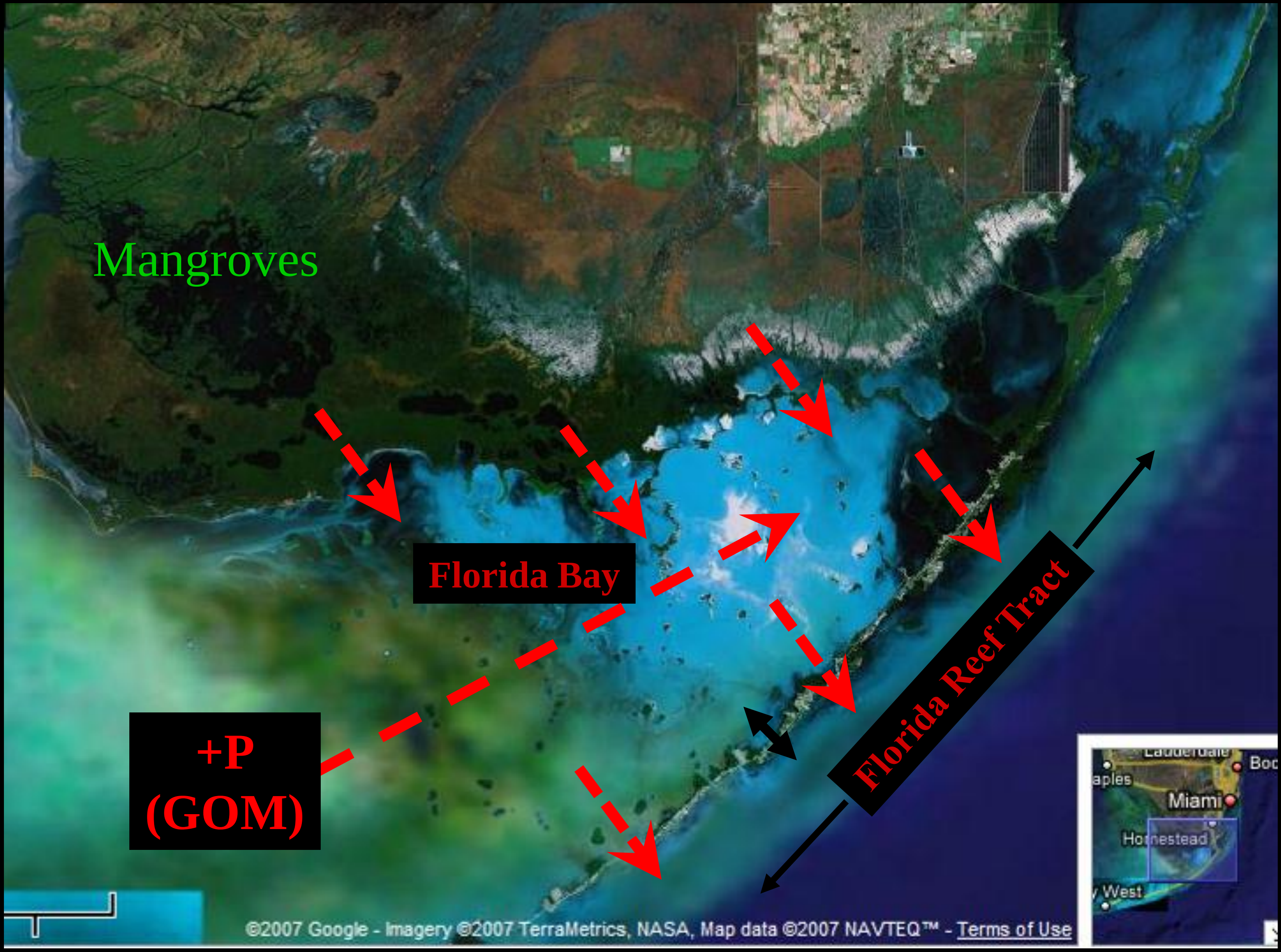
Modeled Increases Freshwater Flows

- Upper basins increased *Halodule* (*Ruppia*) over *Thalassia (CERP Goal)*
- Western basins insensitive up to 4xs flows because of mudbanks/basins
- Sea level rise dilute these modest effects



Herbert et al. 2011

Landscape Nutrient Flux with Sea Level Rise (Linkages between slr, water quality and light)



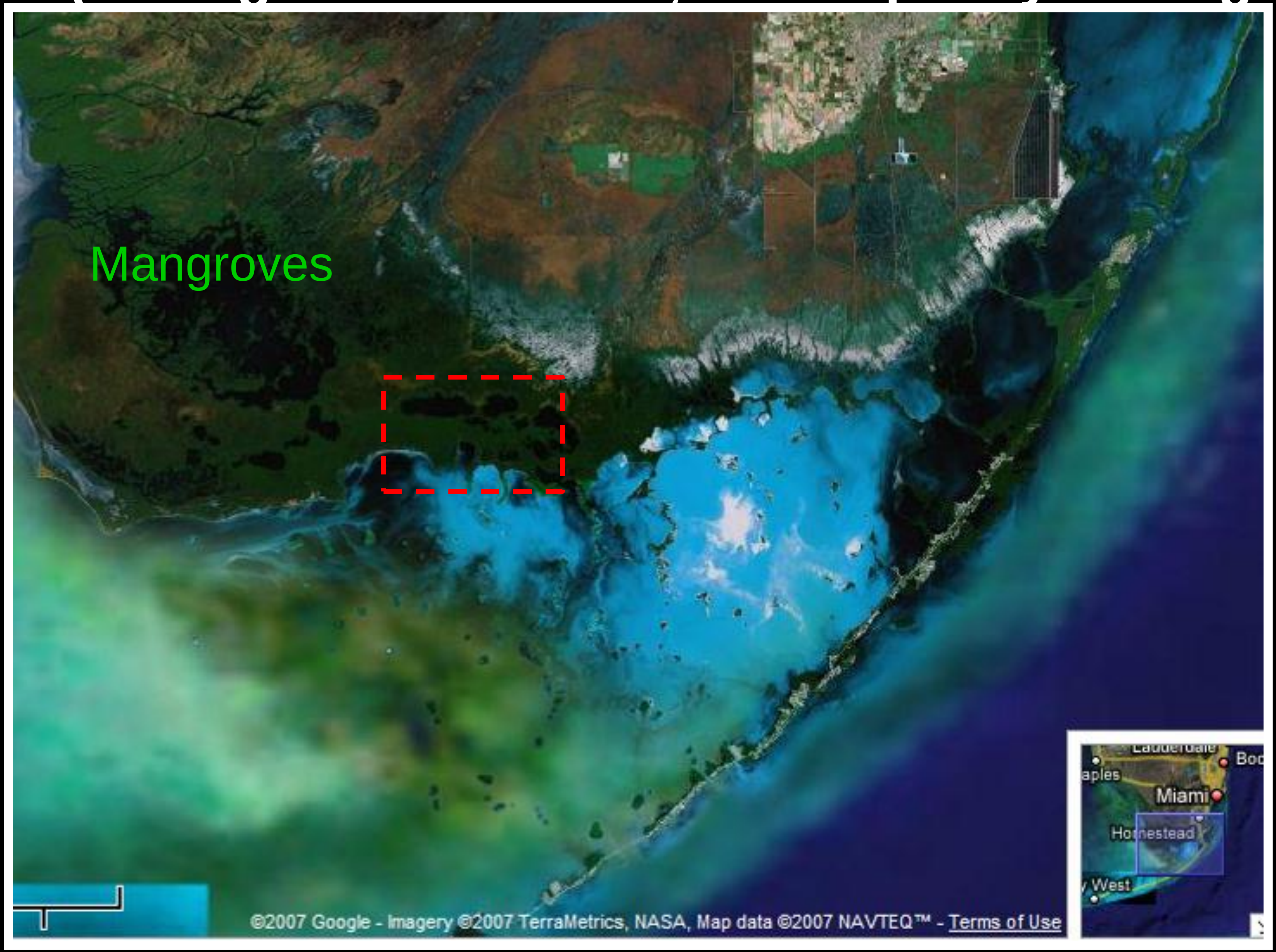
Large Scale Seagrass Mortality Events
Nutrient Pulses to Water Column Florida Bay

4 to 5
mmol P m^{-2}

1 m Depth
(4-5 µmol P L^{-1})

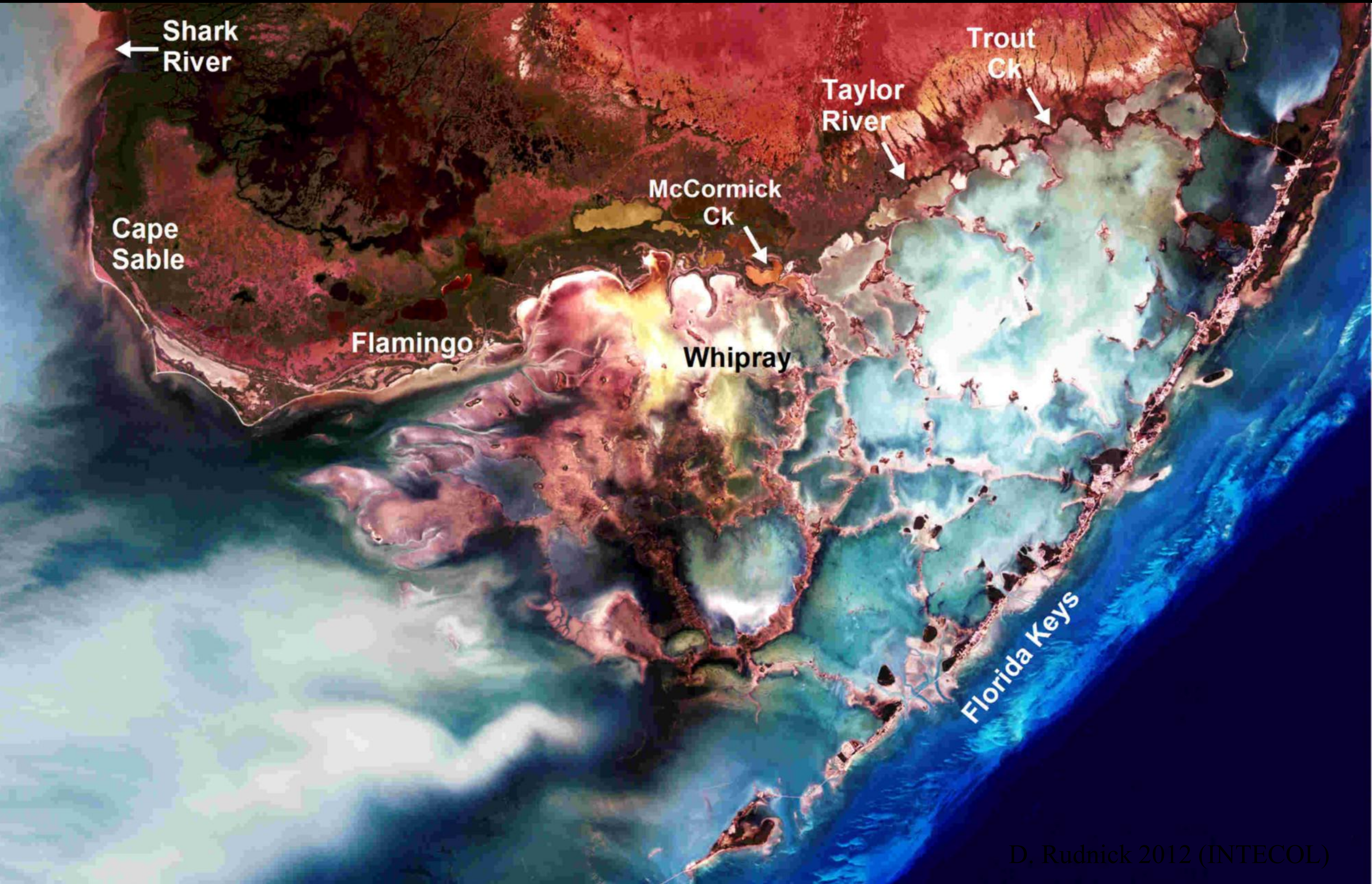
Rosch and Koch (2009)

Landscape Nutrient Flux with Sea Level Rise (Linkages between slr, water quality and light)

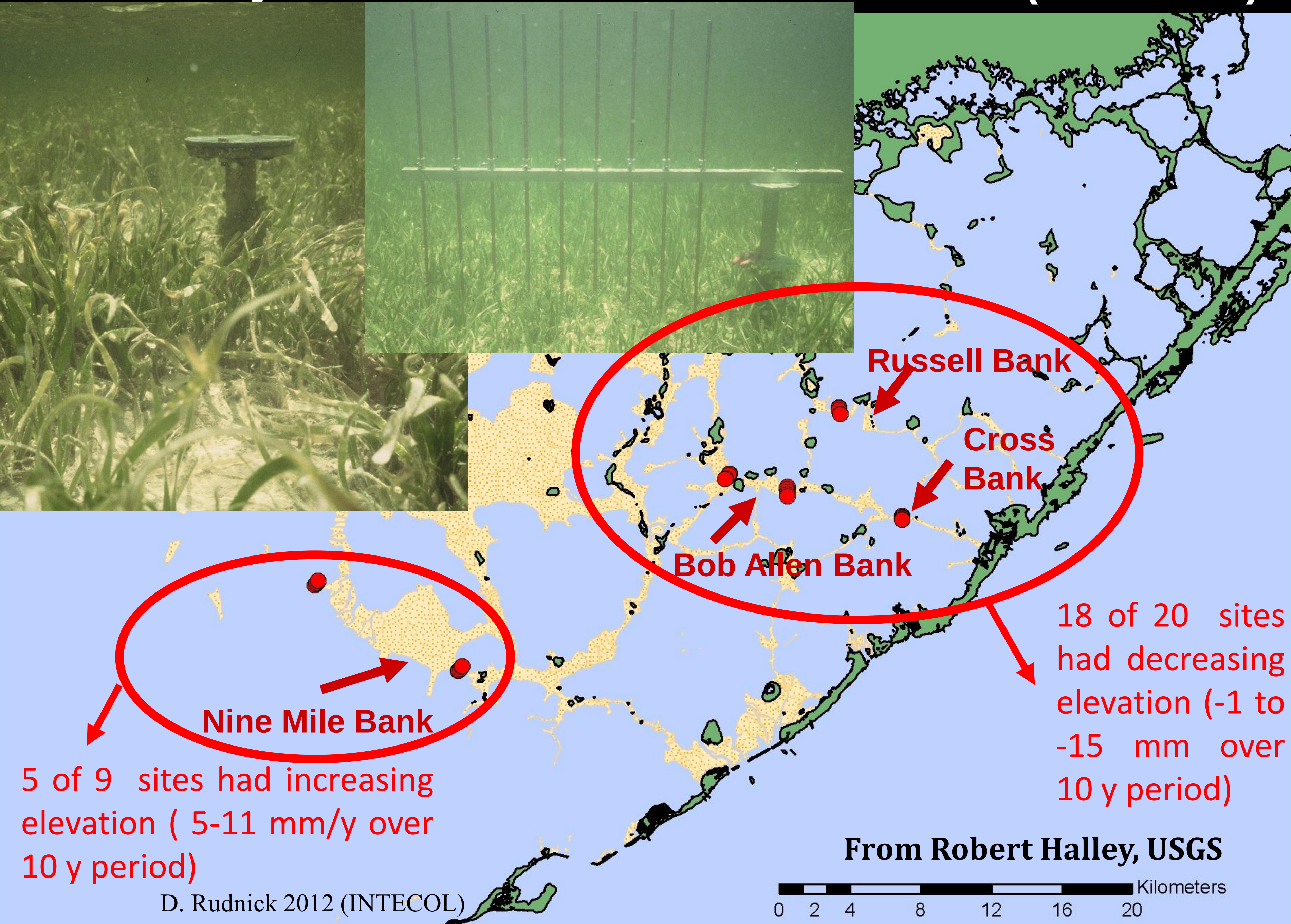


Florida Bay Bank Elevation Changes - Critical GOM and Internal Circulation

- **Currently Wide-Ranging Estimates Mudbank Accumulation Rates**
- **^{210}Pb high rates 3 to 30 mm y^{-1} (Median = 4.6 mm y^{-1}) (Holmes et al. 2001)**



Florida Bay Mudbank Surface Elevation Tables (1997-2007)

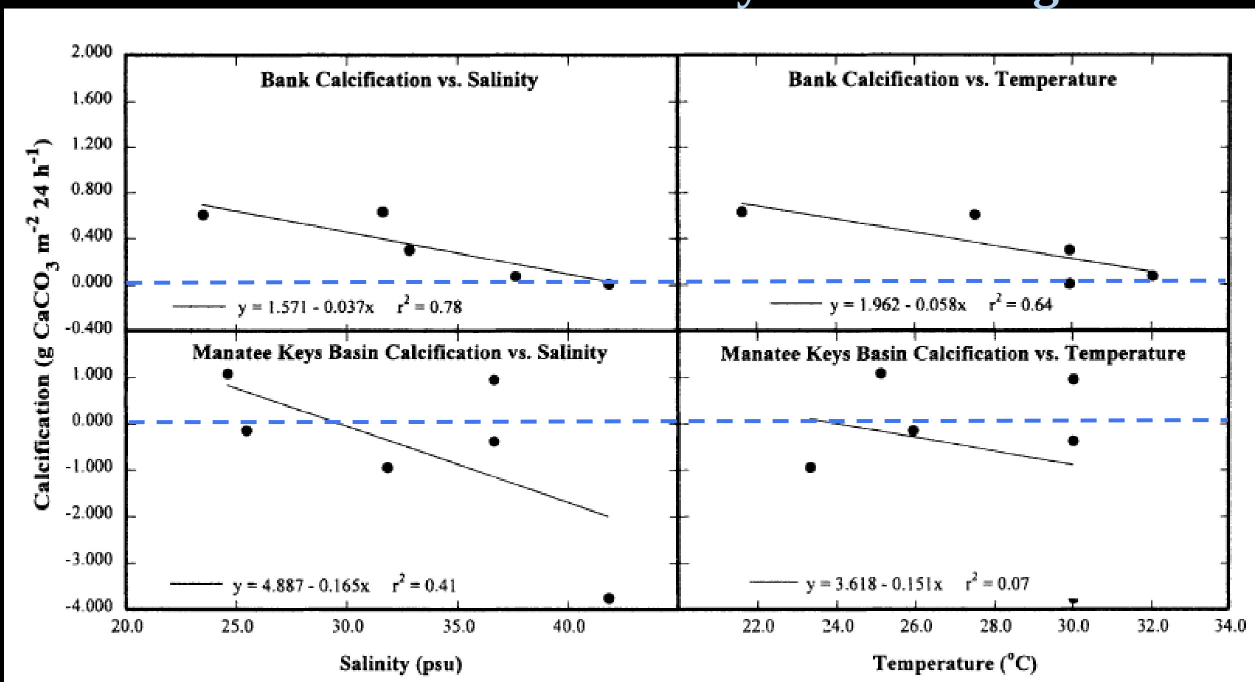


Direct Calcification-Dissolution Rates $CaCO_3$ on Banks

Substrate type	Area (m^2)	C_{net} (g $CaCO_3$ m^{-2} yr^{-1})	Sediment accumulation (cm 1000 yr^{-1})
Basins			
Sparse seagrass	375,128,462	−112.0	−9.6
Intermediate seagrass	190,807,051	−83.9	−7.2
Hard bottom	439,668,144	776.0	66.9
Mud bottom	209,804,241	−78.4	−6.8
Dense seagrass	65,288,753	235.0	20.2
Mixed bottom	57,619,872	126.0	10.8
Open sand	59,182,515	nd	nd
Banks			
Mud bank suite	309,493,603	235.0	20.2

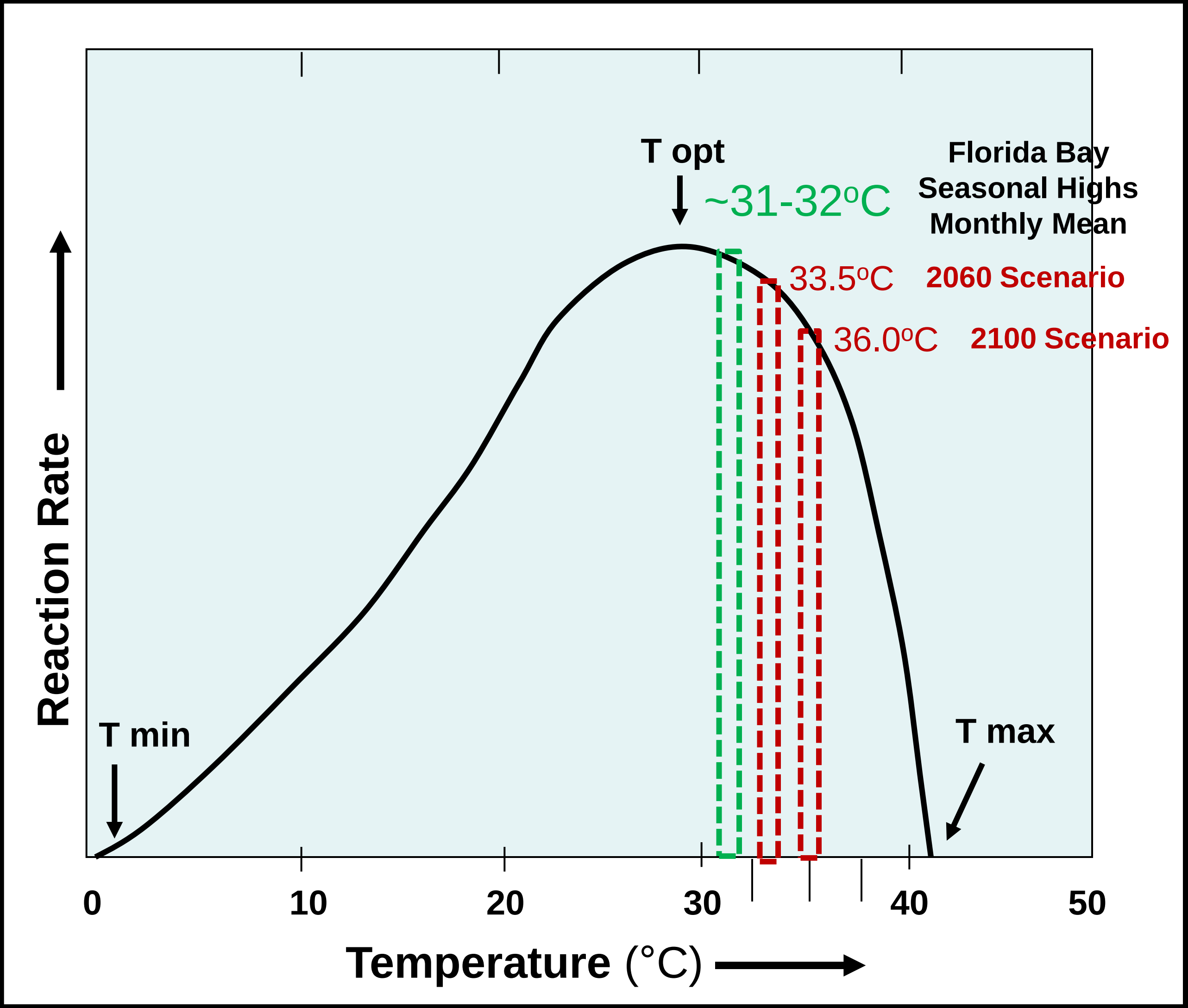
-0.1 to 0.7 mm y^{-1}

Net Calcification Banks and Basins FL Bay Declined higher Salinity and Temp



Yates and Halley (2006)

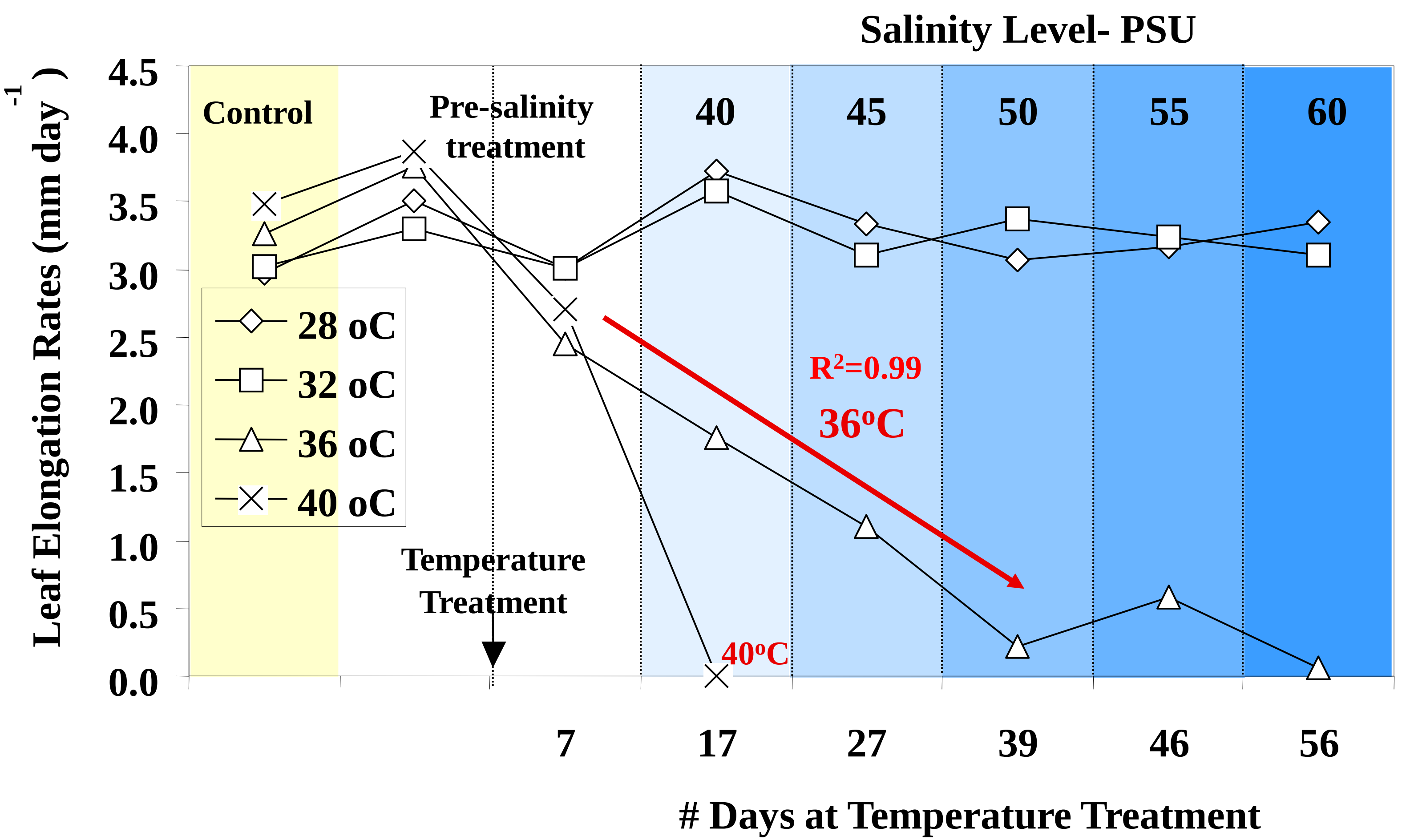
Temperature and Photosynthesis



X CO_2 Marine Plants
??

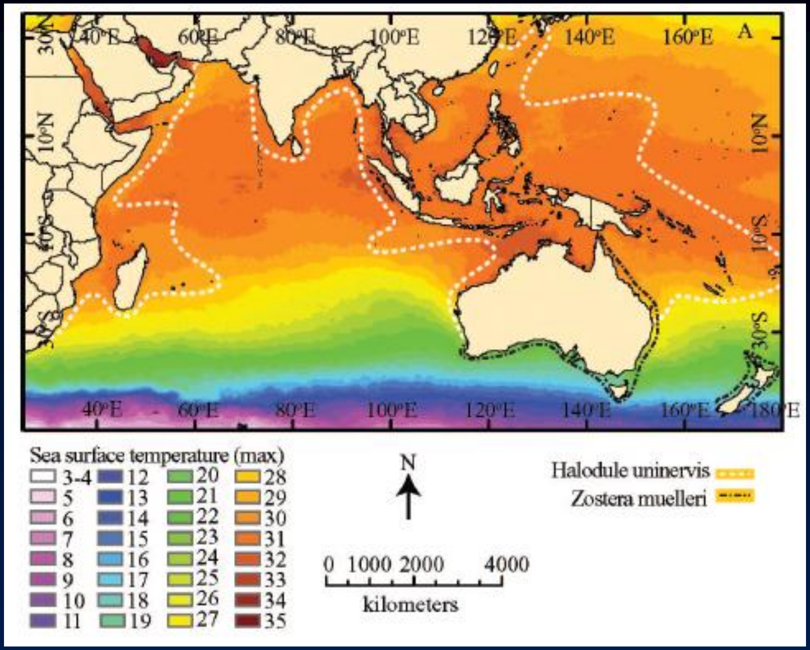
Adapted from Hopkins and Hünter 2004

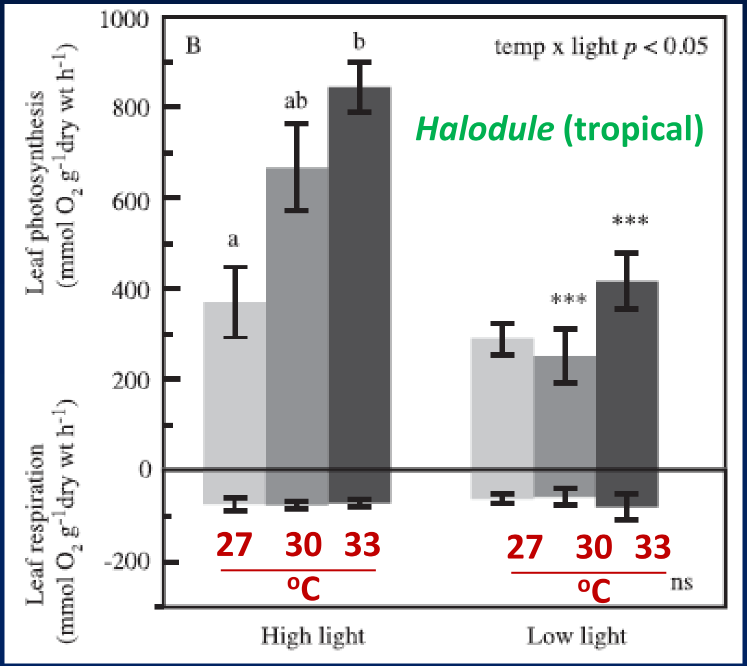
Thalassia-Growth



Koch et al.

Elevated Temperature and Thermal Limits (Australian Seagrasses)





Collier et al. 2011

Sargassum-Temperature Threshold

Koch and Anderson in prep.

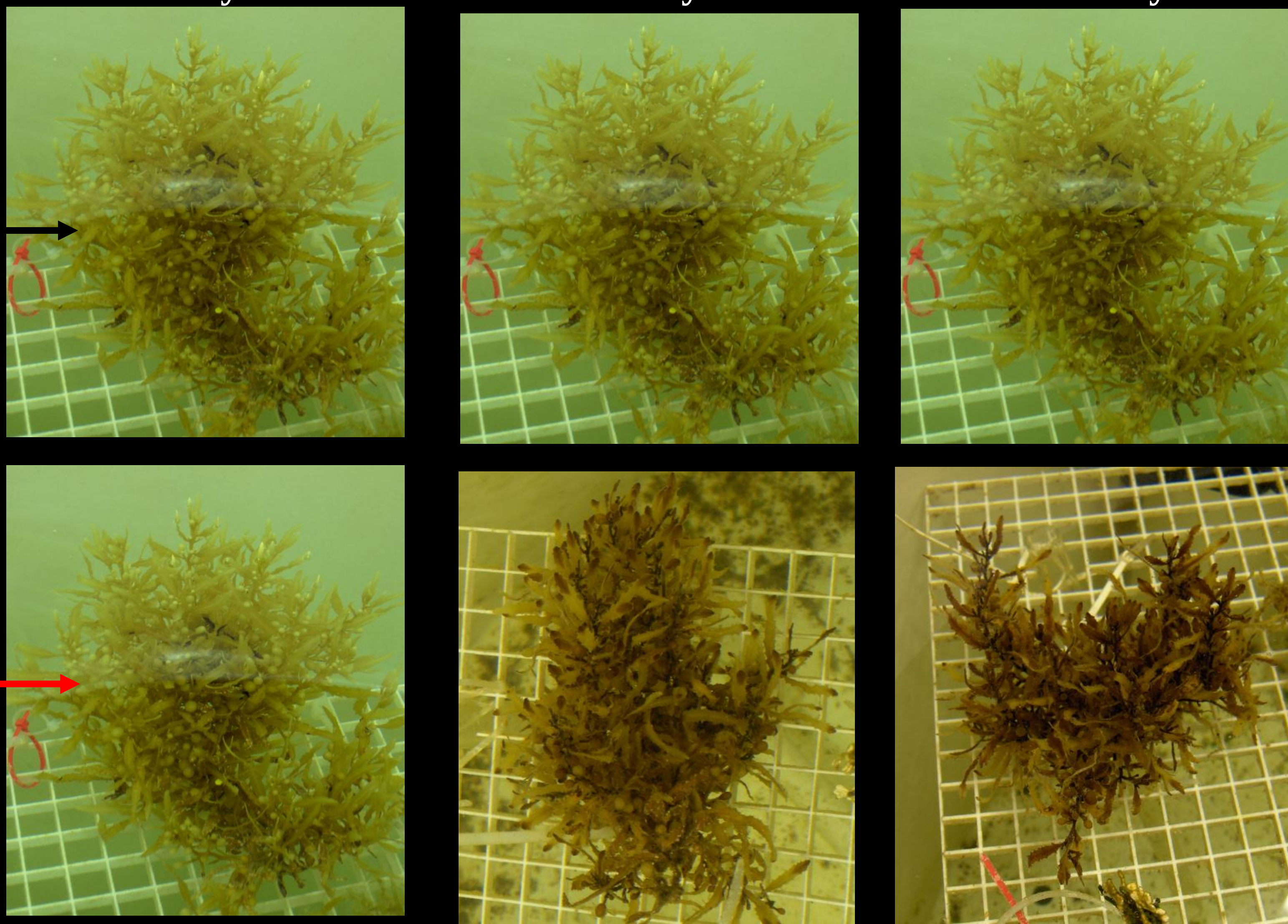
0 days | **6-7 days** | **12-13 days**

28ºC

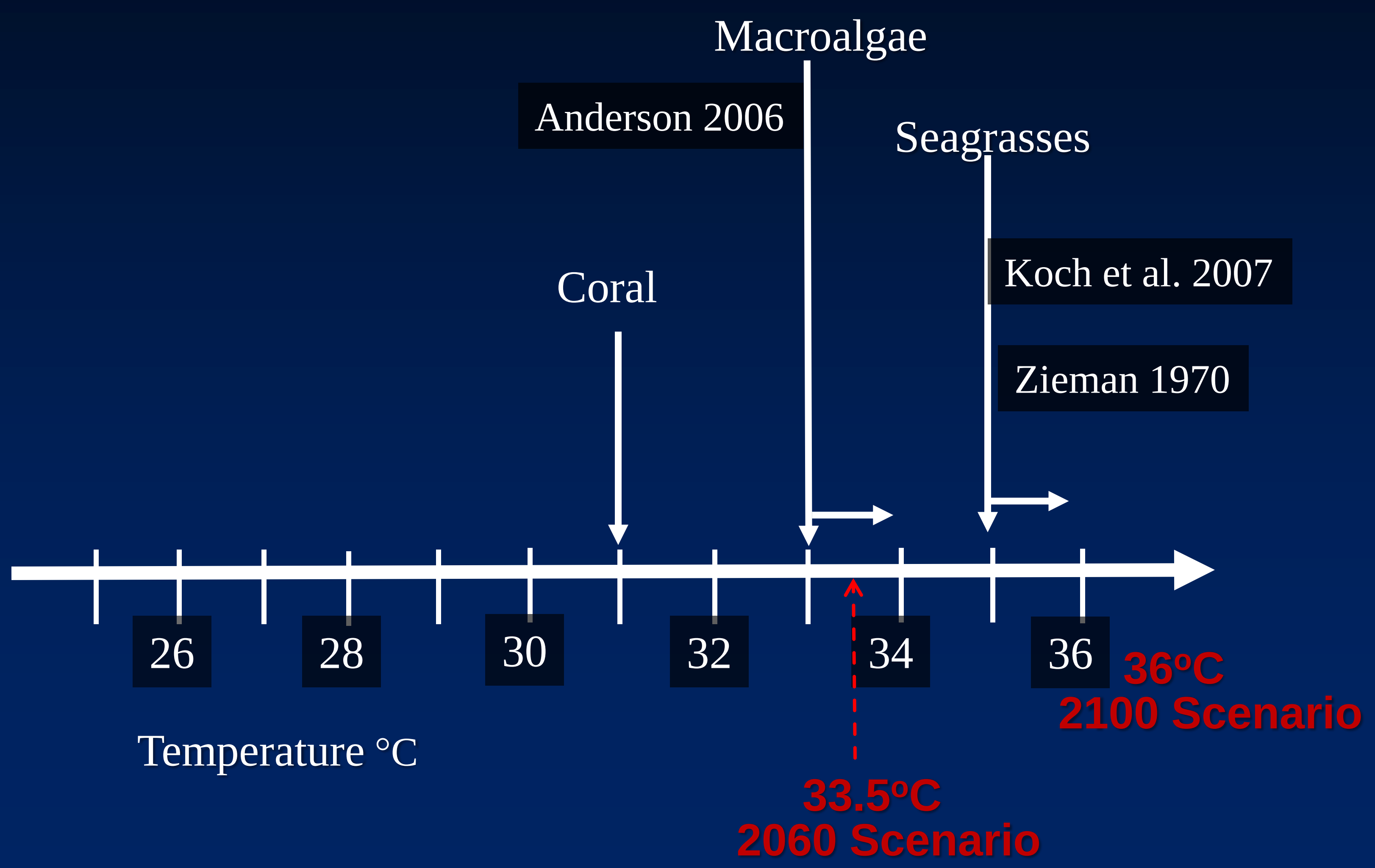
30ºC

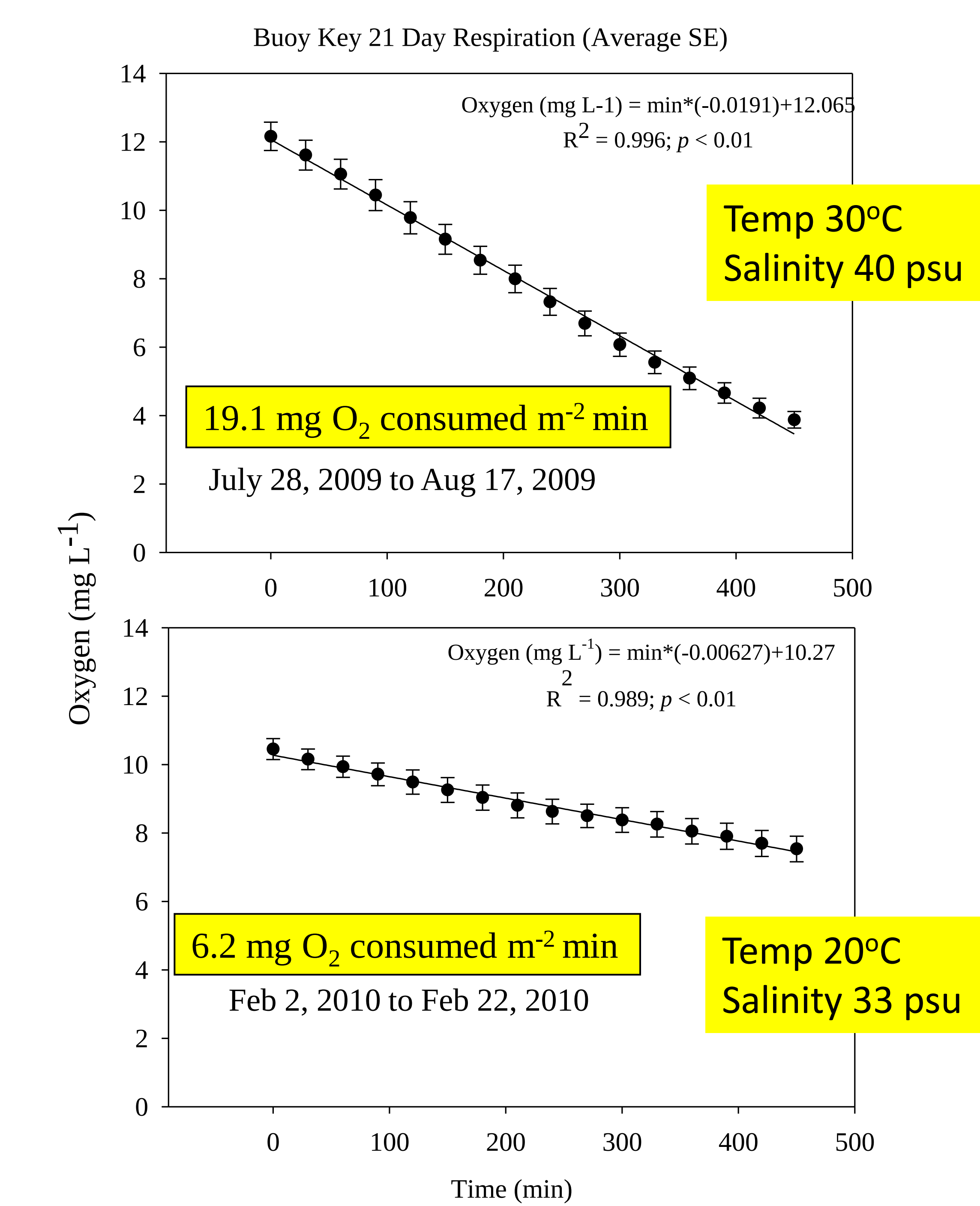
32ºC

34ºC



Thermal Limits Keystone Florida Keys Species




Buoy Key 21 Day Respiration (Average SE)
Oxygen (mg L-1) = min*(-0.0191)+12.065
R2 = 0.996; p < 0.01
Temp 30°C
Salinity 40 psu
19.1 mg O2 consumed m-2 min
July 28, 2009 to Aug 17, 2009
Oxygen (mg L-1)
Oxygen (mg L-1) = min*(-0.00627)+10.27
R2 = 0.989; p < 0.01
6.2 mg O2 consumed m-2 min
Feb 2, 2010 to Feb 22, 2010
Temp 20°C
Salinity 33 psu
Time (min)
0
2
4
6
8
10
12
14
0
100
200
300
400
500

Koch et al.

Oxygen Concentrations (mg/L) at 100% O_2 Saturation as Function Salinity and Temperature

Temperature (ºC)	Salinity (psu)						
	25	**30**	**35**	**40**	**45**	**50**	**55**
10	9.62	9.32	9.02	8.74	8.47	8.20	7.94
15	8.65	8.39	8.14	7.89	7.65	7.42	7.20
20	7.85	7.62	7.40	7.18	6.97	6.77	6.57
25	7.17	6.97	6.77	6.58	6.40	6.22	6.04
30	6.59	6.41	6.24	6.07	5.90	5.74	5.59
35	6.08	5.92	5.77	5.62	5.47	5.33	5.19
40	5.64	5.49	5.35	5.22	5.08	4.95	4.83

CO_2 Enrichment
Seawater
"Ocean Acidification"

More Complex in the Ocean!!

Inorganic Carbon Speciation – Carbonate Equilibria

Air
CO_2 (g)

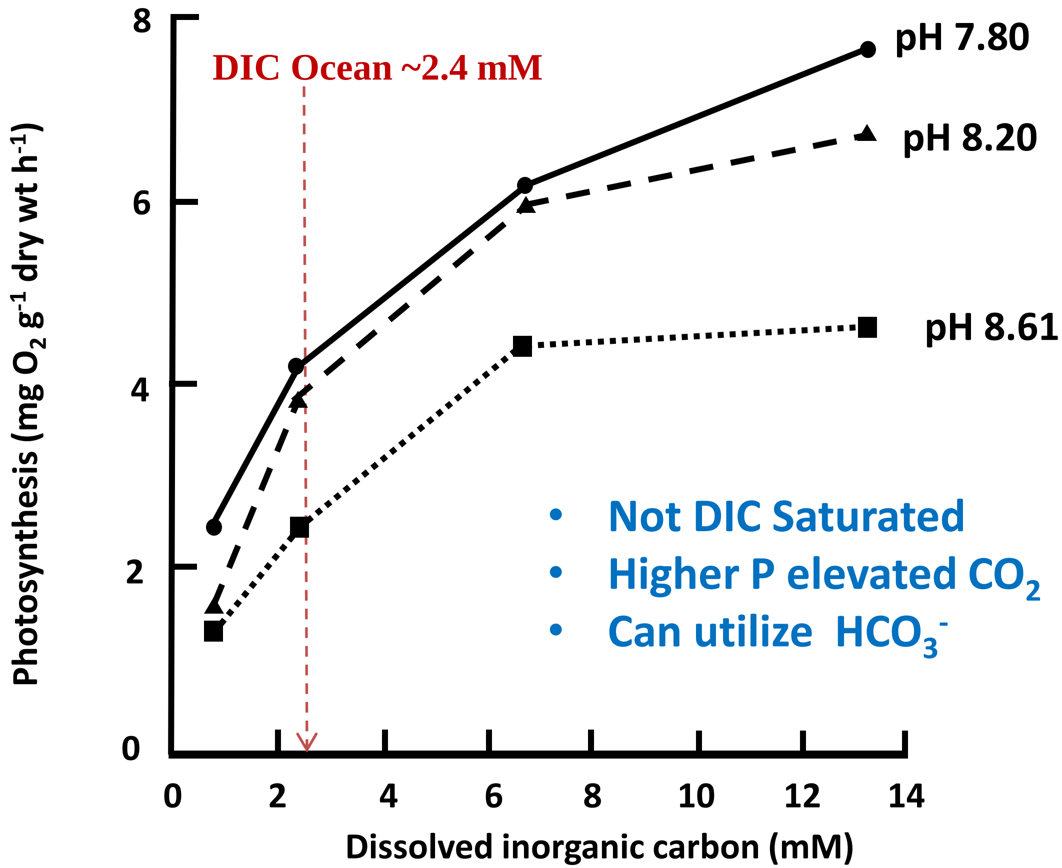
Gas Exchange

Seawater

		Pre-industrial	Present	Yr 2100	Change pre-industrial to Yr 2100
	pCO_2 Carbon Dioxide in µatm	280 [277]	394 [392]	1,000 [1,087]	257% [292%]
	Carbon Speciation µmol kg^{-1}				
CO_2 (aq) $+H_2O$ ⇌	H_2CO_3 Carbonic Acid	8	11	31	288%
H_2CO_3 ⇌	$H^+ + HCO_3^-$ Bicarbonate	1650	1771	2046	24%
HCO_3^- ⇌	$H^+ + CO_3^{2-}$ Carbonate	264	215	104	(- 61%)
	DIC	1922	1997	2180	13%
	$pH_{(sws)}$	8.16	8.04	7.66	(- 6%)
	$\Omega_{(calcite)}$	6.36	5.18	2.49	(-61%)
	$\Omega_{(agragonite)}$	4.19	3.41	1.64	(-61%)

(In Koch et al. 2012; modified from Fabry et al . 2008)

Seagrasses and Marine Macroalgae Utilize HCO_3^- and CO_2
Are They Saturated with Ci?

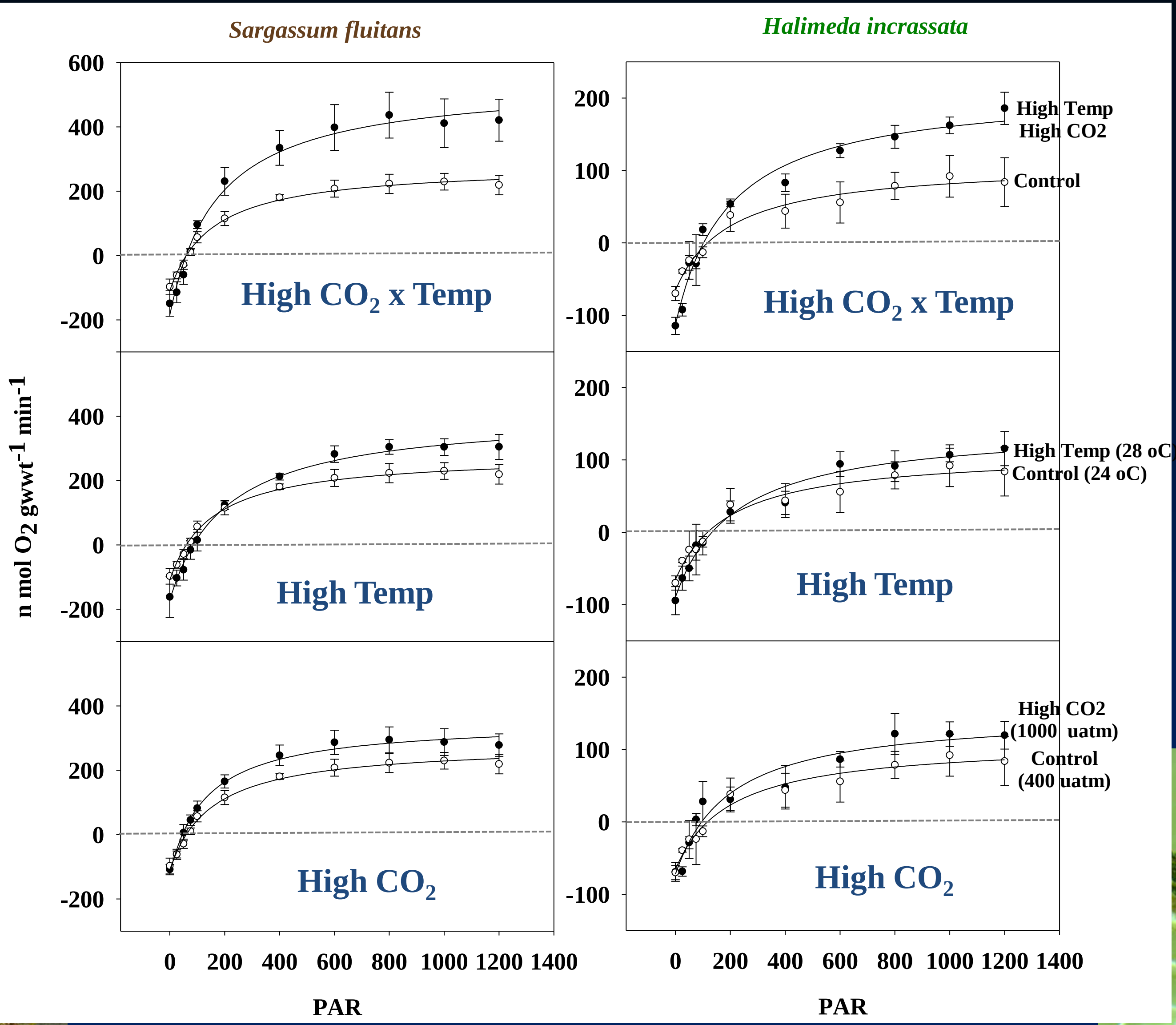


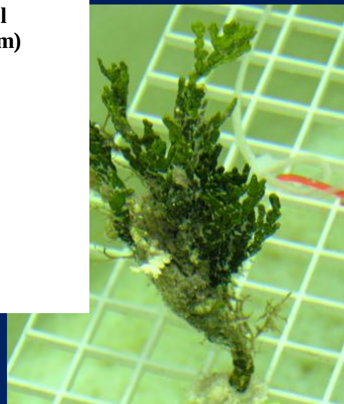
- Not DIC Saturated
- Higher P elevated CO_2
- Can utilize HCO_3^-

Durako 1993

Thalassia testudinum
(Seagrass – Angiosperm)

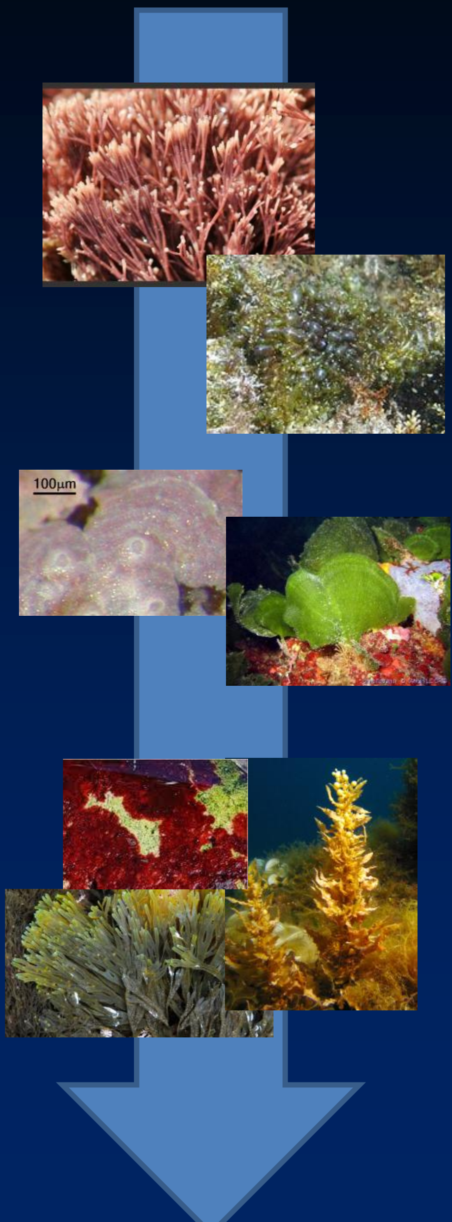
Elevated pCO_2 x Temperature Winter Experiment





Koch et al.

Field CO_2 Vent Studies



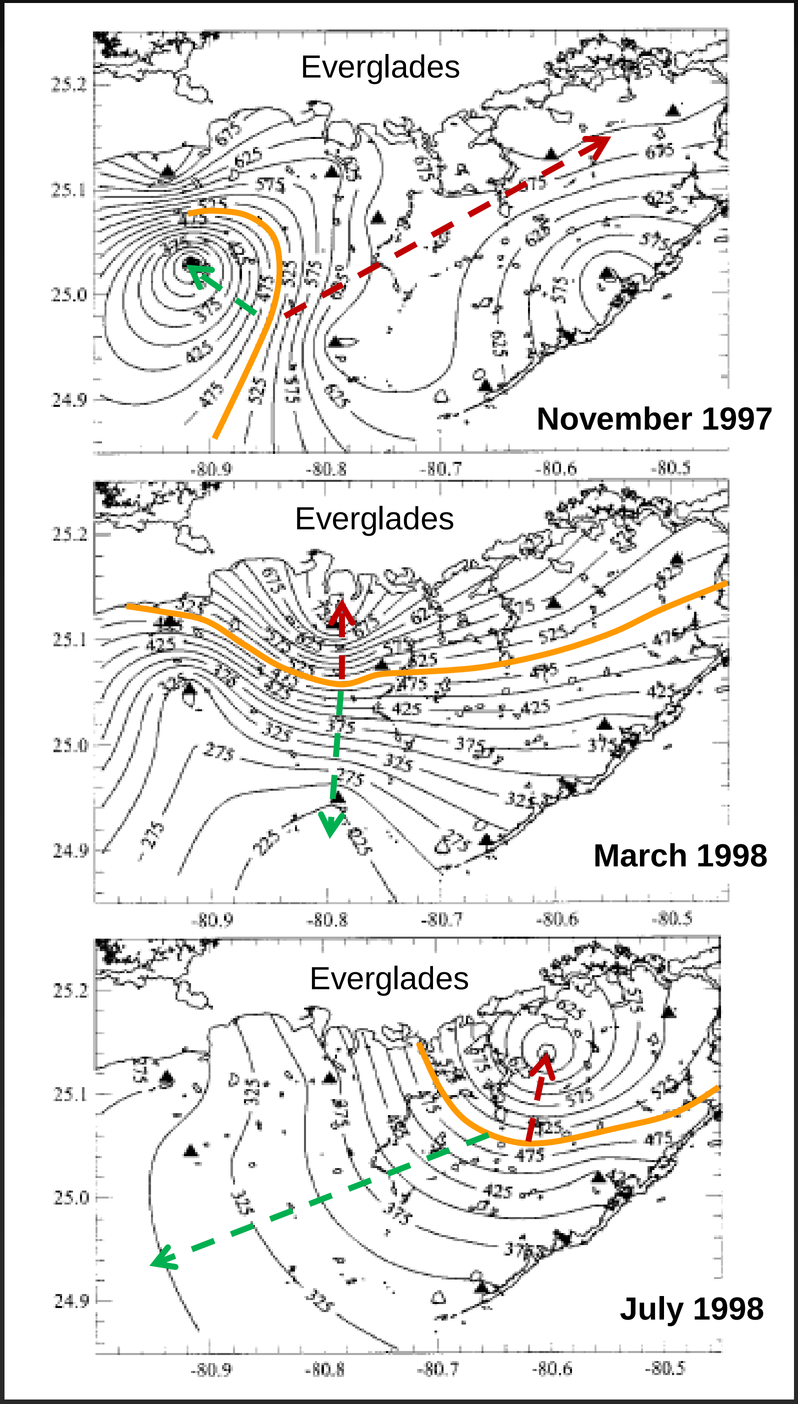
Hall-Spencer et al. (2008)

Carbonate Dynamics
Estuarine Systems
Driven by Metabolic Processes

~490 ppm pCO_2 Contour
2060 Senario

> 490 ppm pCO_2

< 490 ppm pCO_2



Millero et al. (2001)

Conclusions

- **Increased freshwater flows not likely balance increased salinities with a 9.5 mm y^{-1} SLR scenario unless higher precipitation occurs and banks overtop increasing basin exchange**

- **Higher salinity and P and lower light promote *Halodule* and Phytoplankton over *Thalassia*, using NW lakes as a model**

- **Major losses of Thalassia in the Bay will elevate water column P and recycling, promoting Phytoplankton blooms**

- **Sustained 1.5ºC increase (33.5ºC, 2060) modest physiological effects on macro-autotrophs, but 4ºC (36ºC, 2100) significant impacts**

- **Elevated temperatures (+salinity) increase ecosystem respiration, sulfide production and lower saturation of dissolved O_2 in the Bay**

- **CO_2 dynamics in productive coastal systems primarily driven by ecosystem metabolism: > heterotrophy:autotrophy promote fleshy over calcifying algae and sediment dissolution (compounded over long term by ocean acidification)**

Scientific Needs

- Regional measurements and estimates of SLR
- Bank and basin water quality and vegetation monitoring in support FATHOM model – validation and tracking system metabolic shifts
- Better quantification of changes in bank elevation and movements
- Sensitivity of dissolution basin/bank carbonate sediments (temp, salinity, light and pCO_2) and linkage with seagrass metabolism
- Temperature x light x CO_2 interactions marine benthic autotrophs

Future Management Scientific Needs

- Integrate regional hydrodynamic models to landscape and ecosystem models of mangrove-seagrass-reef tract system capture synergistic responses from various climate change scenarios (SLR, precip, tidal, hydrodynamic, temp changes)
- Include major drivers of seagrasses, phytoplankton and carbonate sediment processes in new models developed to test scenarios of climate change impacts (light, nutrients, temperature, metabolism)

Questions?