Carbon Sequestration in Pocosins and Southeastern Peatlands.

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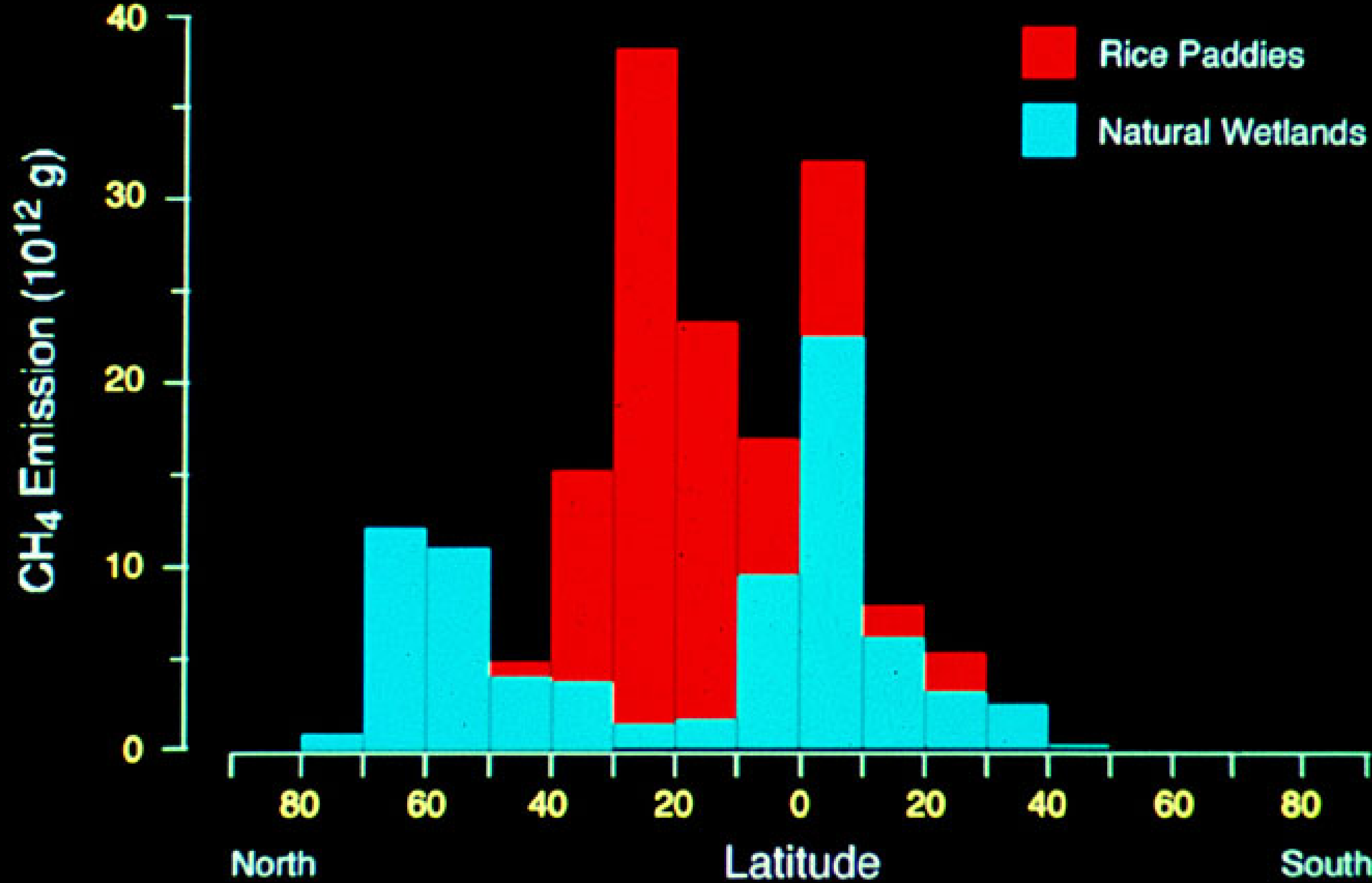
Objectives

- Briefly review the status of peatlands worldwide
- Give an overview of Pocosins and Carolina Bay Origin and Ecology
- Assess carbon storage and loss potential in SE Peatland ecosystems
- Utilize carbon storage data for selected wetland case studies (Pocosins) to develop trends and storage potential

Importance of Freshwater Wetlands Contributions to Global Attributes

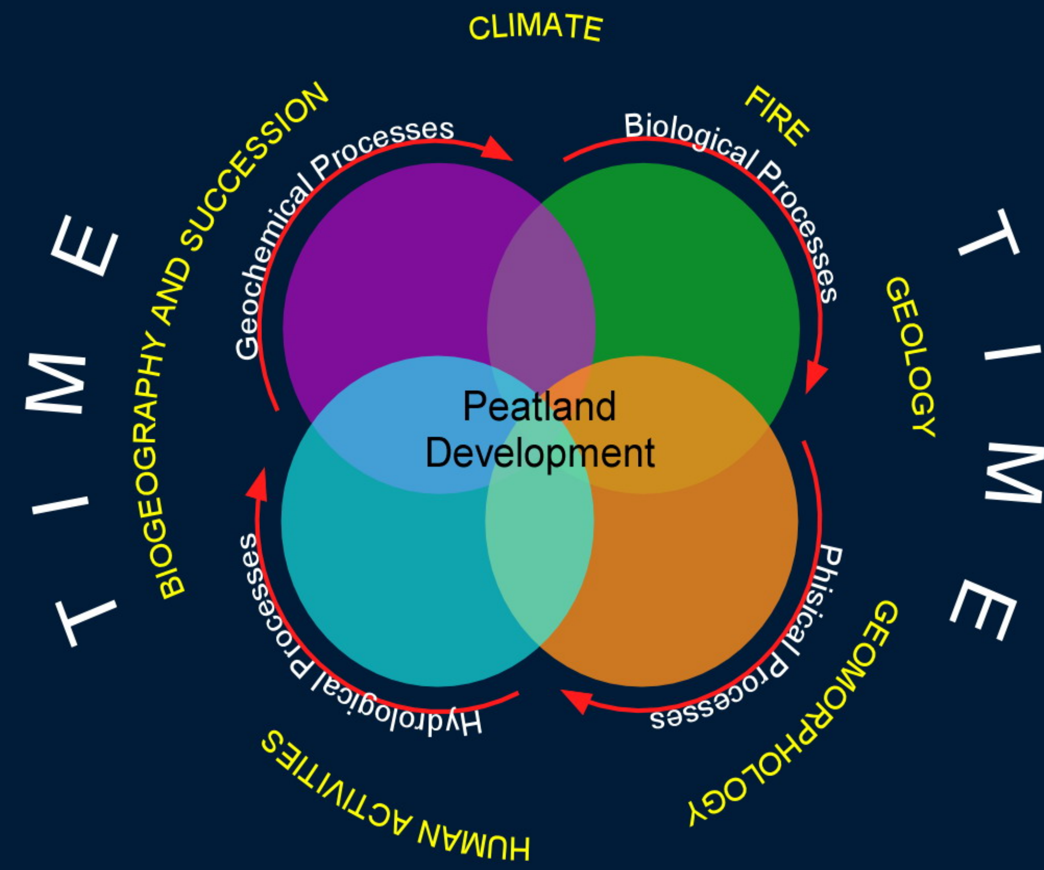
Land Area	1.4-3.6 %	x area
Net Primary Productivity	6.3	2x
Soil Carbon Storage	9.4	3x
Soil Respiration (CO_2)	2.0	1x
Methane Flux	29.9	8x
Denitrification (as N_2)	50.0	14x
Atmospheric Phosphorus Flux (PH_3)	3.8	1x
Hydrogen Sulfide (H_2S)	2.6	1.5x
Dimethyl Sulfide ($(CH_3)_2S$)	0.5	<1
Carbonyl Sulfide (COS)	3.8	1x

(Richardson and Schlesinger , in preparation)

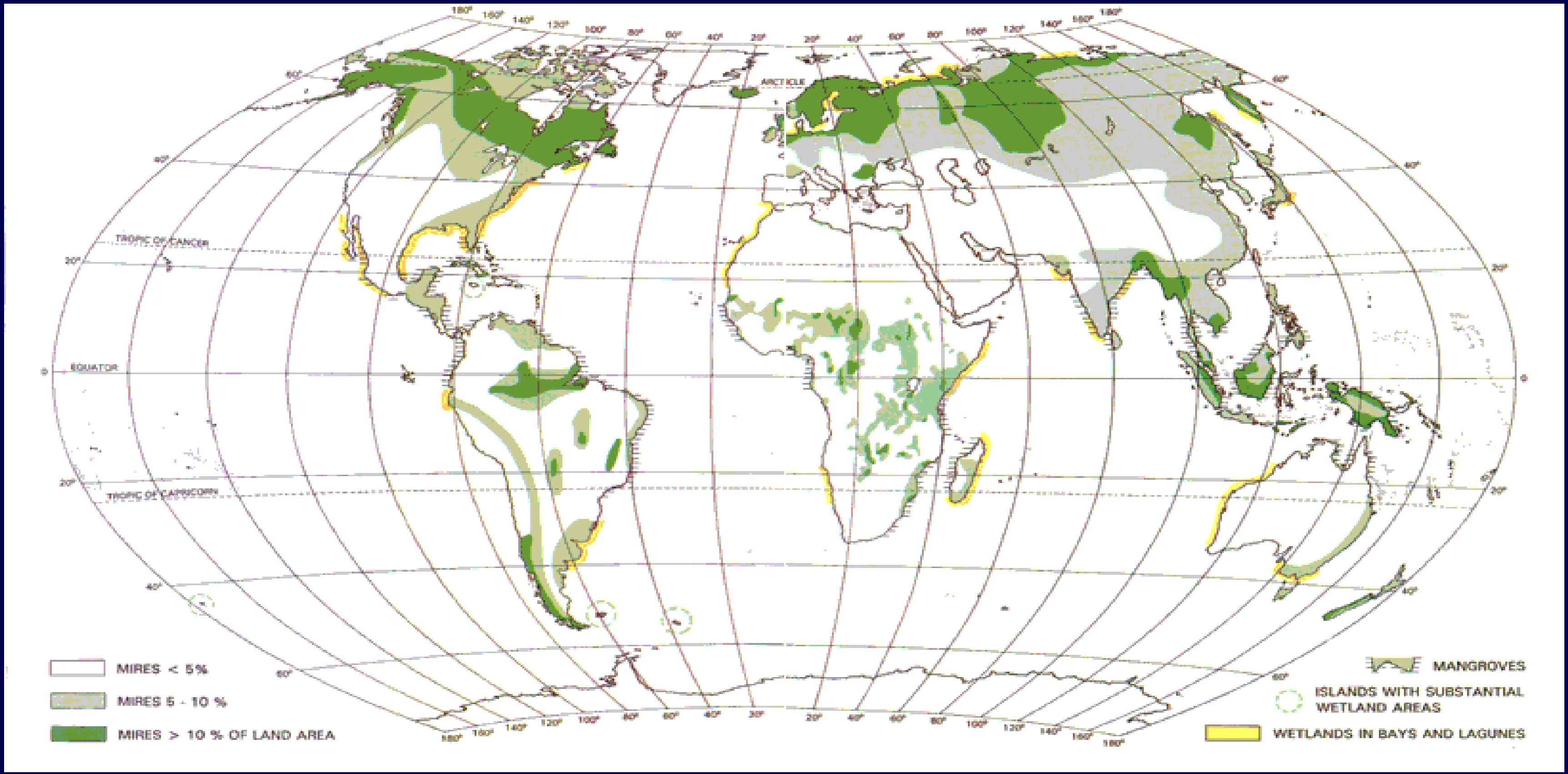


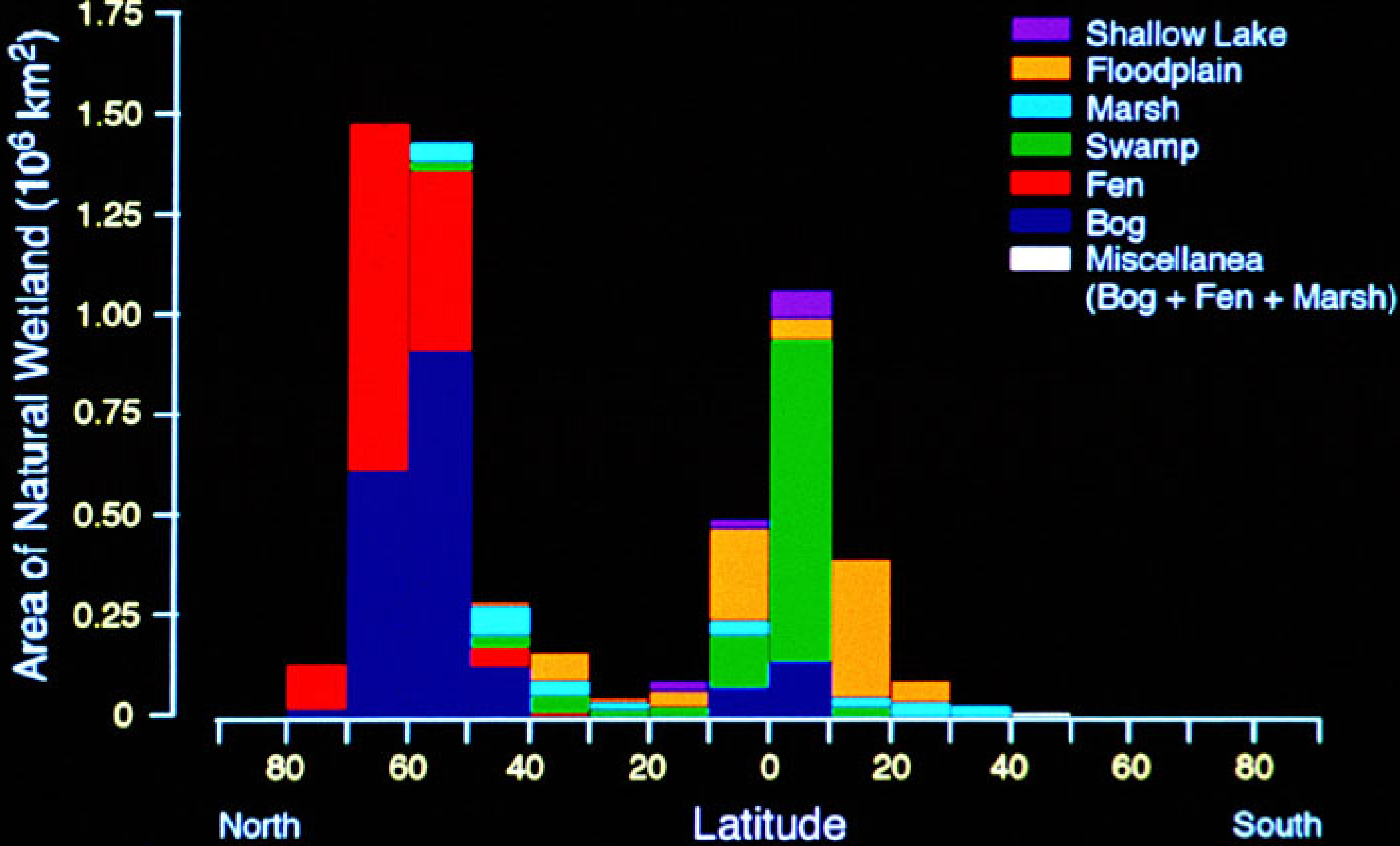
Aselmann and Crutzen 1989, J. Atmos. Chem 8, 307-358)

Factors Controlling Peatland Development

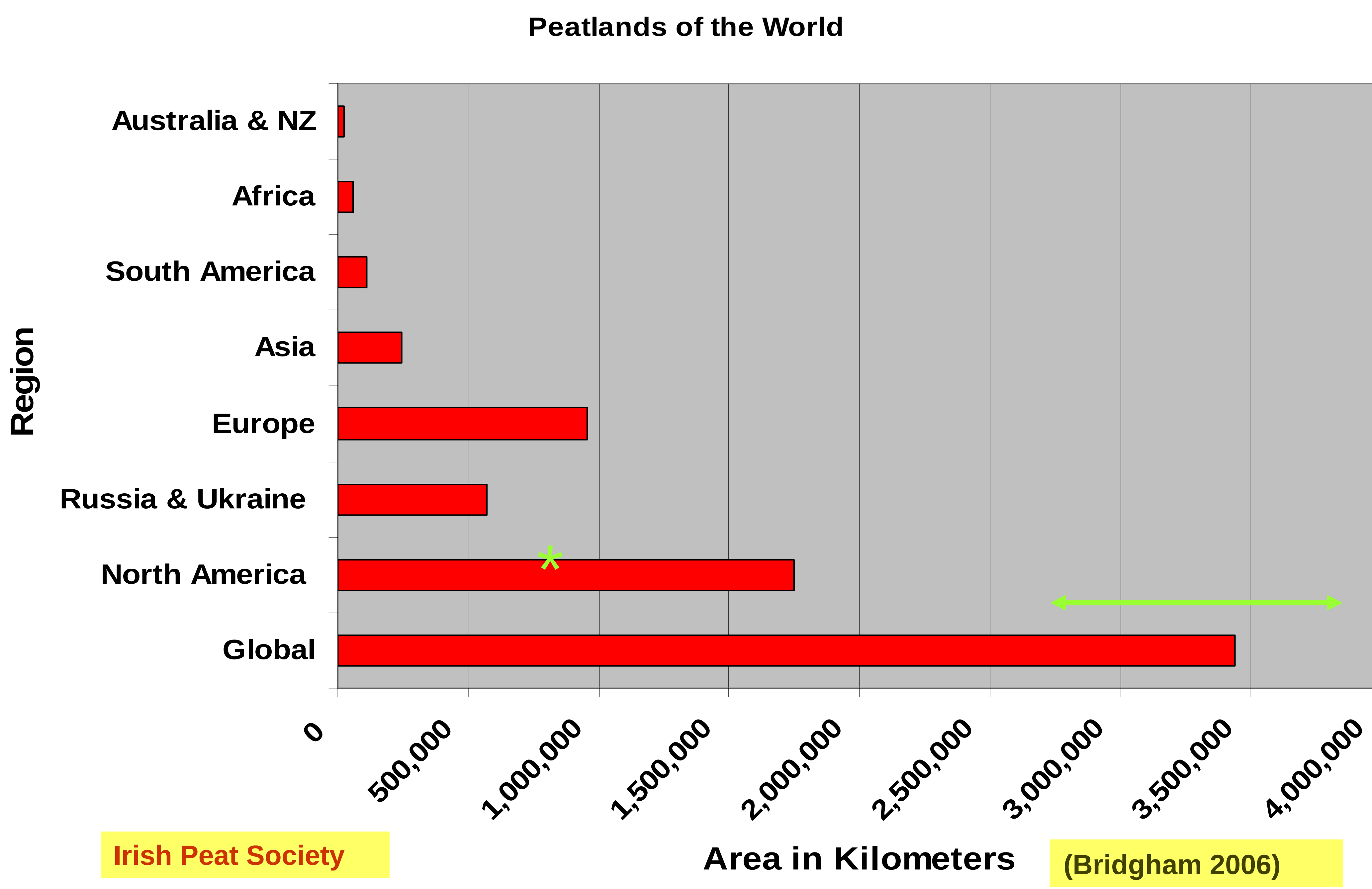


Global Distribution of Peatlands



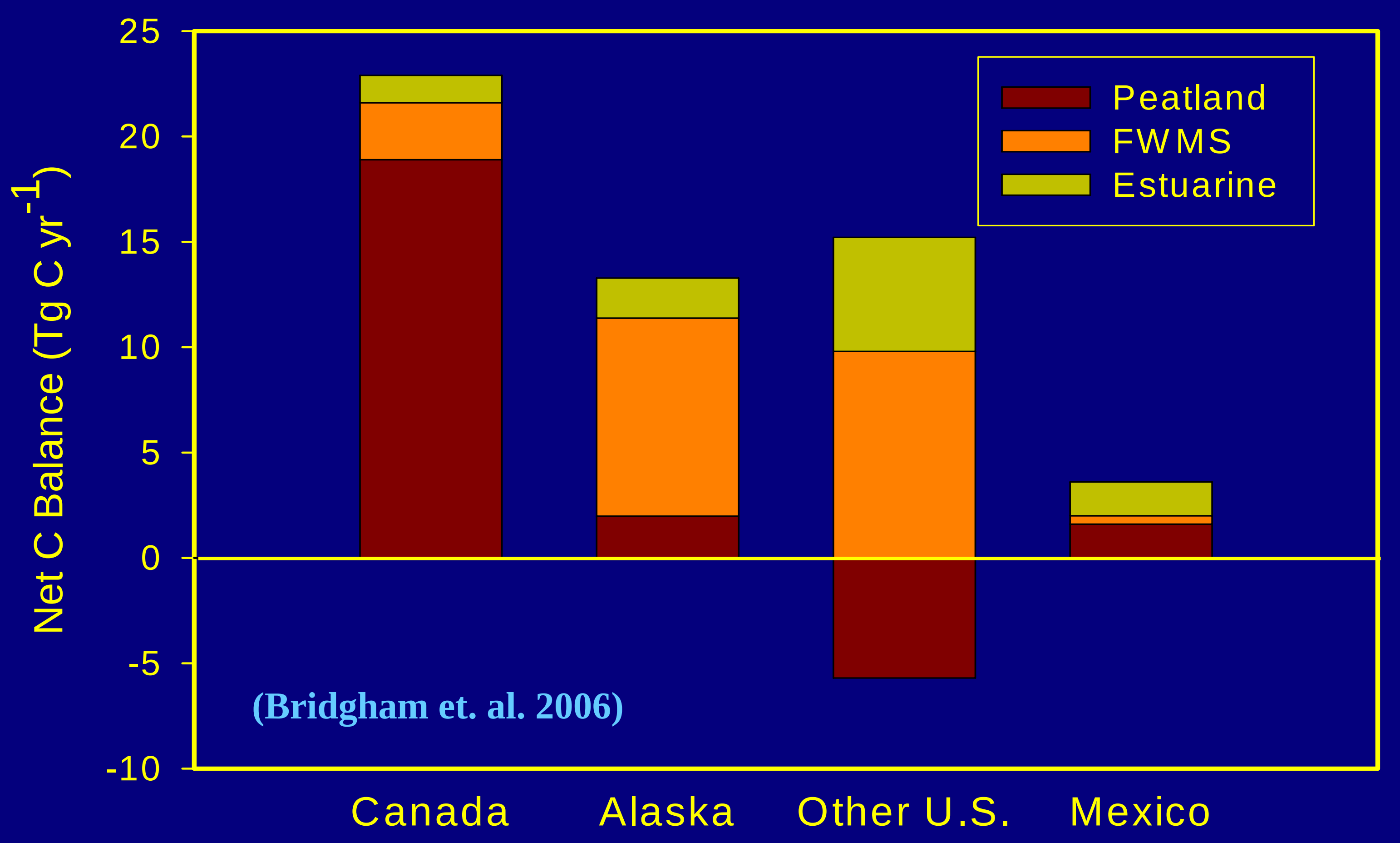


(Aselmann and Crutzen 1989, J. Atmos. Chem 8, 307-358)



Peatlands of the World
Region
Australia & NZ
Africa
South America
Asia
Europe
Russia & Ukraine
North America
Global
*
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
4,000,000
Area in Kilometers
Irish Peat Society
(Bridgham 2006)

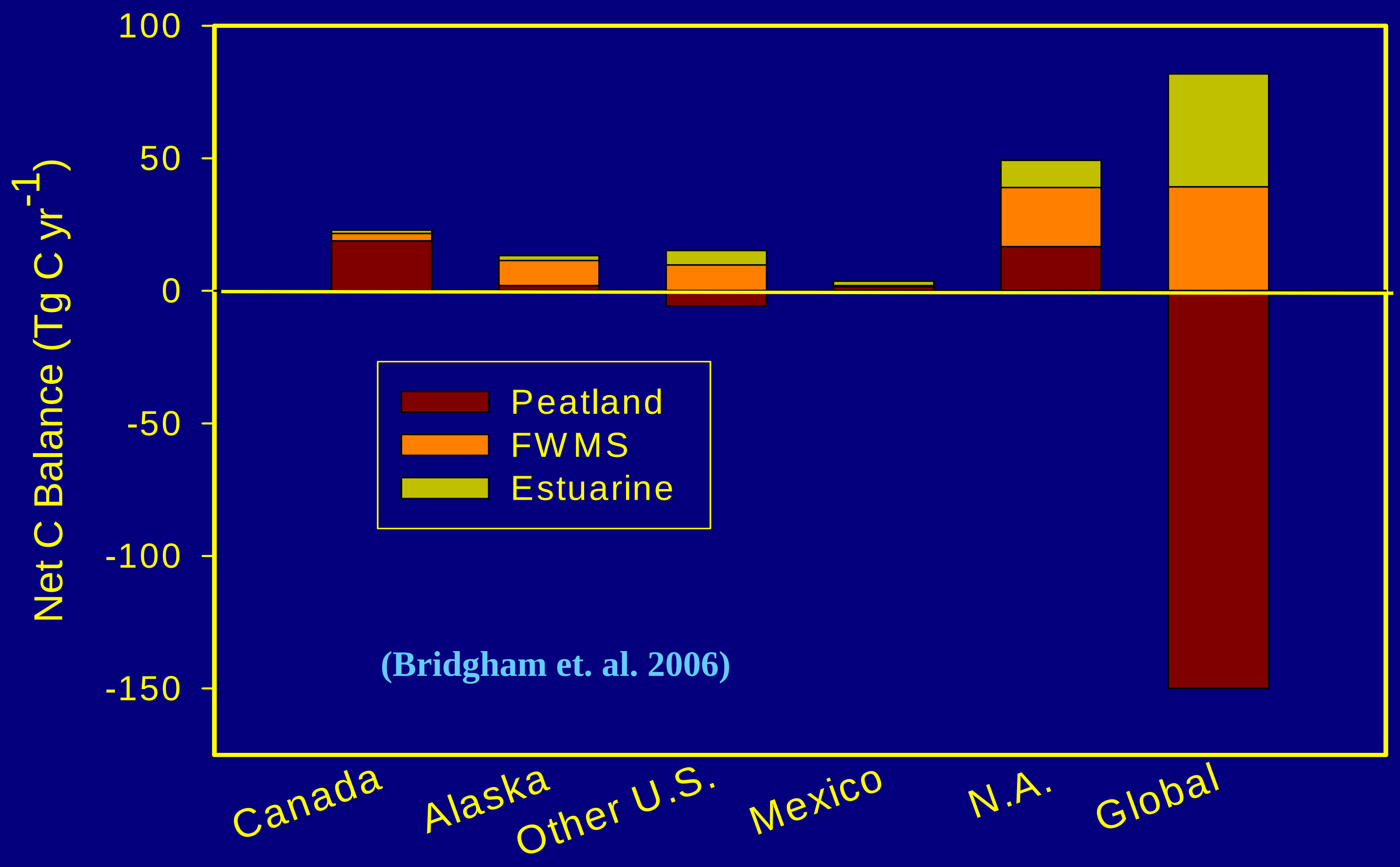
North American Wetland Net Carbon Balance



Total net C balance = 49 Tg C yr^{-1} (but estimate has very low confidence).

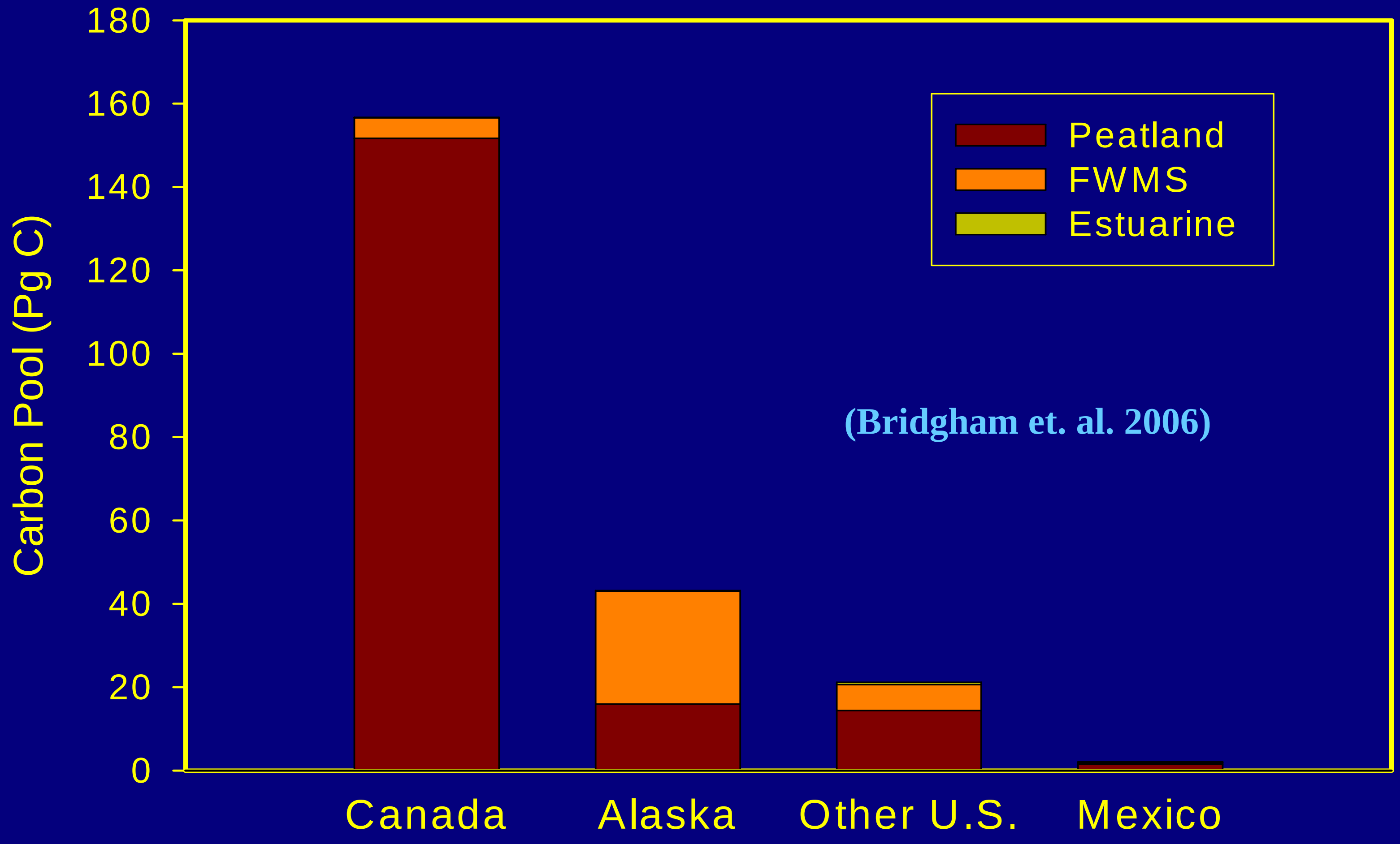
Note: Positive number = net flux into wetland, negative number = net flux from wetland

Wetland Net Carbon Balance



Note: Positive number = net flux into wetland, negative number = net flux from wetland

North American Wetland Carbon Pool

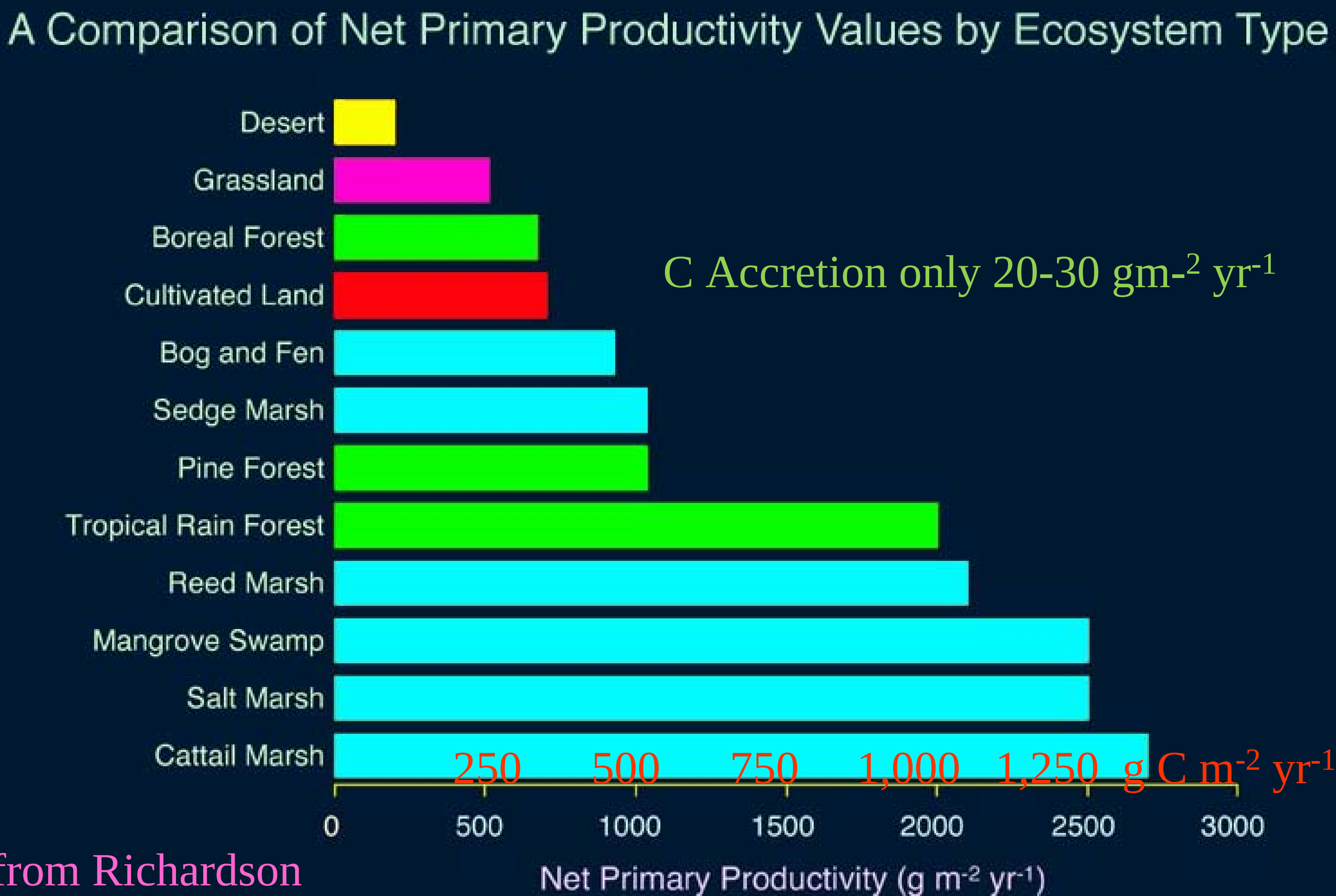


Total C pool = 220 Pg C, 43% of global total wetland pool.

Worldwide Peatlands

- **Over past 10,000 –14,000 yrs have accumulated**
  - **200 - 450 Pg C**
    - **Approximately 25 – 33% global C soil pool**
- **Southern Hemisphere wetland C storages and losses are not well quantified or mostly ignored**

(Gorham 1991, Roulet et.al. 2007)



(from Richardson 1995)

Rate of Carbon Accumulation in Some Peatland Ecosystems

Location	Vegetation	Interval (yrs)	Rate*	Reference
Alaska	*Picea* and *Sphagnum*	4790	11-61	Billing 1987
Alaska	*Eriophorum vaginatum*	7000	26.6	Viereck 1966
Finland	*Sphagnum-Carex* mire	------	20-28	Francez and Vasander 1995
Former Soviet Union	Mire, bogs, and fens	3000-7000	12-80	Botch et al. 1995
Manitoba	*Picea* and *Sphagnum*	2960-7939	13-26	Reader and Stewart 1972
Ontario	*Sphagnum* bog	5300	30-32	Belyea and Warner 1996
Western Canada	*Sphagnum* bogs	9000	13.6-34.9	Kuhry and Vitt 1996
Wisconsin	*Sphagnum*	8260	17-38	Kratz and DeWitt 1986
Massachusetts	*Sphagnum*	132	90	Hemond 1980
North Carolina	Mixed forest	27700	8	Whitehead 1981
Georgia	*Taxodium*	6500	22.5	Cohen 1974
Florida	*Cladium* swamp	25-30	70-105	Craft and Richardson 1993

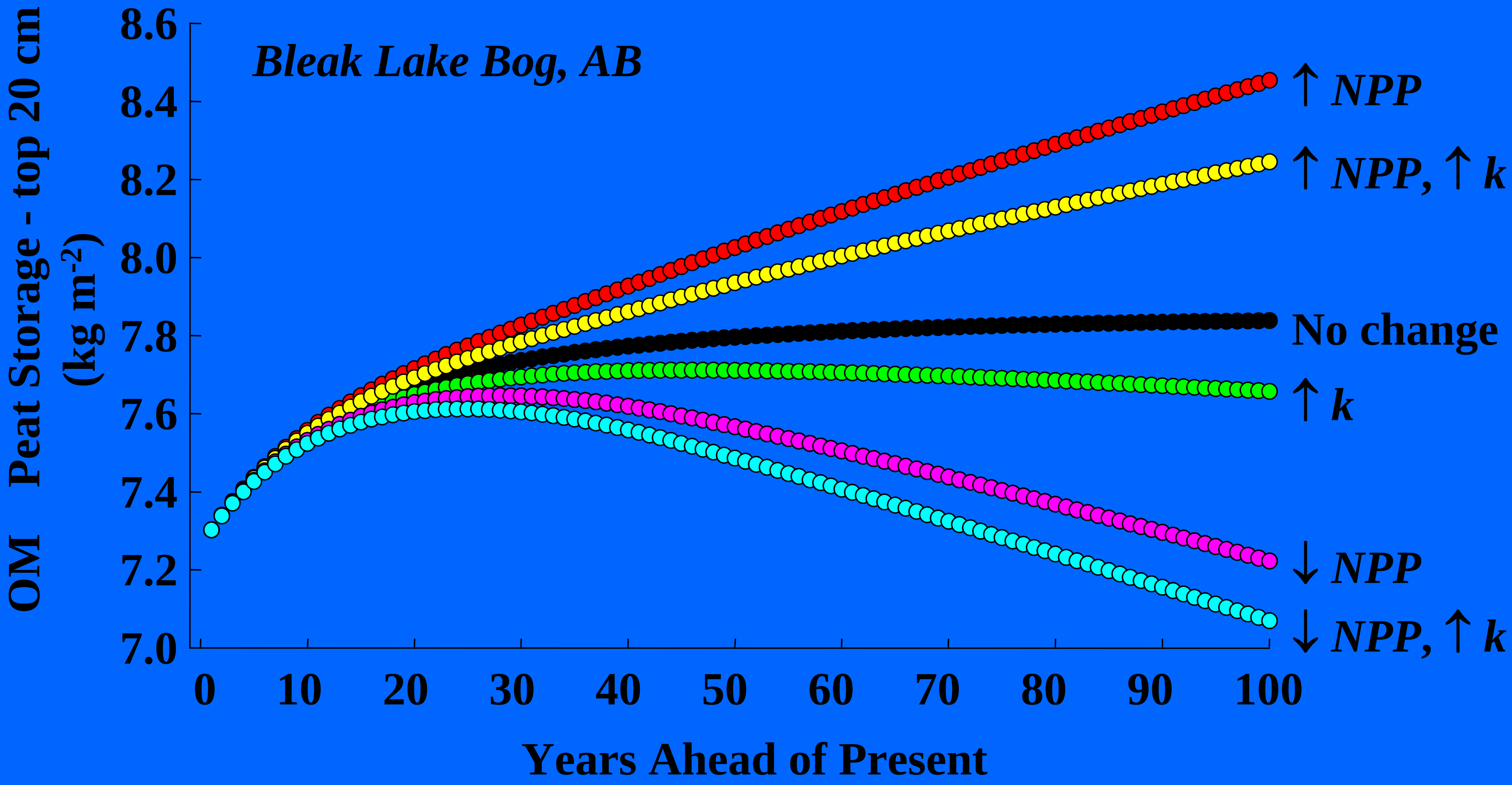
* (g C m^{-2} yr^{-1})

Vegetation tissue decomposition rates (from Frolking et al., 1998, Schlesinger 1997)

Peatland	Tissue Type	k^*
Subarctic fens	*Sphagnum*	0.06 to 0.09
Boreal bogs	sedges	0.20 to 0.28
	ericaceous leaves and stems	0.06 to 0.31
	conifer needles	0.11 to 0.28
	Sphagnum	0.04 to 0.58
Tropics	vegetation	***>1.0***
World Average	vegetation	***0.33***
Peatlands	*(deep peat)*	***0.001***

* Parameter in fit of exponential mass loss equation, ln (mass remaining) =
$c + kt$, with t in years.

PROJECTING INTO THE FUTURE



Wieder, 2001, Ecol. Applic. 7: 321-336.

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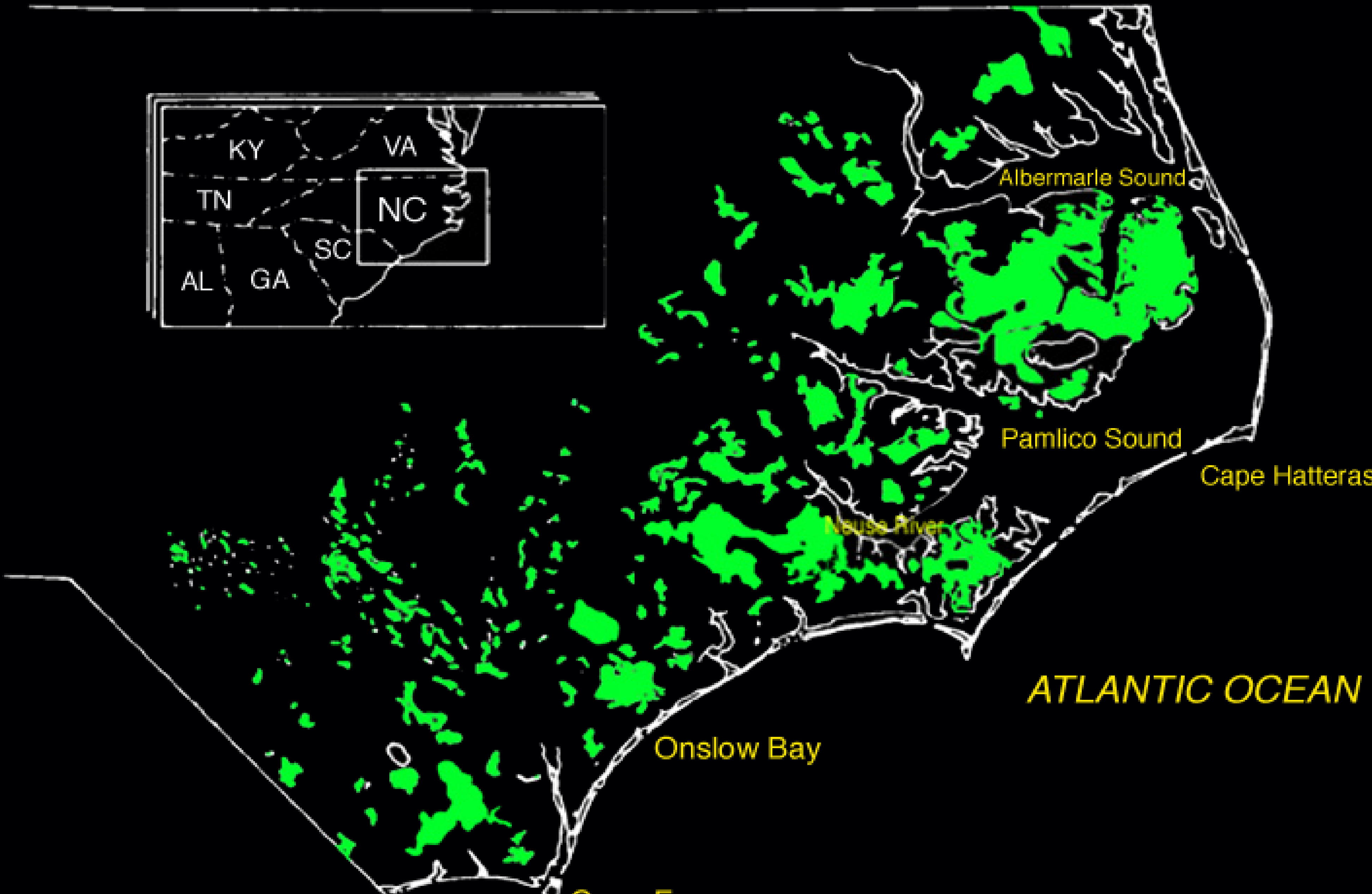
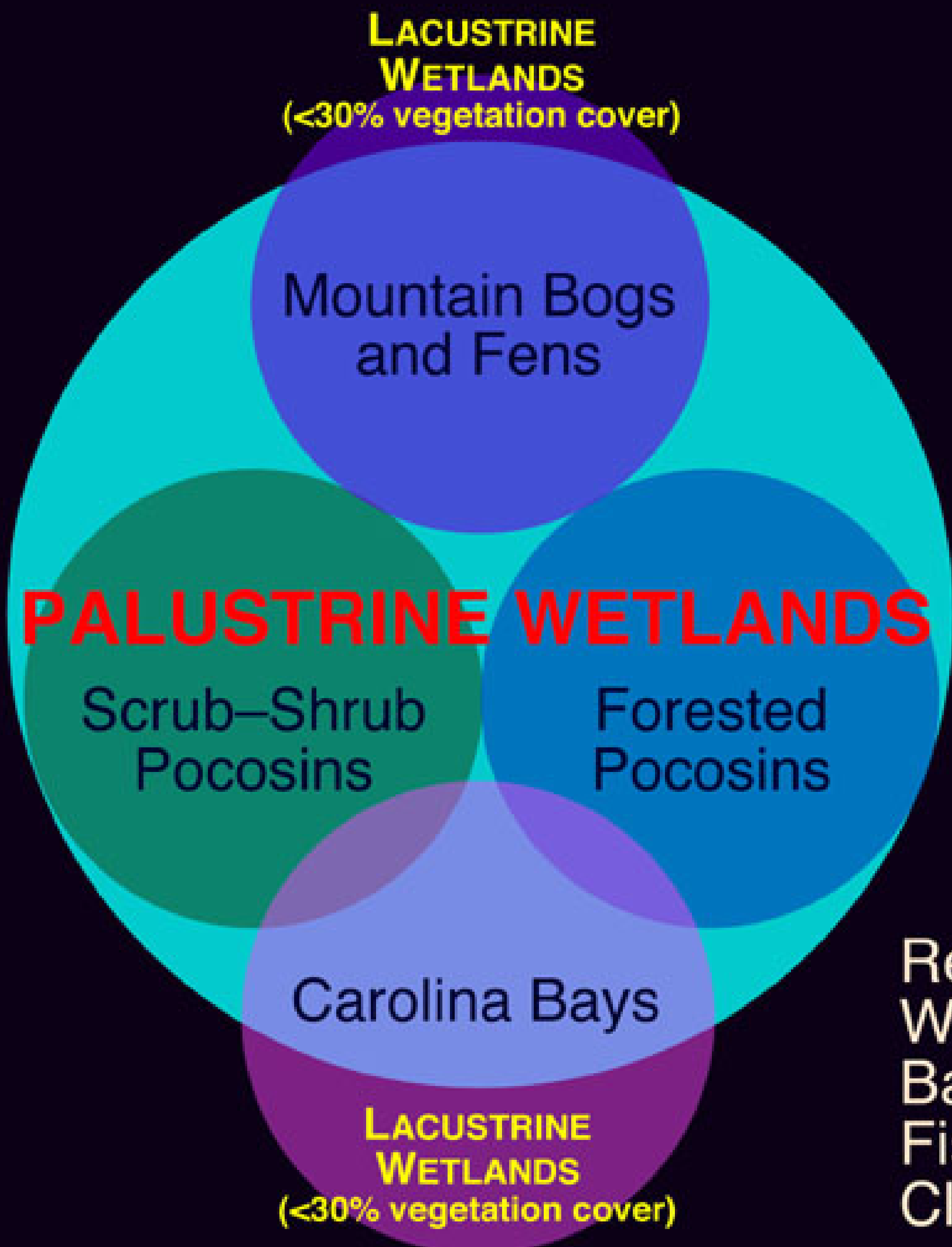


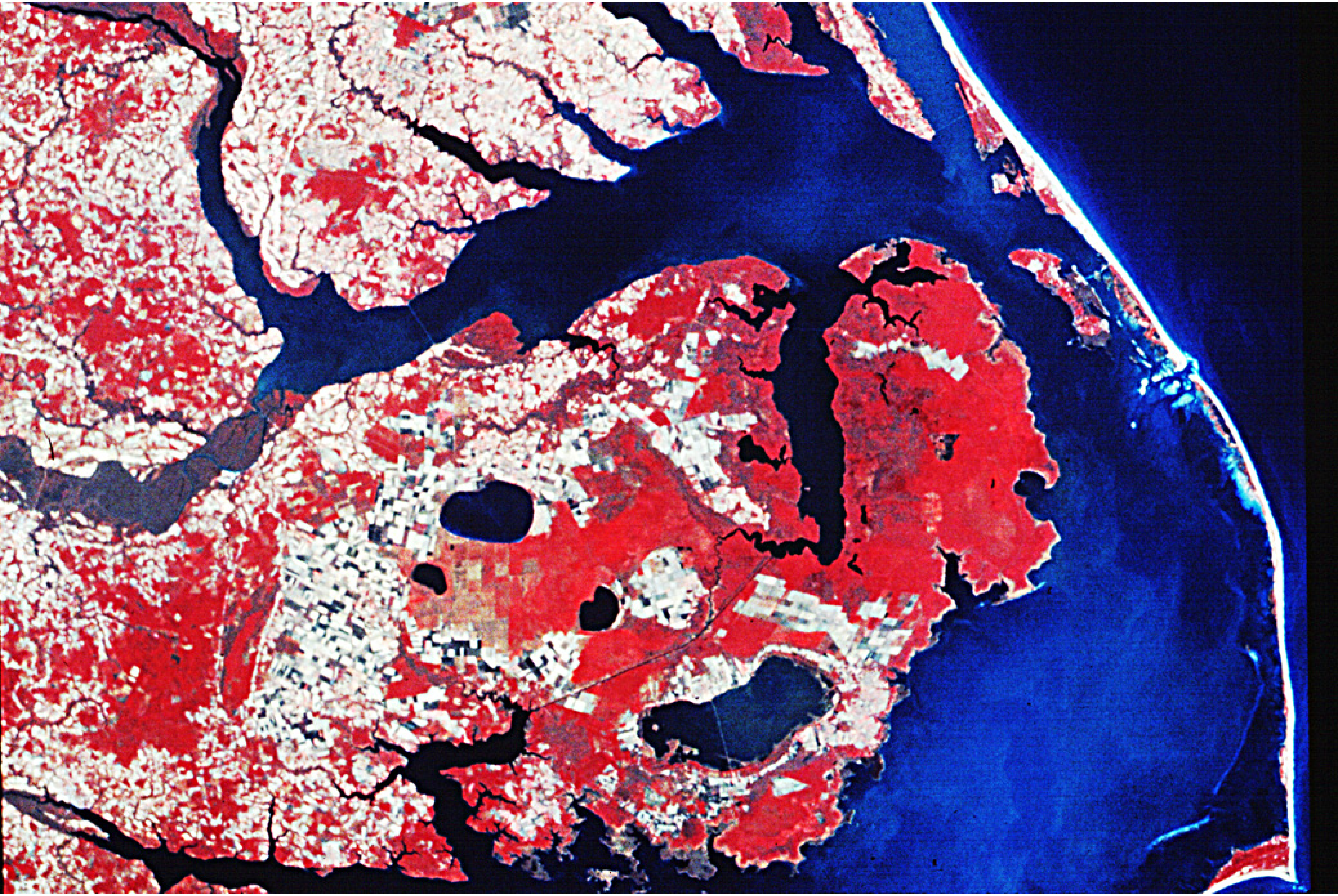
Pocosins (adapted from Wilson 1962)
(Richardson 1981)



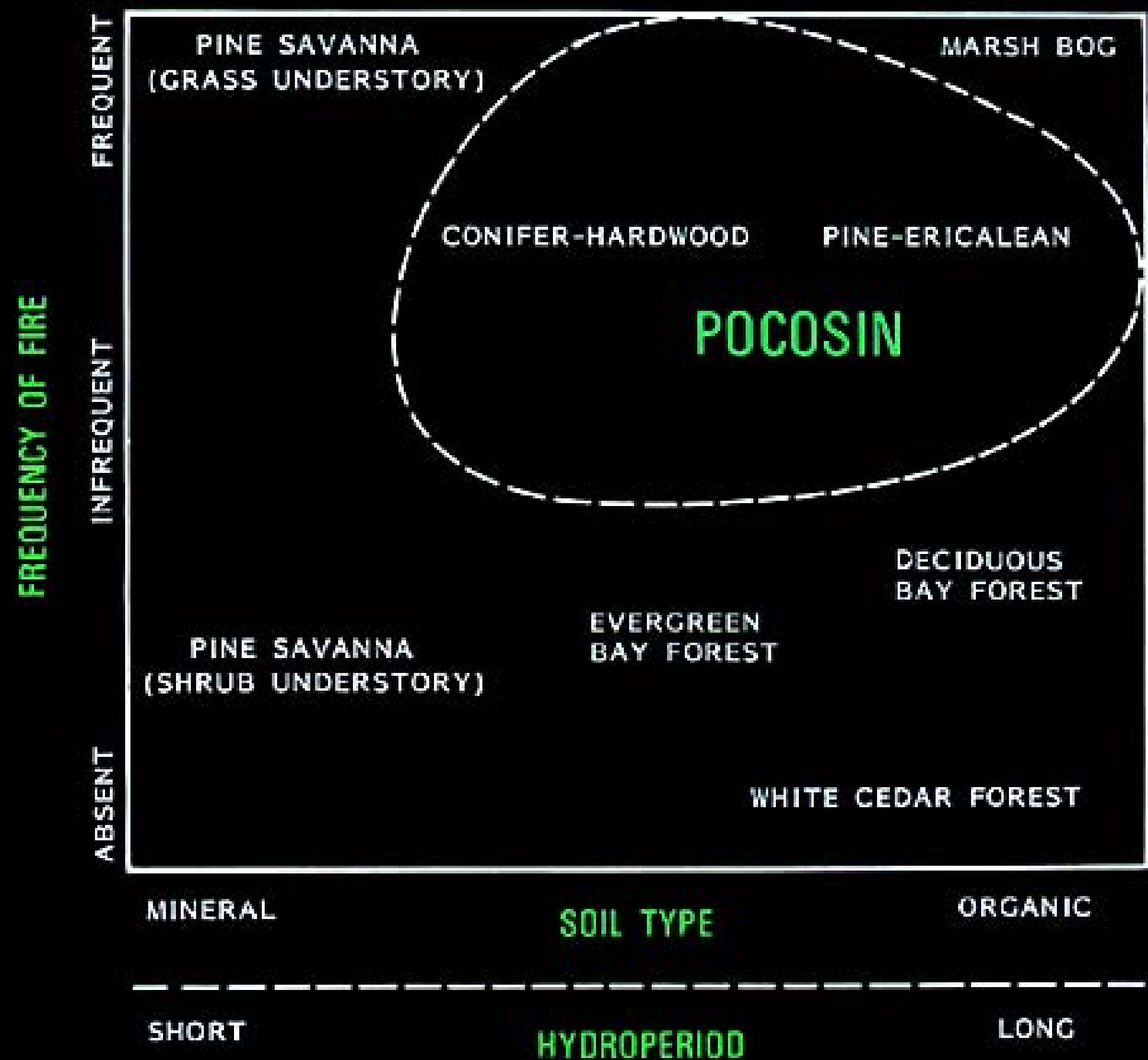
Relationship Among Wetland Types Based on the Fish and Wildlife Service Classification System

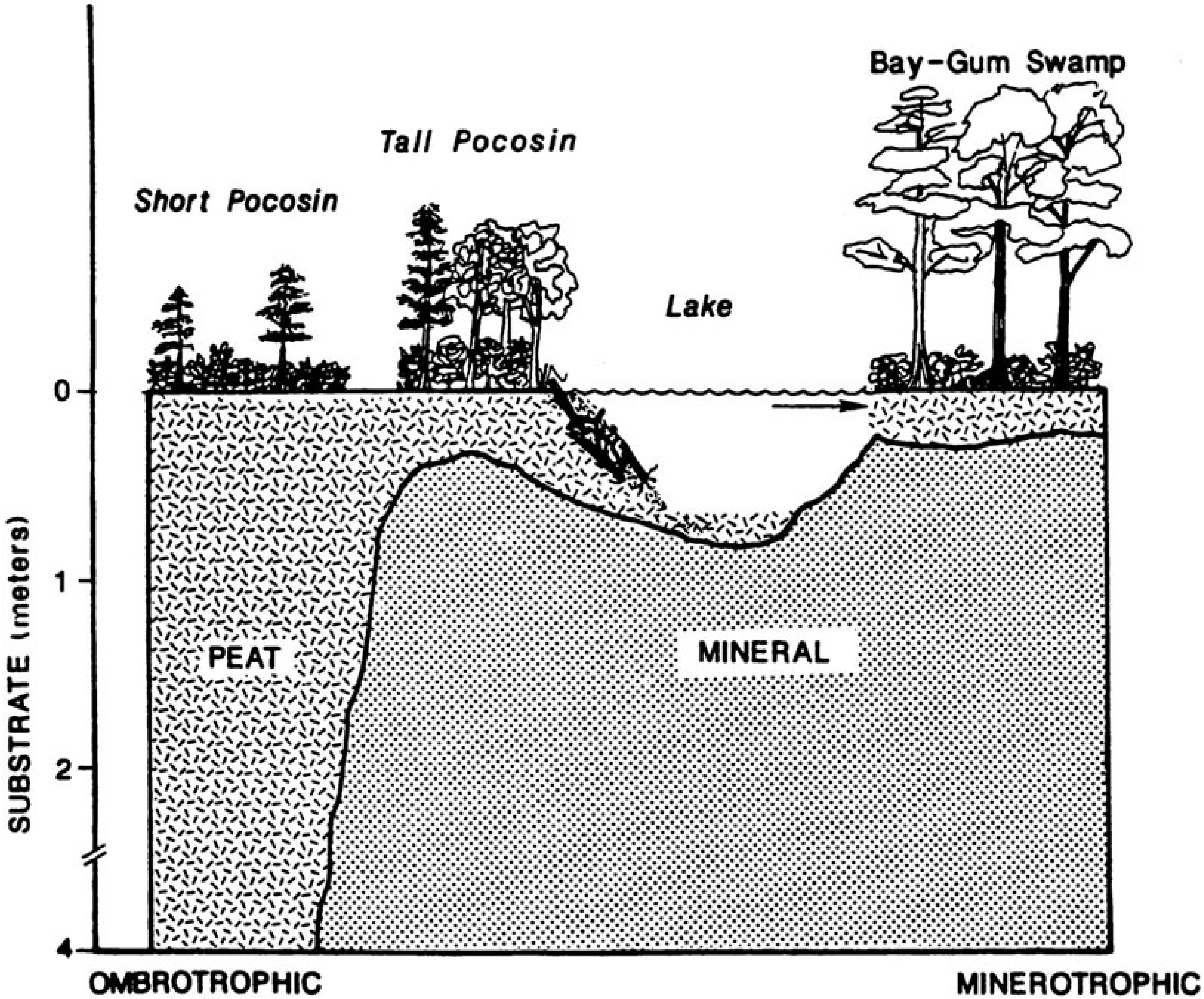
Geographic Distribution of Pocosins

- **Pocosins occur on the southeastern coastal plain from Virginia to north Florida and once covered more than one million hectares in North Carolina**
- **A broad definition of pocosins (sensu lato) would include all shrub and forested bogs, as well as Atlantic white cedar stands and some loblolly pine stands on flooded soils on the Coastal Plain.**



Relationship Among Vegetation, Soil Types, Hydroperiod, and Fire in Pocosin Habitats (based on Kologoski 1977)

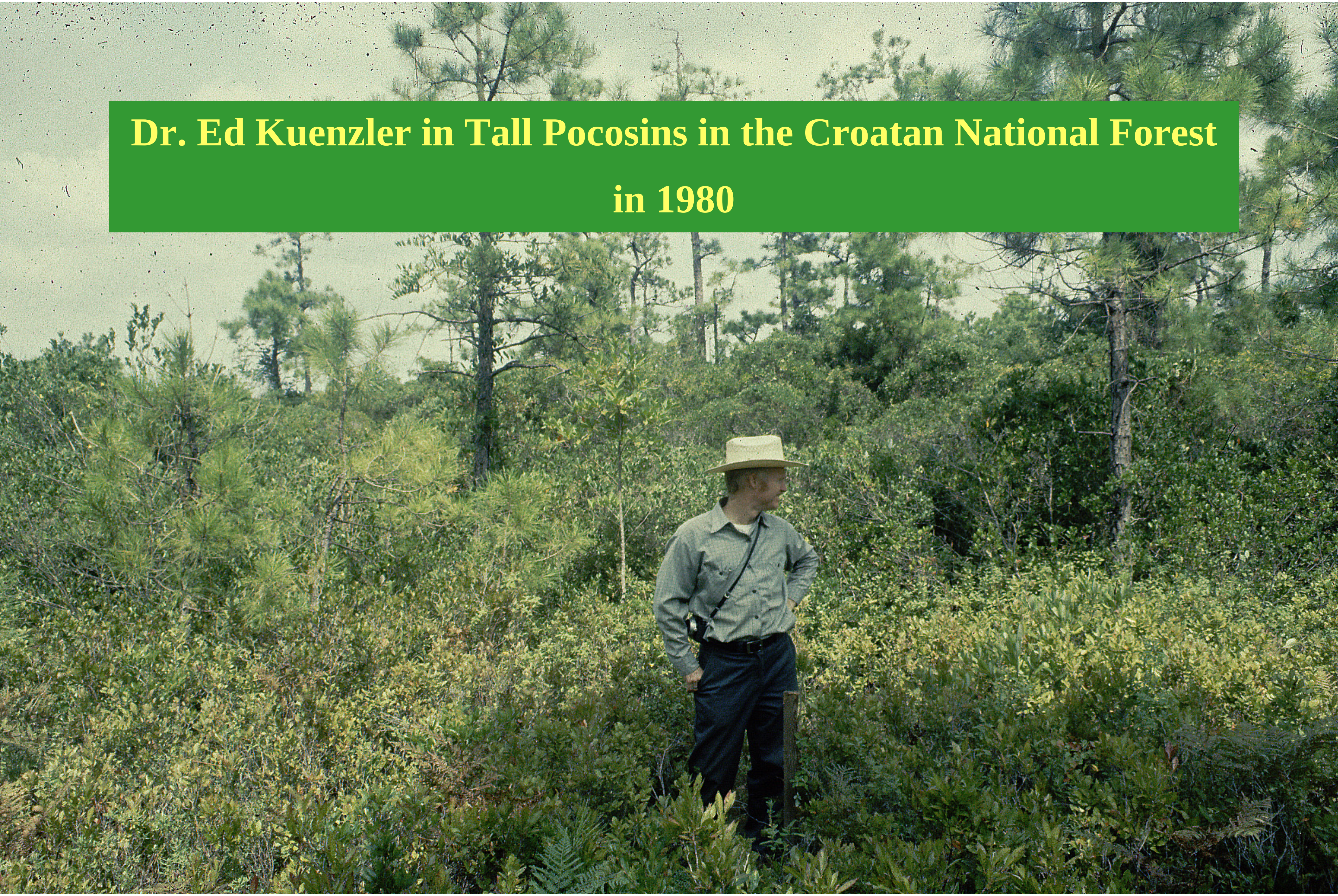



Bay-Gum Swamp
Tall Pocosin
Short Pocosin
Lake
0
1
2
4
SUBSTRATE (meters)
PEAT
MINERAL
OMBROTROPHIC
MINEROTROPHIC

Characteristics of Bay Forest, Tall Pocosins, and Short Pocosins in the Croatan National Forest (adapted from Snyder, 1980 and field data)

	Bay Forest	Tall Pocosin	Short Pocosin
Hydroperiod	Wet most of year	Wet in winter, but dry in summer	Wet most of year, but root zone dry in summer
Soils	Shallow peat (<1 m)	Shallow peat (<1 m)	Deep peat (>1 m)
Canopy Height	12 – 20 m	8 – 18 m	1 – 2 m
Common Species			
— shrubs	*Lyonia lucida* *Ilex coriacea* *Cyrilla racemiflora*	*Cyrilla racemiflora* *Lyonia lucida* *Ilex coriacea*	Similar to tall pocosin
— trees	*Persea borbonia* *Acer rubrum* *Nyssa sylvatica* *Gordonia lasianthus* *Magnolia virginiana*	Trees species of shrub stature in low pocosin become prevalent *AWC*	*Myrica heterophylla* *Pinus serotina* *Magnolia virginiana* *Nyssa sylvatica* *Gordonia lasianthus*
Rare Species		*Zenobia pulverulenta*	*Liquidambar styraciflua*

Short Pocosin in Croatan National Forest

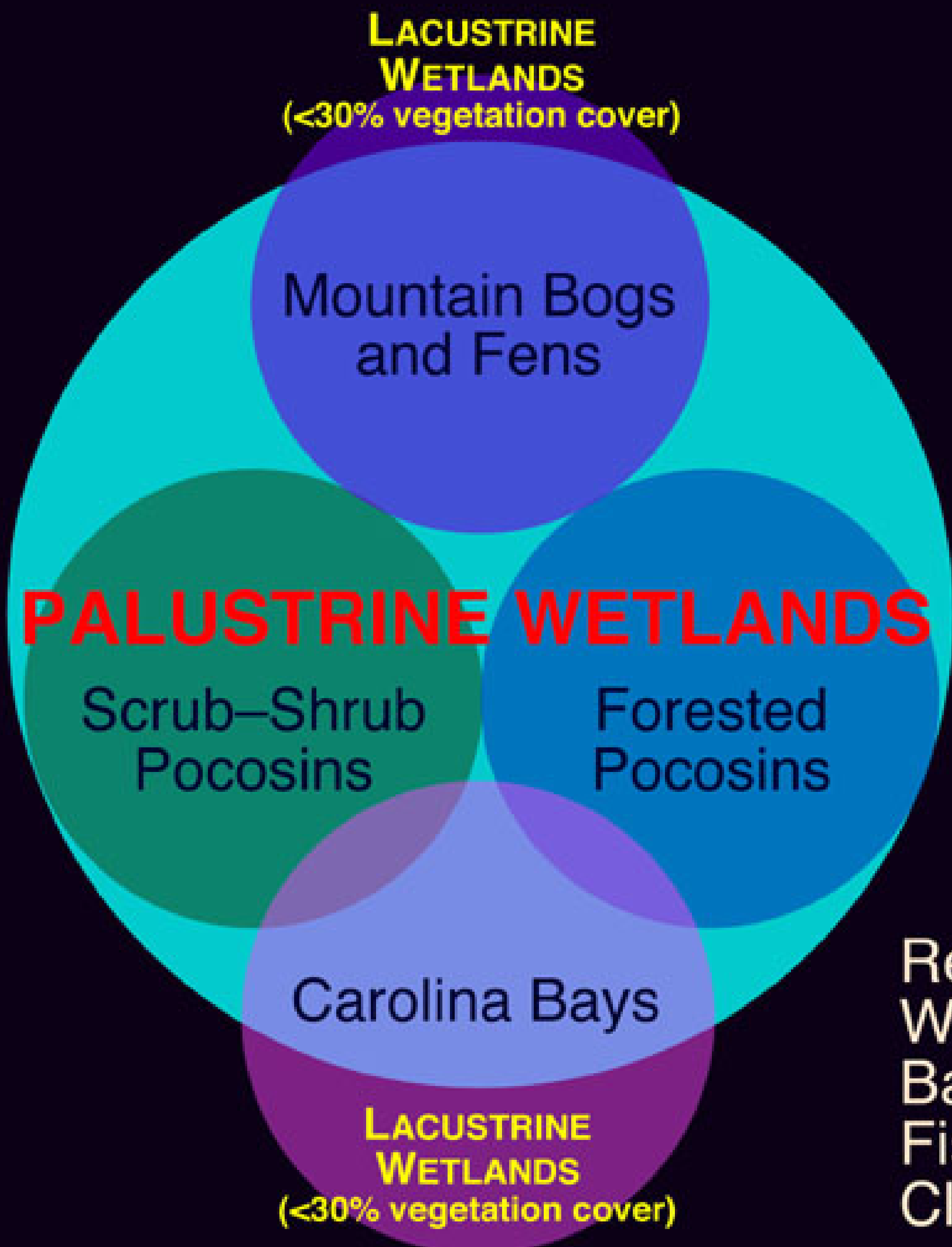

Dr. Ed Kuenzler in Tall Pocosins in the Croatan National Forest
in 1980

Natural Regeneration of Southern White Cedar

C. F. Korstian, 1924, Ecology, Vol. 5, No. 2 pp. 188-191

C. F. Korstian and W.D. Brush, 1931.Southern White Cedar USDA Tech Bull: 251

Although locally a natural resource of great importance, southern white cedar *Chamaecyparis thyoides* has remained one of our least known forest trees. Aside from brief studies by Mohr (1899), Pinchot (1899), and Krinbill (1915), all very limited as to data, little has been done to discover the silvical characteristics of this valuable timber tree of the coastal swamps.



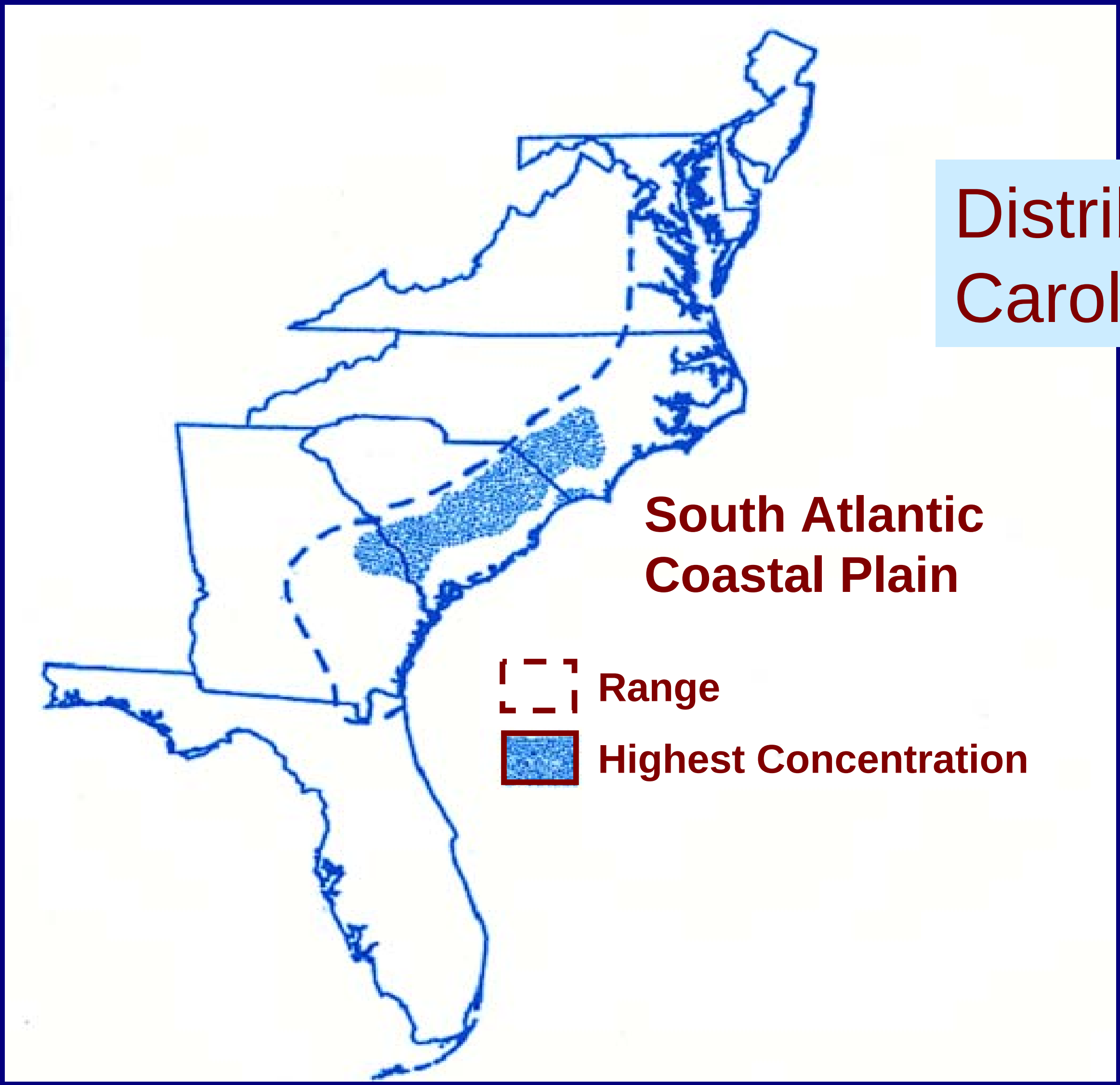
Relationship Among Wetland Types Based on the Fish and Wildlife Service Classification System

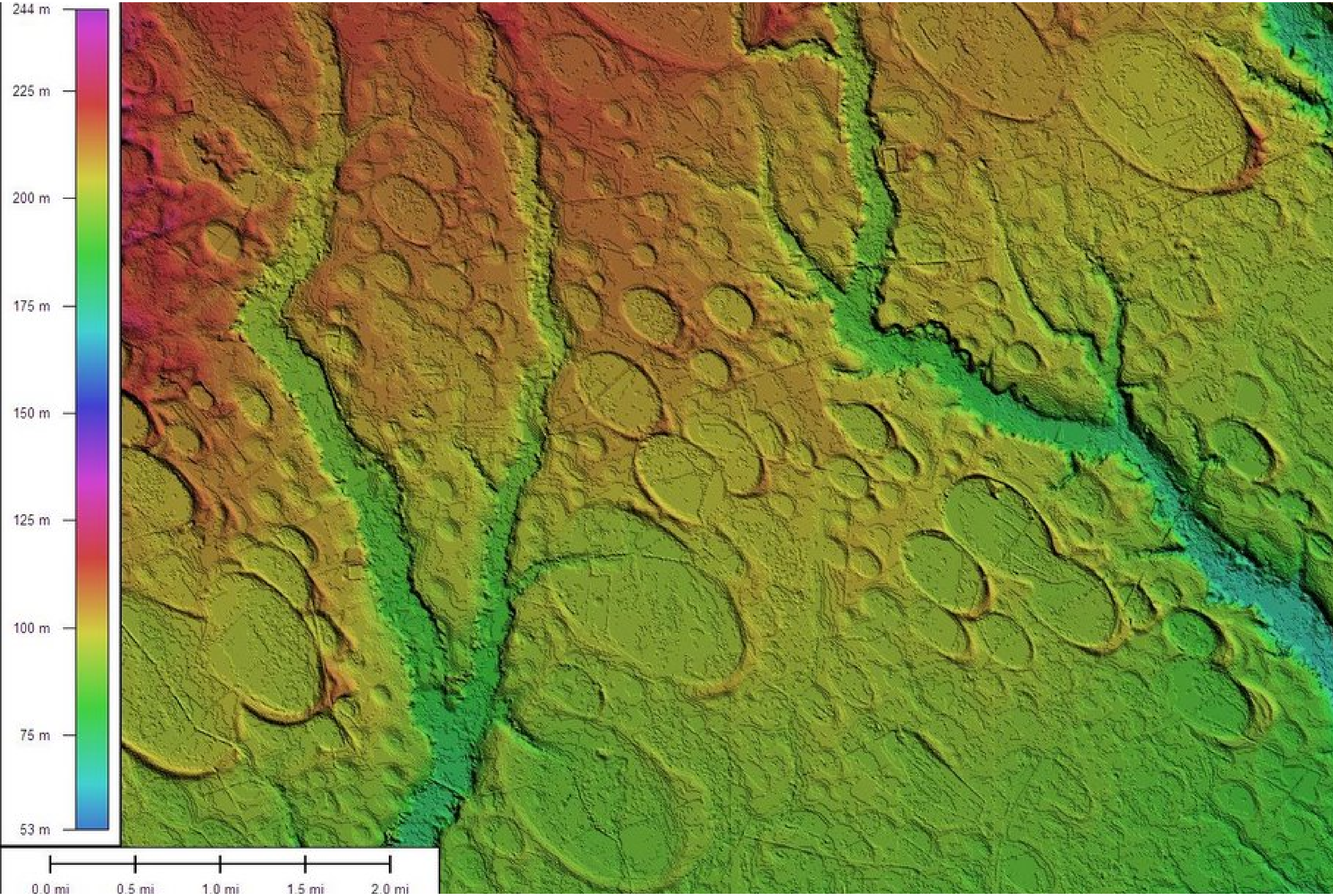
Carolina Bays

- introduction to Carolina bay wetlands
- formation & ecological significance
- degree of hydrologic isolation



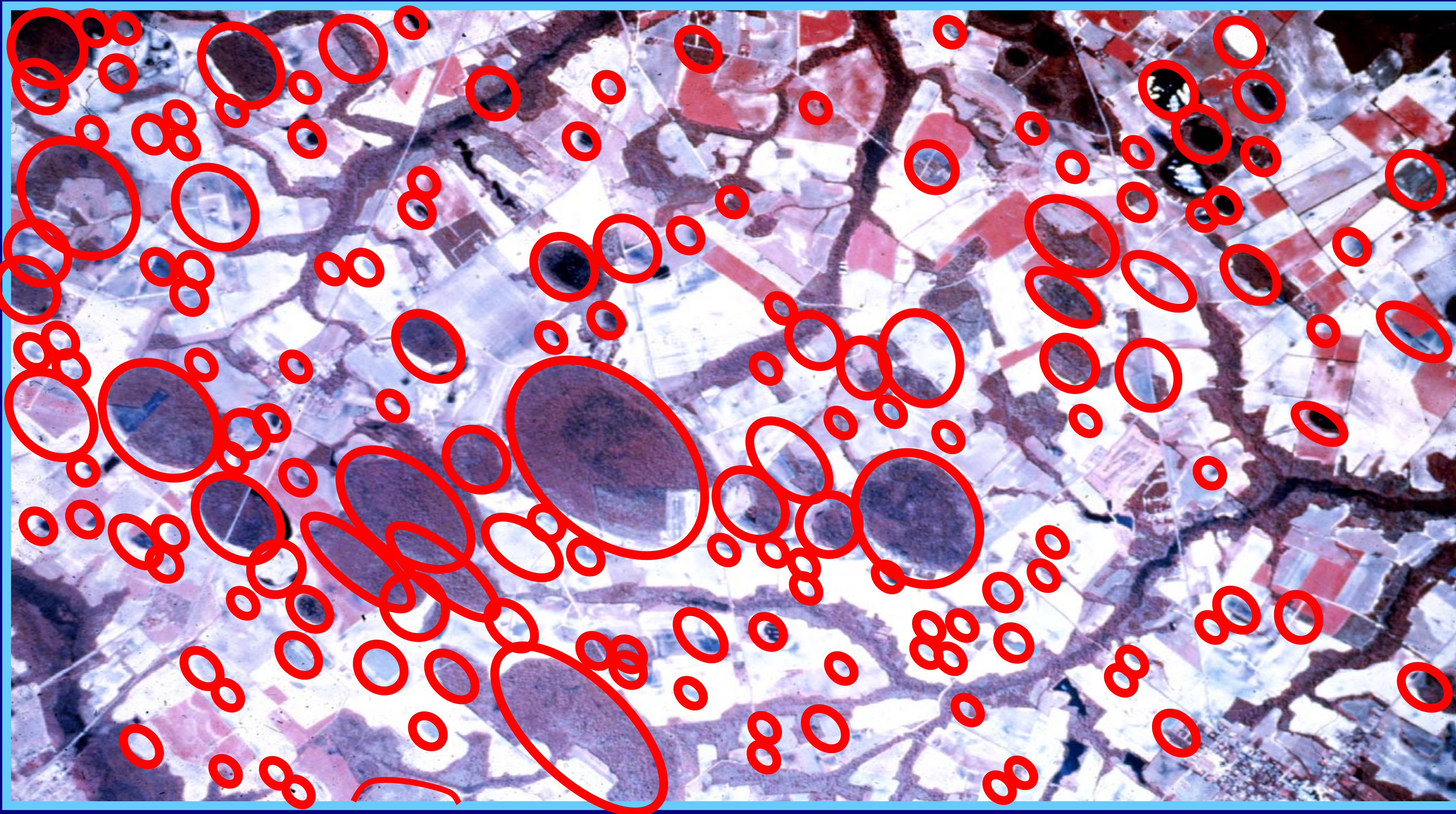
Distribution of Carolina Bays





244 m
225 m
200 m
175 m
150 m
125 m
100 m
75 m
53 m
0.0 mi
0.5 mi
1.0 mi
1.5 mi
2.0 mi

Cluster of Carolina Bays in South Carolina



Carolina Bays and Lakes: Possible origins

1. Spring basins (Toumey, 1848).

2. Sand bar dams of drowned valleys (Glenn, 1895).

3. Depressions dammed by giant sand ripples (Glenn, 1895).

4. Craters of meteor swarm (Melton and Schriever, 1952; Prouty, 1952; Wells and Boyce, 1953).

5. Submarine scour by eddies, currents, or undertow (Melton, 1934).

6. Lakes in sand elongated in direction of maximum wind velocity (Raisz,1934).

7. Solution depressions, with wind-drift sand forming the rims Johnson,1936).

8. Solution depressions, with magnetic highs near bays due to redeposition of iron compounds leached from the basins (Lobeck, 1939).

9. Basins scoured out by confined gyroscopic eddies (Cooke, 1940, 1954).

10. Solution basins of artesian springs with lee dunes (Johnson, 1942).

11. Fish nests made by giant schools of fish waving their fins in unison over submarine artesian springs (Grant, 1945).

12. Eolian blowouts (Prouty, 1952).

13. Bays are sinks over limestone solution areas streamlined by groundwater (Le Grand, 1953; Shockley et al., 1956).

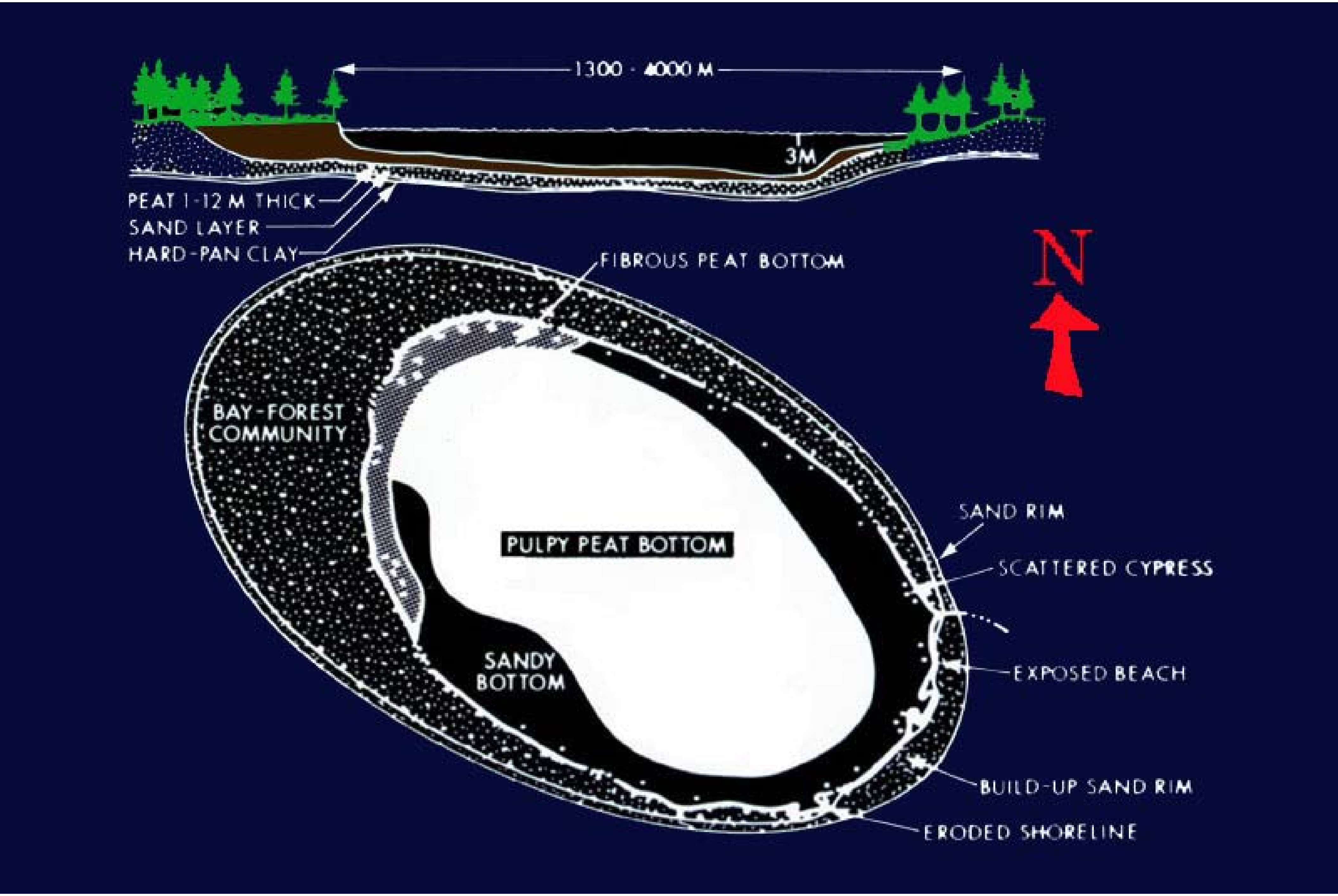
14. Oriented lakes of stabilized grassland interridge swales of former beach plains and longitudinal dune fields with some formed from basins in Pleistocene lagoons (Price, 1951, 1958).

15. Black hole striking in Canada (Hudson Bay) throwing ice onto coastal plain (Davis, 1971).

16. Cometary fragments exploding above surface, their shock waves creating depressions (Eyton and Parkhurst, 1975).

17. Drought with subsequent fire in peat bogs followed by eolian activity (Ross, 1986).

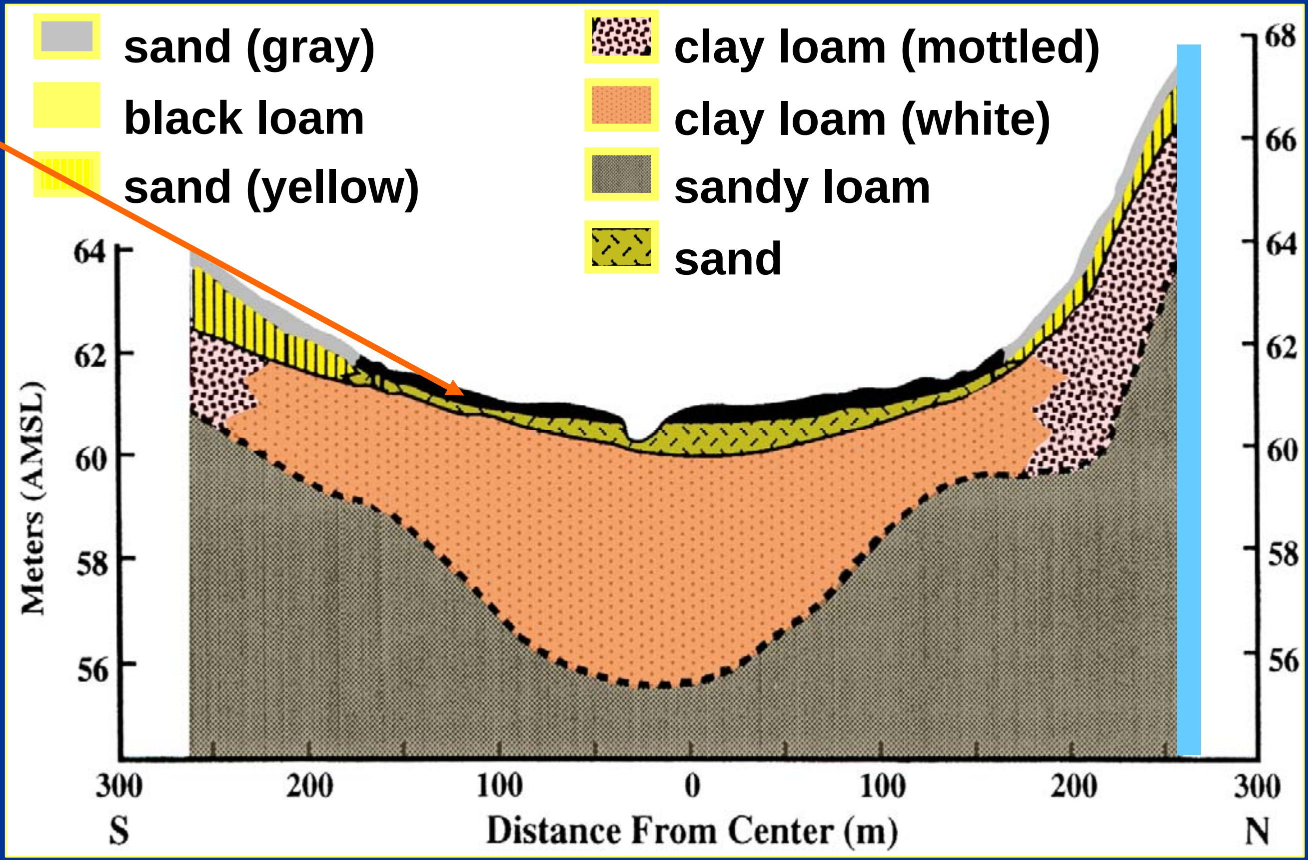
18. My theory is they were formed by the tail end of a comet hitting the earth. It would be made of ice and leave no trace. Thus, a perfect theory that cannot be easily disproved (Richardson 1981).

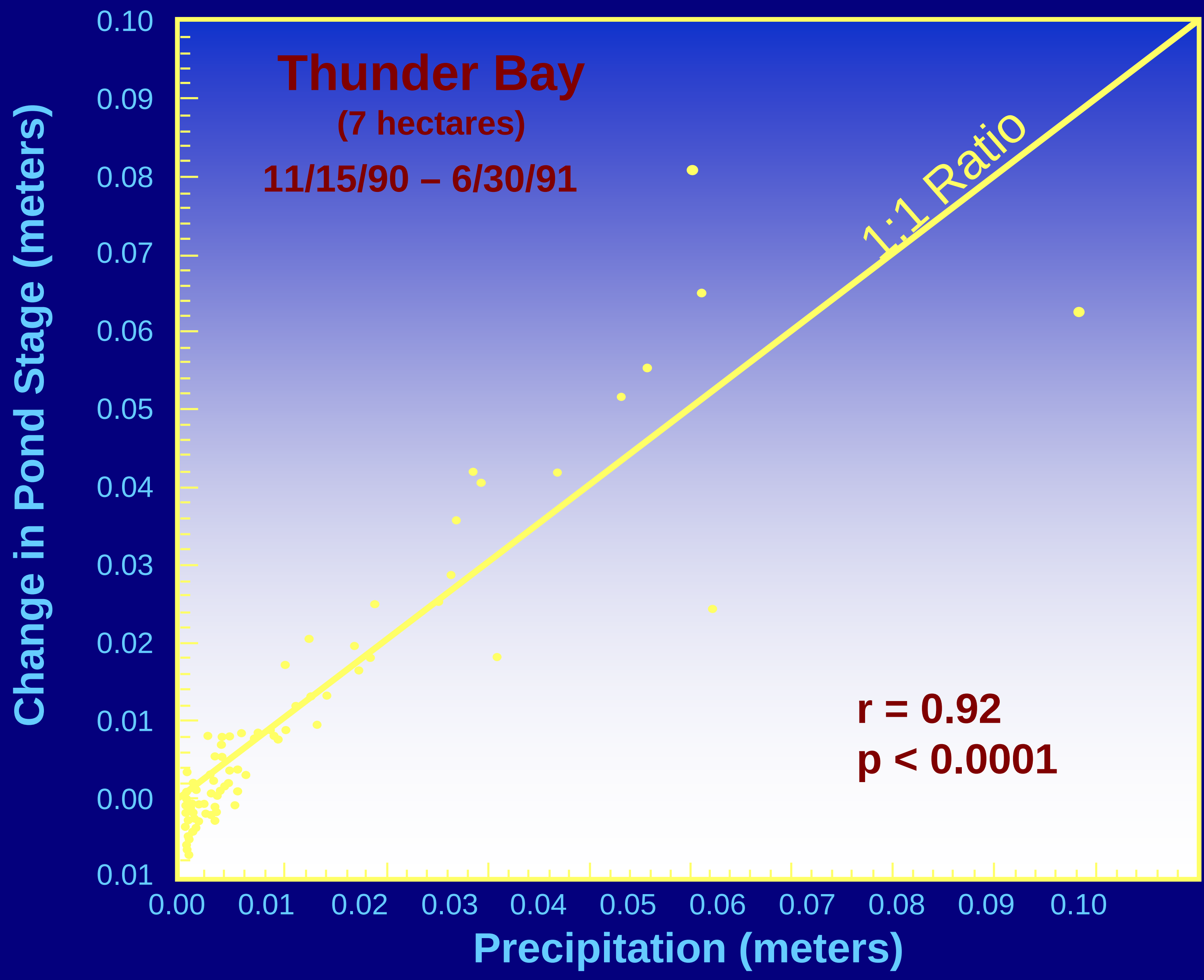


1300 - 4000 M
3M
PEAT 1-12 M THICK
SAND LAYER
HARD-PAN CLAY
FIBROUS PEAT BOTTOM
N
BAY-FOREST COMMUNITY
SAND RIM
PULPY PEAT BOTTOM
SCATTERED CYPRESS
SANDY BOTTOM
EXPOSED BEACH
BUILD-UP SAND RIM
ERODED SHORELINE

Carolina Bays of the Savannah River Site, SC
(SC information from Rebecca Sharitz)

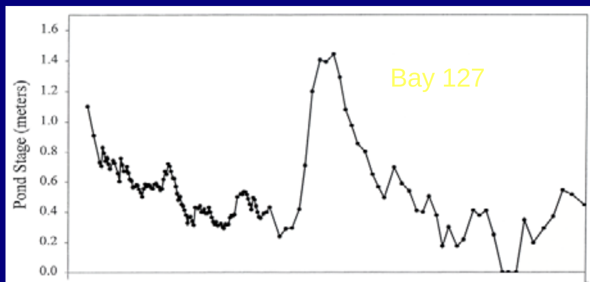
Geologic section along the long axis of Thunder Bay

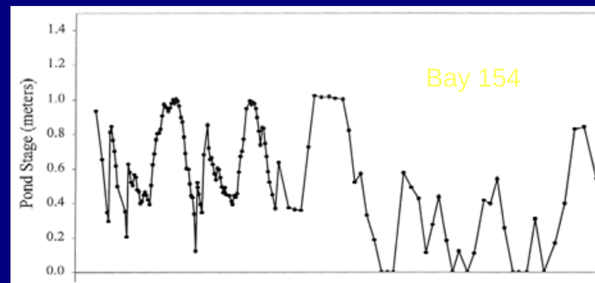


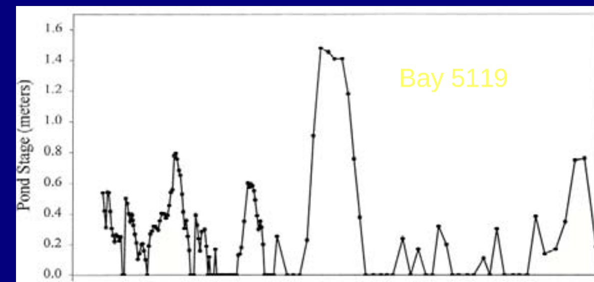


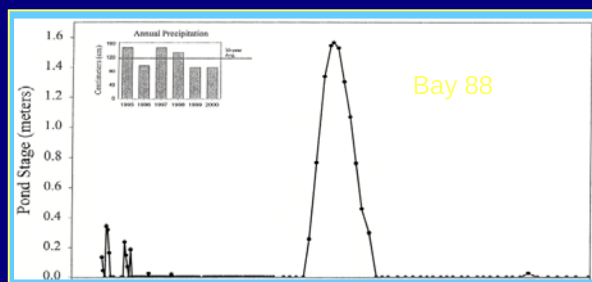
Lide et al. 1995, Wetlands 15:47-57

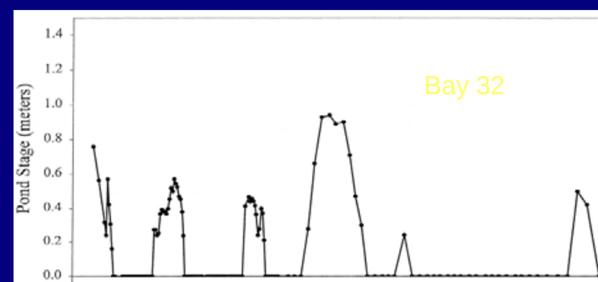
Hydrographs of Five SRS Carolina Bays
March 1995 – June 2001

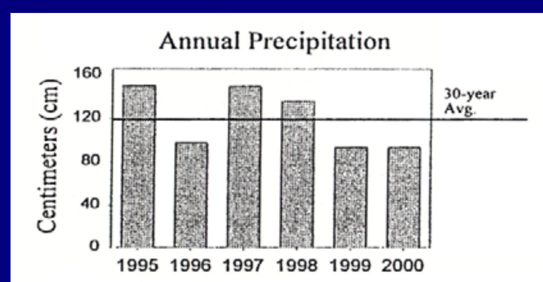












Water Chemistry of 49 Carolina Bays and Bay Lakes

	Median	Range
Peat depth (cm)		**<1 – >200**
pH	**4.6**	**3.4 – 6.7**
Ca (mg/l)	**1.69**	**0.16 – 11.75**
Mg (mg/l)	**1.12**	**0.36 – 3.53**
Na (mg/l)	**4.05**	**1.06 – 14.19**
K (mg/l)	**0.86**	**0.27 – 16.22**
SO_4 (mg/l)	**3.9**	**0.2 – 23.9**
DOC (mgC/l)	**17.2**	**2.1 – 70.0**
SiO_2 (mg/l)	**3.6**	**0.1 – 21.8**

Newman and Schalles. 1990. Arch. Hydrobiol. 118:147-168

Carolina Bays

- introduction to Carolina bay wetlands
- ecological significance
- degree of hydrologic isolation



Values and Functions

- store and gradually release stormwater runoff
- provide essential habitat
- improve water quality by removing toxic substances
- provide aesthetic, historic, cultural and wilderness values
- provide sites for education and research
- serve as recharge and discharge areas for groundwater
- critical to the long-term protection of natural water resources

Rare Plants in Depression Wetlands of the Southeastern Atlantic Coastal Plain

- 22 of the 29 vegetation alliances contain rare plants
- G1 – G3: 69 species, 23 families
- G4 – G5: 128 species, 34 families




Edwards and Sutter, 2001. Natural Areas Journal 21:12-35

Size and Richness of FW Wetland Seed Banks

Wetland	Density ($\overline{X}/m^2$)	Species no.	Location	Reference
Carolina bays	72,600	107	SC	Kirkman 1992
bogs	165	1	CAN	McCarthy 1987
bogs	171,830	12	WV	McGraw 1987
lakeshore	10,089	41	CAN	Keddy & Reznicek 1982
nontidal marsh	3,203	29	IA	van der Valk & Davis 1976
nontidal marsh	29,753	45	IA	van der Valk & Davis 1978
nontidal marsh	110,000	50	IA	van der Valk & Davis 1979
riverine	2,576	59	SC	Schneider & Sharitz 1986
swamp	600	6	GA	Gunther et al. 1984
temporary ponds	17,943	21	NJ	McCarthy 1987
tidal marsh	9,293	52	NJ	Leck & Graveline 1979
tidal marsh	26,957	53	NJ	Leck & Simpson 1987

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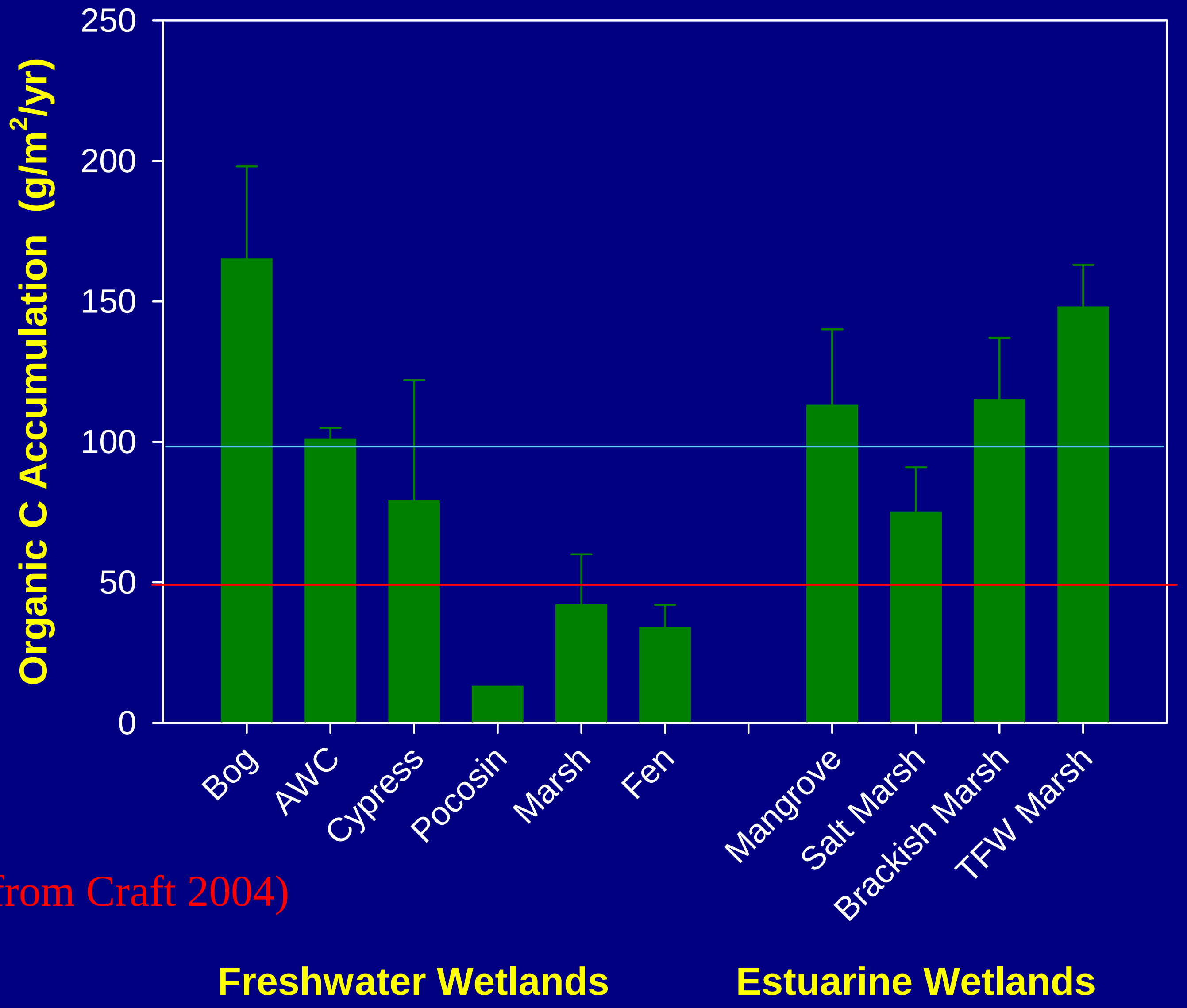


(from Craft 2004)

North Carolina Peat Resources

Deposit		> 0 ft		> 4 ft	
		Area (10^3 acres)	Weight* (10^6 tons)	Area (10^3 acres)	Weight* (10^6 tons)
I.	**Coastal Swamps (Pocosins)**	**581.7**	**436.9**	**246.1**	**283.7 -- G** **
	Dismal Swamp	76.8	67.8	34.7	43.4 -- G
	Pamlimarle	373.0	278.0	175.0	196.0 -- G
	Gull Rock	8.1	4.6	1.3	1.6 -- G
	Van Swamp	6.6	5.8	2.6	3.8 -- G
	Bay City-Gum Swamp	12.3	5.9	1.1	1.1 -- G
	Light Grounds	5.9	5.2	2.8	3.5 -- G
	Open Grounds	11.0	6.3	0.5	0.6 -- G
	Croatan Forest	35.3	26.9	11.6	14.4 -- G
	Hofmann Forest	5.2	4.2	1.0	1.6 -- G
	Angola Swamp	21.9	15.2	8.8	9.6 -- G
	Holly Shelter	9.2	6.7	3.1	3.8 -- G
	Green Swamp	16.4	10.3	3.6	4.3 -- G
II.	**River Flood Plains**	**81.0**	**77.0**	**41.0**	**38.0 -- P**
	Chowan	25.0	25.0	13.0	12.0 -- P
	Roanoke	32.0	30.0	16.0	15.0 -- P
	Tar	6.0	6.0	3.0	3.0 -- P
	Neuse	6.0	6.0	3.0	3.0 -- P
	Cape Fear	12.0	10.0	6.0	5.0 -- P
III.	**Carolina Bay**	**35.3**	**15.4**	**8.1**	**8.4 – F**
	TOTAL	**698.0**	**529.3**	**295.2**	**330.1**

* Weight in moisture-free tons.
** Quality of estimate: G – good, F – fair, P – poor.

(from Ingram et. al. 1983)

Summary of Composition and Heating Values of NC Peats

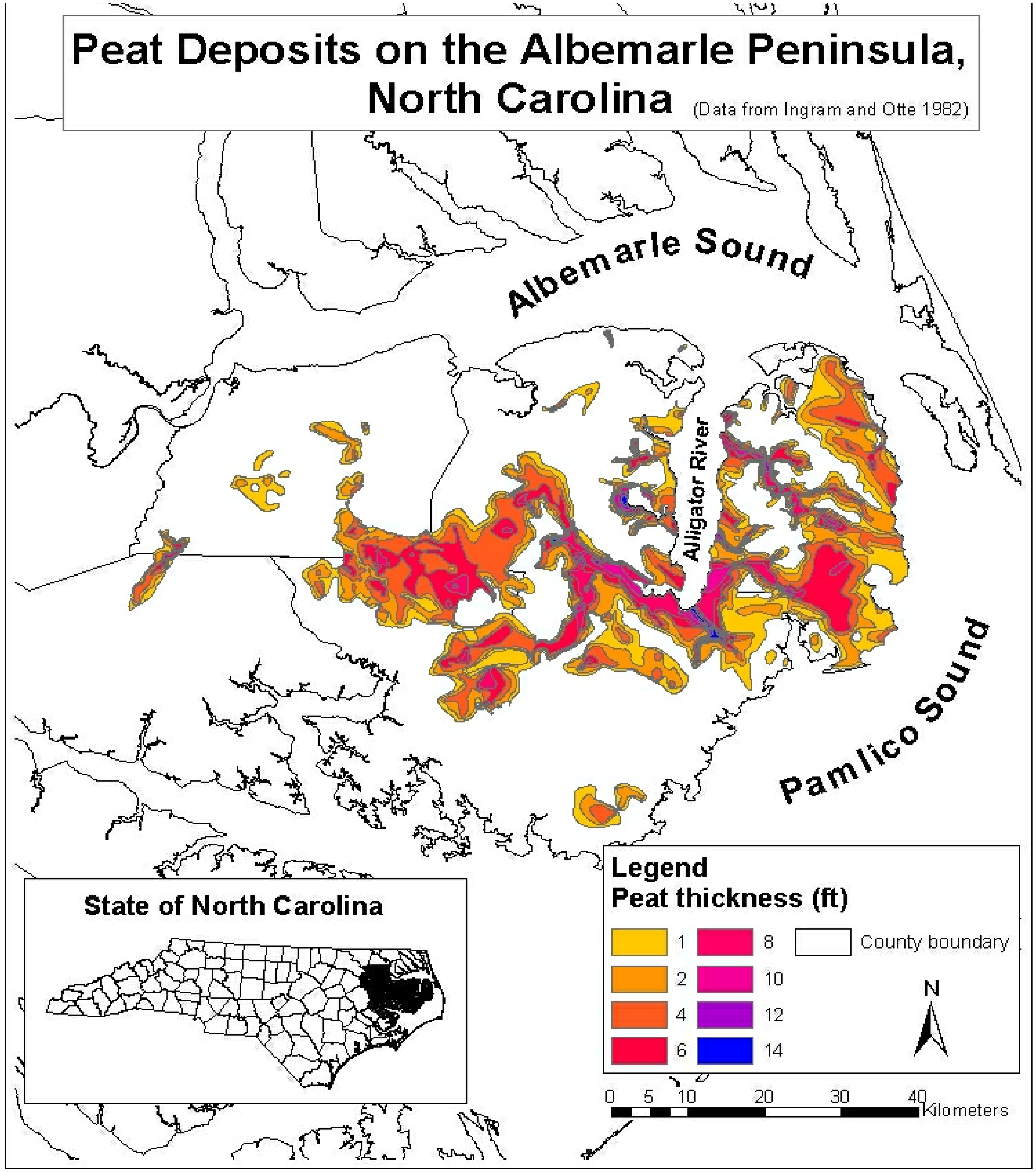
(200samples with less than 10% ash)

	Low	Median	High
BTU/lb*	8700	10200	11200
% H_2O	70	85-90**	94
Proximate Analysis*			
% Volatiles	52	61	67
% Fixed Carbon	26	35	43
% Ash	1	4	10
Ultimate Analysis*			
% C	53	60	66
% H	4.1	5.2	6.2
% O	25	29	34
% N	0.9	1.4	2.4
% S	0.1	0.2	0.8
% Ash	1	3	10

* Moisture-free basis.

** Average moisture content of 1092 samples with less than 25% ash was 84%

(from Ingram and Otte 1981)


Peat Deposits on the Albemarle Peninsula, North Carolina
(Data from Ingram and Otte 1982)
Albemarle Sound
Alligator River
Pamlico Sound
State of North Carolina
Legend
Peat thickness (ft)
1
2
4
6
8
10
12
14
County boundary
N
0 5 10 20 30 40
Kilometers

Comparison of peat accretion and nutrient accumulation rates of Various organic soil freshwater wetlands in the U.S.A. (Craft and Richardson 1998)

Type	Accretion Rate	C	N	P	S
	mm yr^{-1}	----------------------	g m^{-2} yr^{-1}	----------------------	
Bogs (MA)	4.3	90	1.2	---	---
(MD, PA, WV)	1.4 – 3.1	64 – 89	1.4 – 3.1	0.07 – 0.16	1.0 – 2.0
(MN)	2.4	79	---	---	0.5
Fens (MI)					
Unenriched	0.9	42	3.0	0.11	---
Unenriched	---	---	---	0.30	---
Enriched	---	---	---	0.90	---
Pocosins (NC)	**2.6**	**127**	**3.0**	**0.06**	**---**
Okefenokee (GA)	**---**	**82**	**3.8**	**0.15**	---
Everglades (FL)					
Enriched					
^{137}Cs	6.7	223	16.6	0.46	4.3
^{210}Pb	5.8	184	13.6	0.40	4.0
Unenriched					
^{137}Cs	1.4	65	4.7	0.06	4.0
^{210}Pb	1.7	97	6.5	0.06	1.8

Estimate of Carbon Storage in NC

- 282,470 ha of undisturbed peatlands
- 481 million metric tons (530 US tons) of Peat
- 298 million metric tons of C stored in NC
- Pocosin accretion rate of 127 g/m2/yr
- 359,000 metric tons of C stored stored each year in North Carolina Peatlands on 33% of original pocosin land that is still undisturbed

Pocosin Area Losses

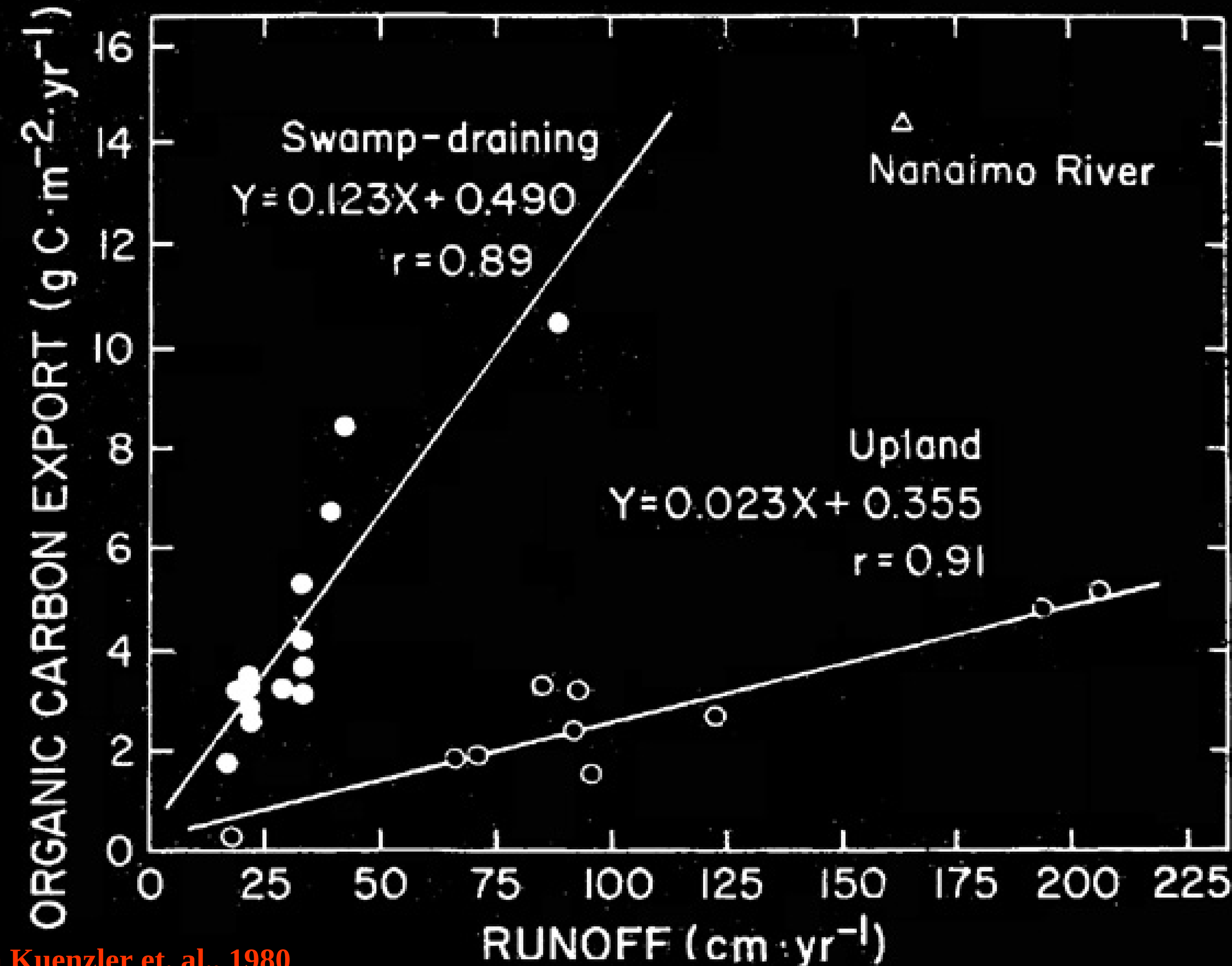
- Once covered 908, 000 ha (nearly 2.2 million acres) in NC
- 33% totally converted to agriculture or forestry
- 36% partially ditched as of late 1980's
- 31% natural undrained peat with only tree harvesting having occurred in the past


NC has lost 49% of its Wetlands

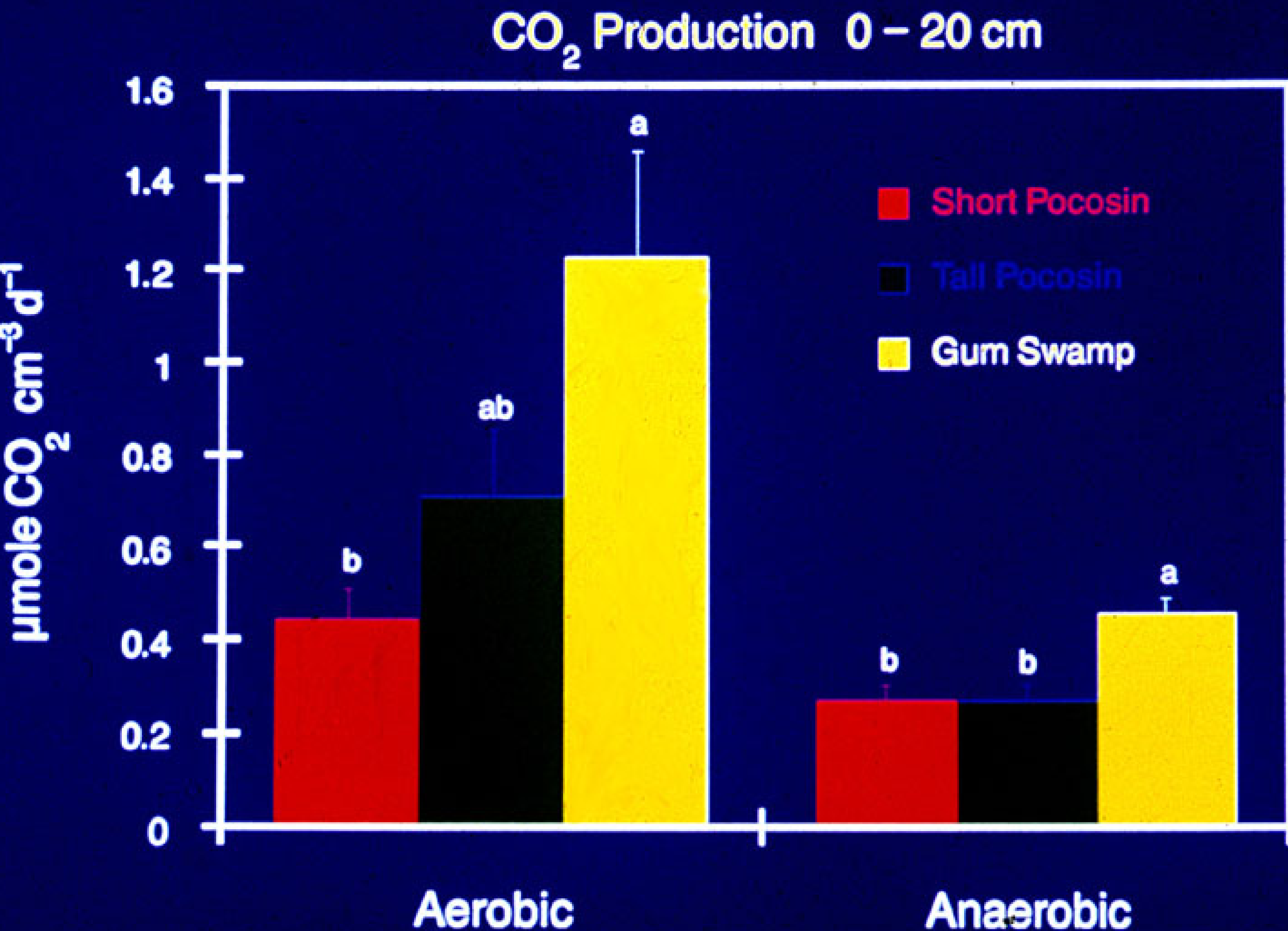
Regional Outputs from Developed Pocosins That Are Considered Potential Problems

- Fresh Water
- Nutrients
- Organic Matter
- Bacteria
- Heavy Metals
- Pesticides

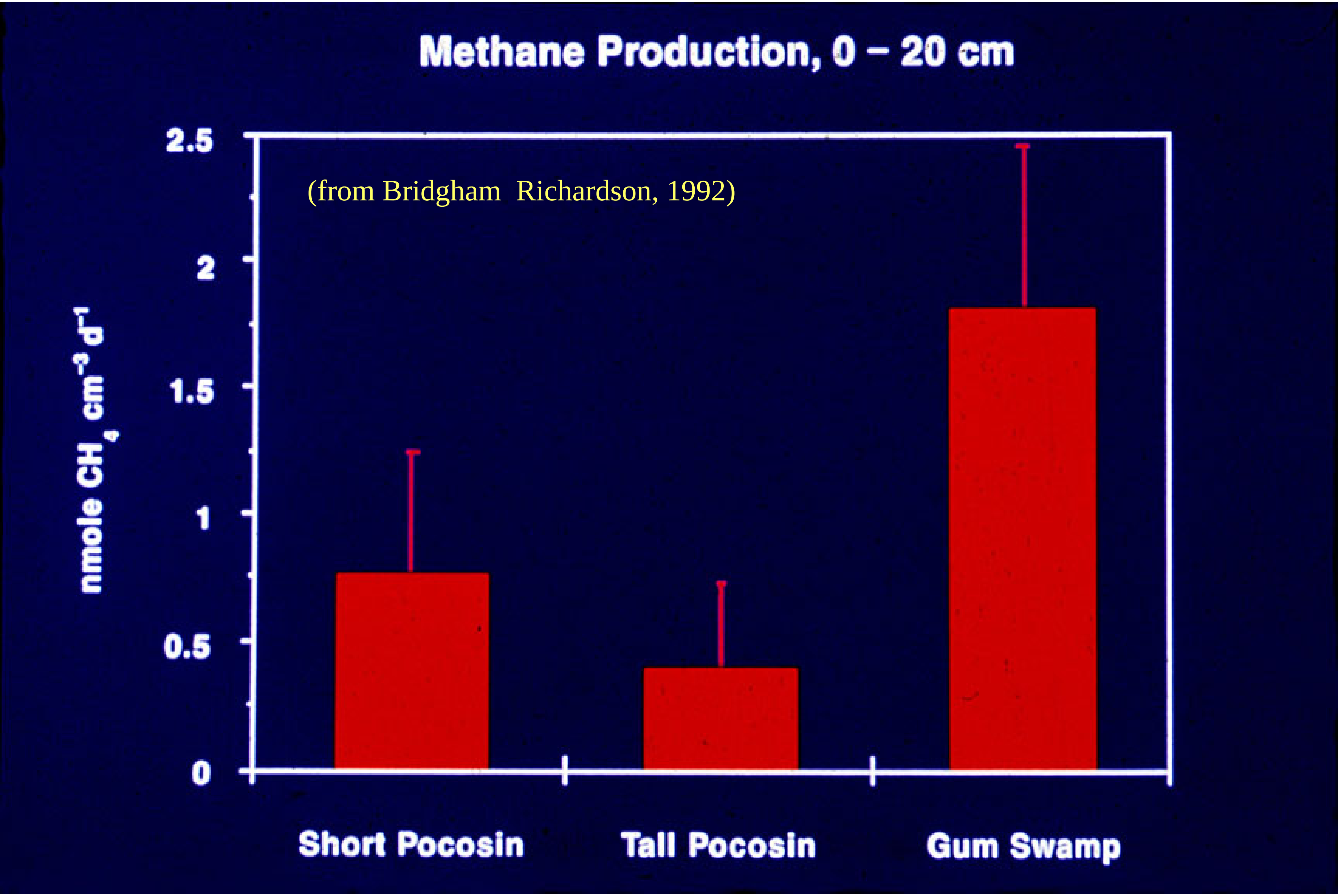
Carbon loss



From Kuenzler et. al., 1980

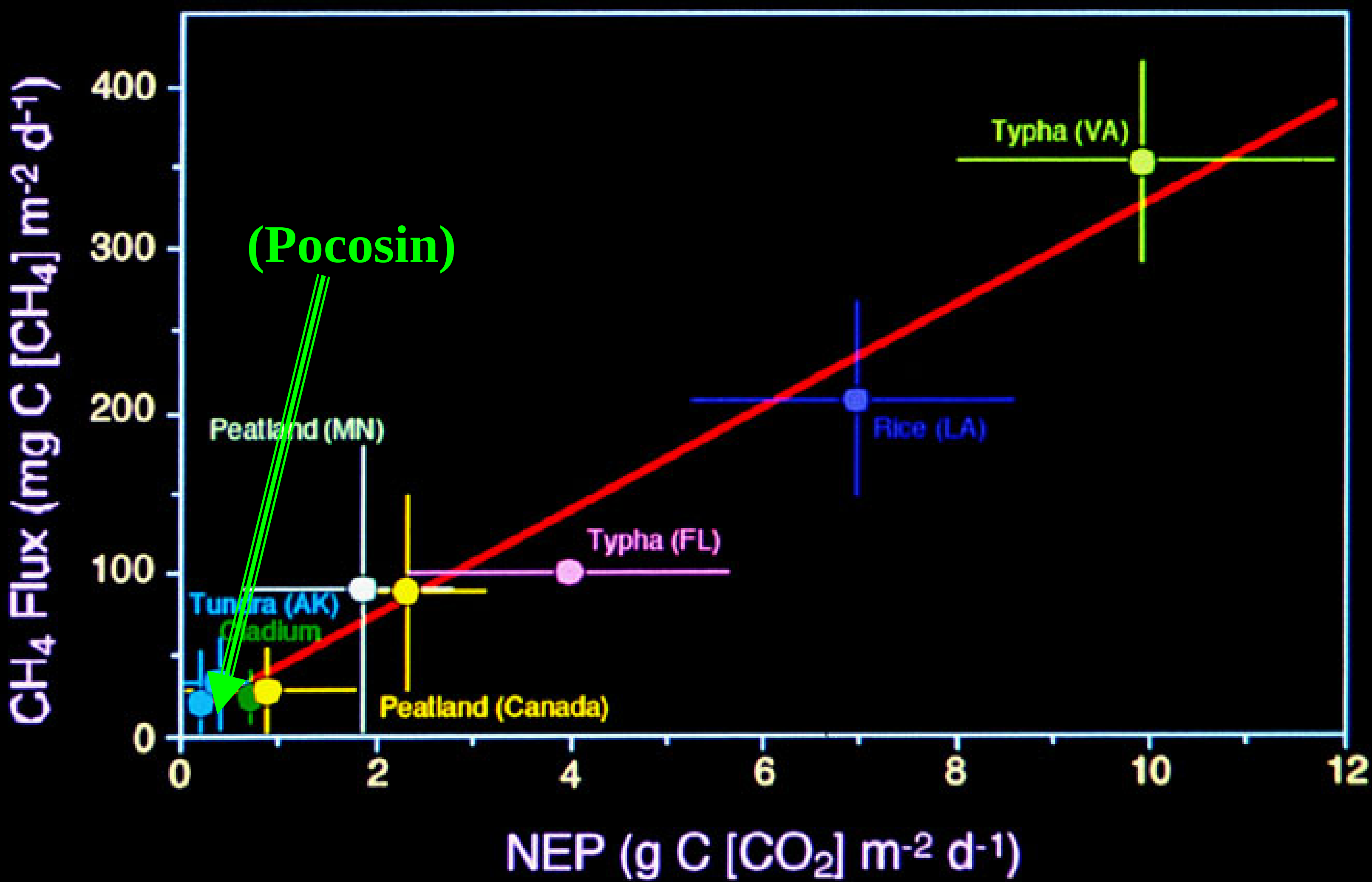


(from Bridgham Richardson,1992)



Methane Production, 0 – 20 cm
(from Bridgham Richardson, 1992)
2.5
2
1.5
1
0.5
0
nmole CH4 cm-3 d-1
Short Pocosin
Tall Pocosin
Gum Swamp

(from Whiting & Chanton 1992)



An Estimate of Annual CO_2 Losses from Converted Wetlands

- Subsidence Rate ($\approx$ 2 cm yr^{-1})
- Bulk Density of Peat (0.45 g cm^{-3})
- Soil Organic Matter Content (68%)
- Carbon Content of Organic Matter (56%)
- Converted Pocosins Land (202,342 ha)
- Calculated Annual Release of CO_2

  (7×10^6 t C yr^{-1})

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- Calculated Annual Release of CO_2 (7 x 10^6 t C yr^{-1})
- San Joaquin Valley, California (8 x 10^6 t C yr^{-1})
- Okeechobee, Florida (9 x 10^6 t C yr^{-1})
- Total = 0.5 –2% Entire World's Fossil Fuel emissions.

Stop Loss

- Prevent loss of C from the Ecosystem
- No credit is allowed at this point

Component/ Activity	*Sequestration* *($g\ ha^{-1}\ yr^{-1}$)*	*Citation*
Soil C Accumulation **Pocosin, NC**	**1.3×10^6**	**Craft and Richardson (1998)**
Vegetation C Accumulation **Pocosin, NC**	**0.5×10^6**	**Linear extrapolation of Wendell et al. (1962) data for 80-year period to stand maturity**
Stop Loss of Soil Respiration Reflooded agricultural	2×10^9	Estimate based on Miller et al. (2000) example

Component/ Activity	*Sequestration* *(g ha^{-1} yr^{-1})*	*Citation*
Pinus taeda Private Forest Stand	1.0-3.8 x 10^6	Huang and Kronrad (2001)
Improved Pasture Management Afforestation of cropland	0.1-3.0 x 10^6 2.0-4.3 x 10^6	NREL, Colorado State University (http://nrel.colostate.edu/splash/cseq.html Lewandrowski et al. (2004)
Management intensive Grazing, VA	0.5 x 10^6	NREL, Colorado State University (http://nrel.colostate.e

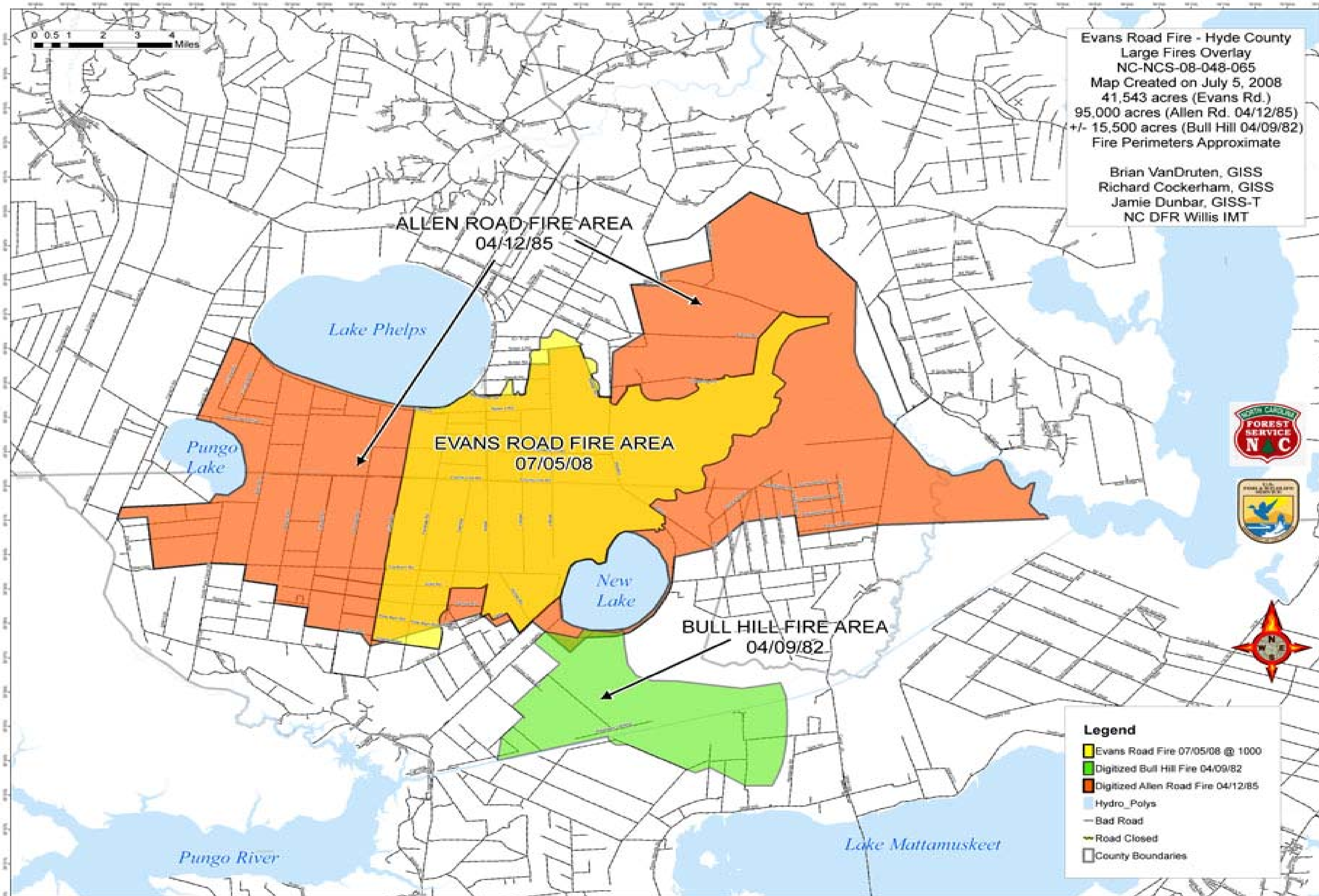
(Peat Fire June –September 2008)

(How much C was lost?)

(41,000 acres Burned)

(41,000 acres Burned)

(NC Pocosin Fire 2008)


Evans Road Fire - Hyde County
Large Fires Overlay
NC-NCS-08-048-065
Map Created on July 5, 2008
41,543 acres (Evans Rd.)
95,000 acres (Allen Rd. 04/12/85)
+/- 15,500 acres (Bull Hill 04/09/82)
Fire Perimeters Approximate
Brian VanDruten, GISS
Richard Cockerham, GISS
Jamie Dunbar, GISS-T
NC DFR Willis IMT
0 0.5 1 2 3 4 Miles
ALLEN ROAD FIRE AREA
04/12/85
EVANS ROAD FIRE AREA
07/05/08
BULL HILL FIRE AREA
04/09/82
Lake Phelps
Pungo Lake
New Lake
Pungo River
Lake Mattamuskeet
Legend
Evans Road Fire 07/05/08 @ 1000
Digitized Bull Hill Fire 04/09/82
Digitized Allen Road Fire 04/12/85
Hydro_Polys
Bad Road
Road Closed
County Boundaries

Last 0 To 12 Hours
Last 12 To 24 Hours
6 Days Previous To Last 24 Hours
Incident Management Team - Type 1
Incident Management Team - Type 2
Incident Management Team - Other
Fire Use Management Team
Pocosin Lakes National Wildlife Refuge
EVANS ROAD
USDA Forest Service
MODIS Active Fire Mapping Program
http://activefiremaps.fs.fed.us
RSAC
© USFWS
© 2008 Europa Technologies
Image © 2008 DigitalGlobe
© 2008 Tele Atlas
Google
lat 35.699343° lon -76.359302°
elev 13 ft
Jul 2006
Eye alt 18.80 mi

New Project

Impacts of Peatland Ditching and Draining on Water Quality & Carbon Sequestration Benefits of Peatland Restoration

USFWS, Duke Wetland Center & NC Nature Conservancy

"Restoring peatlands through re-introduction of wetland hydrology offers the opportunity to stop the loss of carbon from these soils and, in fact, convert them from a source of carbon to a sink."

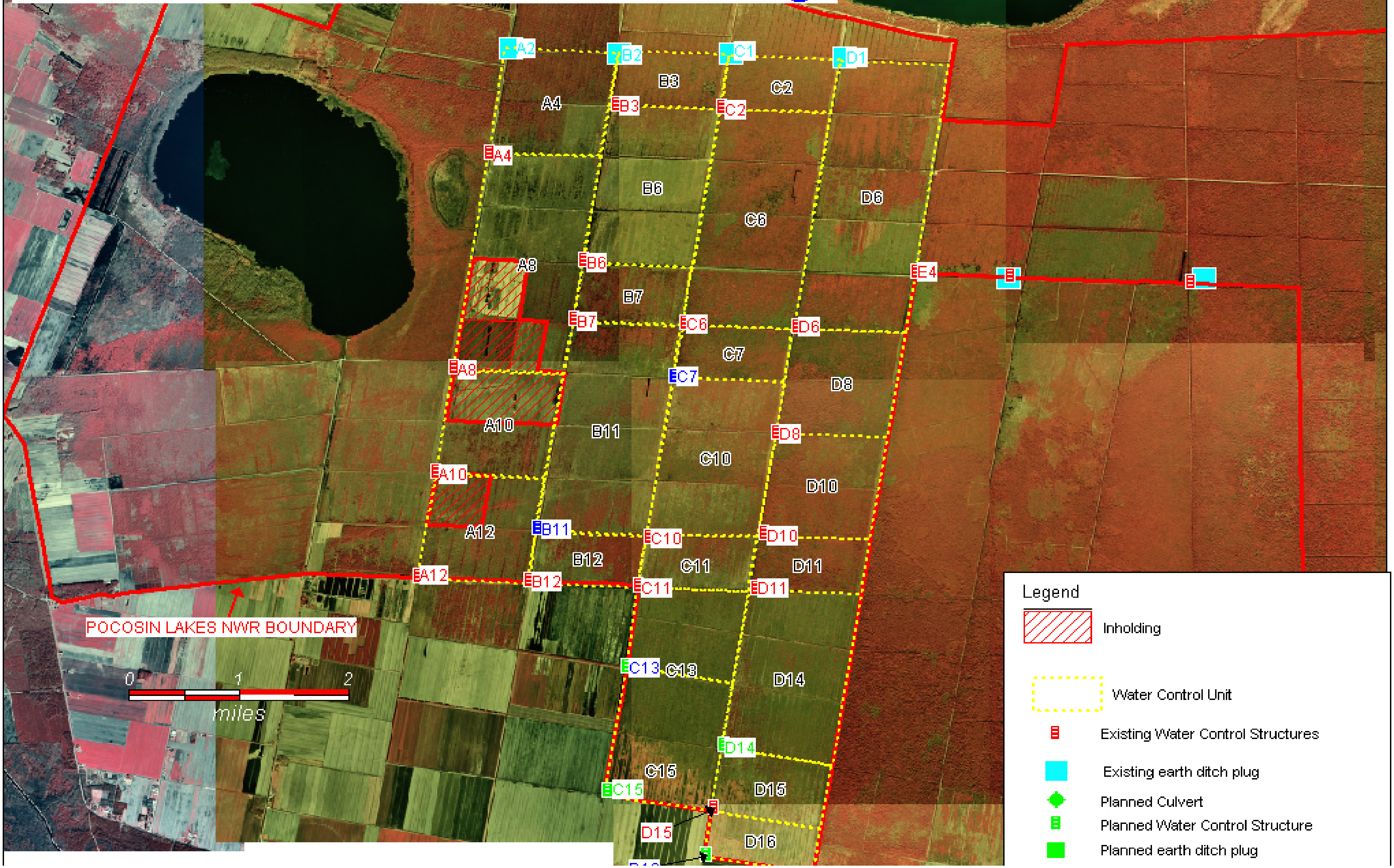
Hypotheses

H1: Restored water levels will result in immediate and significant reductions in CO_2 and N_2O emissions from drained peatland soils.

H2: Due to the poor carbon quality (recalcitrance) of pocosin Histosols, any CH_4 flux following hydrology restoration of drained peatlands will not be ecologically significant.

H3: The measured carbon, and nitrogen sequestration in restored peatlands is within 20% of expected (from synthesis of ecological literature) values of reference sites.

Pocosin Lakes National Wildlife Refuge



Summary

- ≅ 66% of the Pocosins have been drained or have drainage ditches
- 530 million US tons (481 metric tons) of peat exist in NC undisturbed peatlands
- 298 million metric tons of C is stored in NC undisturbed peatlands
- Potential for increased C storage in restored pocosin lands on the coastal plain includes both storage and reduced CO_2 loss to the atmosphere (Stop Loss)


Any Questions?