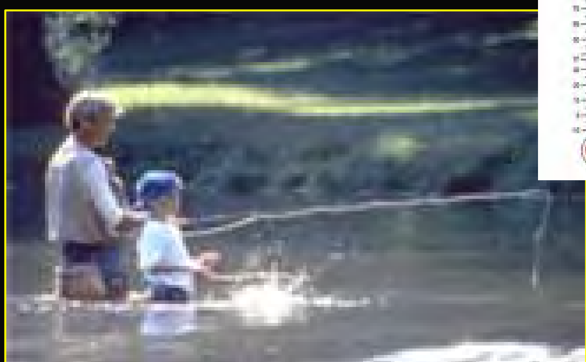
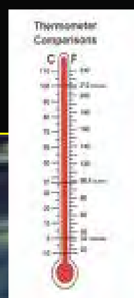
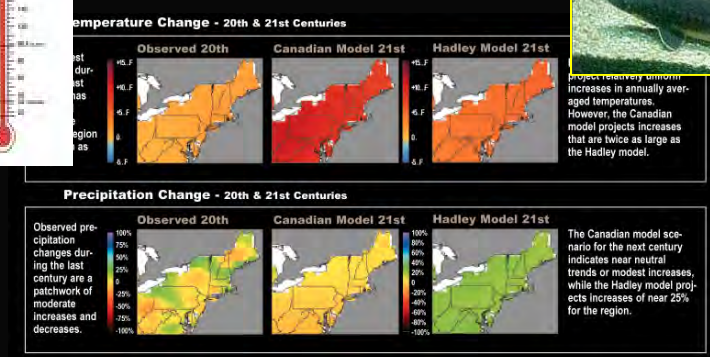
Climate Change Adaptation in an Evolving Delaware Estuary

Danielle Kreeger
Science Director
Partnership for the Delaware Estuary







To be discussed

The Delaware Estuary
- orientation
- expected climate change effects
- possible biological responses

Management Challenges
- complexity
- examples: wetlands, shellfish

Adaptation Needs
- vulnerability assessments
- management, policy options

PDE Climate Ready Pilot
- goals, approach
- anticipated outcomes

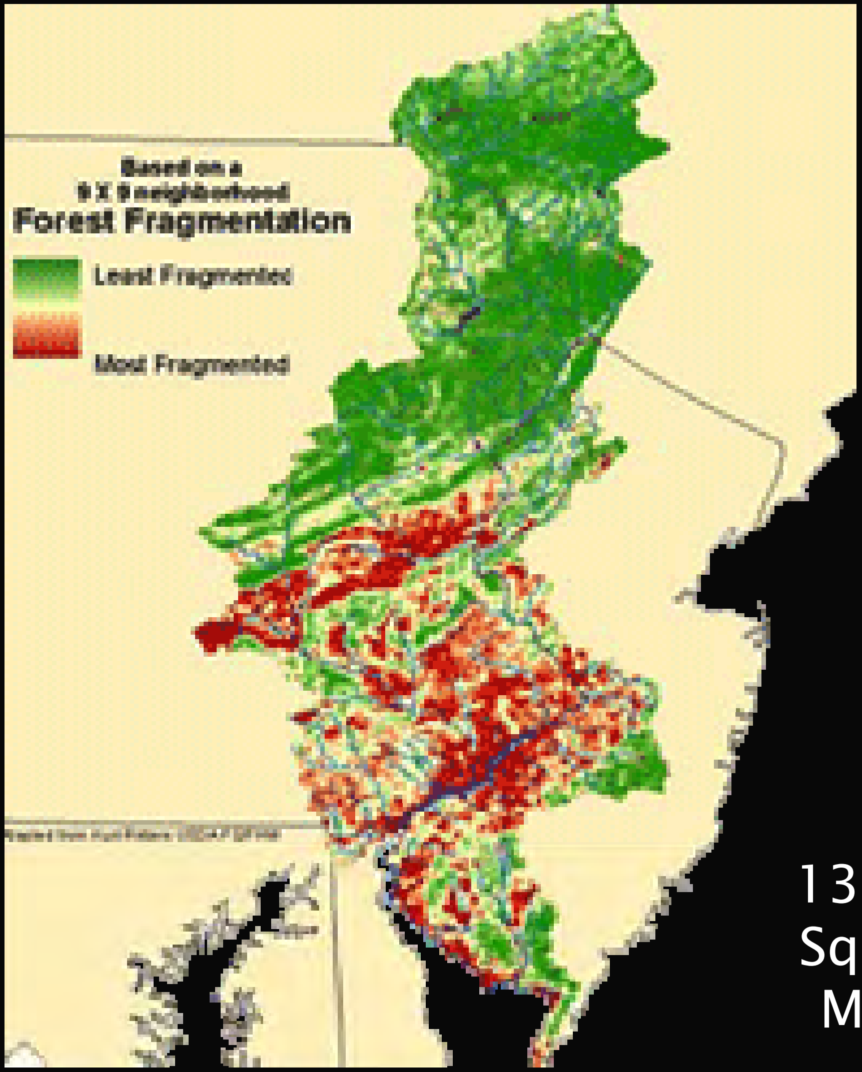
VOLUME 17 • ISSUE 2 • WINTER 2007

ESTUARY NEWS

NEWSLETTER OF THE PARTNERSHIP FOR THE DELAWARE ESTUARY: A NATIONAL ESTUARY PROGRAM

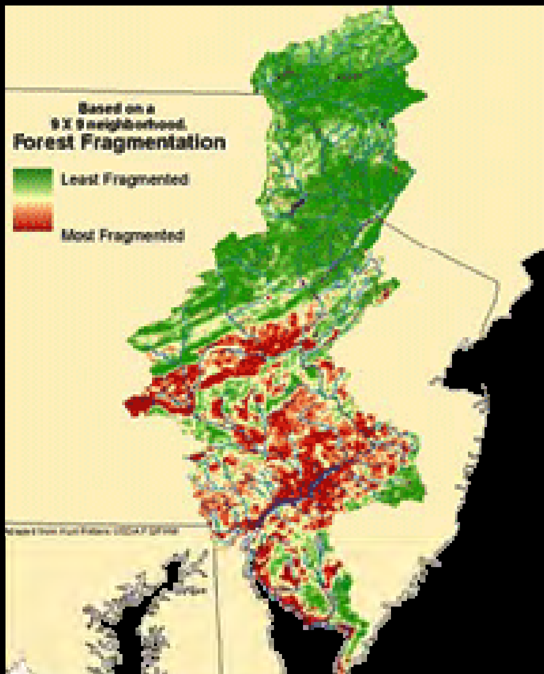
Climate Change Hits Home

The Watershed



13,611
Square
Miles

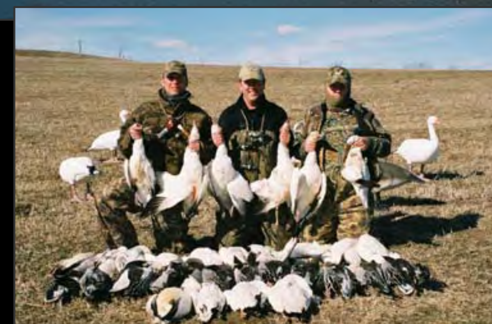
Climate Change in a Complex Landscape



Upper Watershed:
- "pristine" recreational area
- water supply for NYC

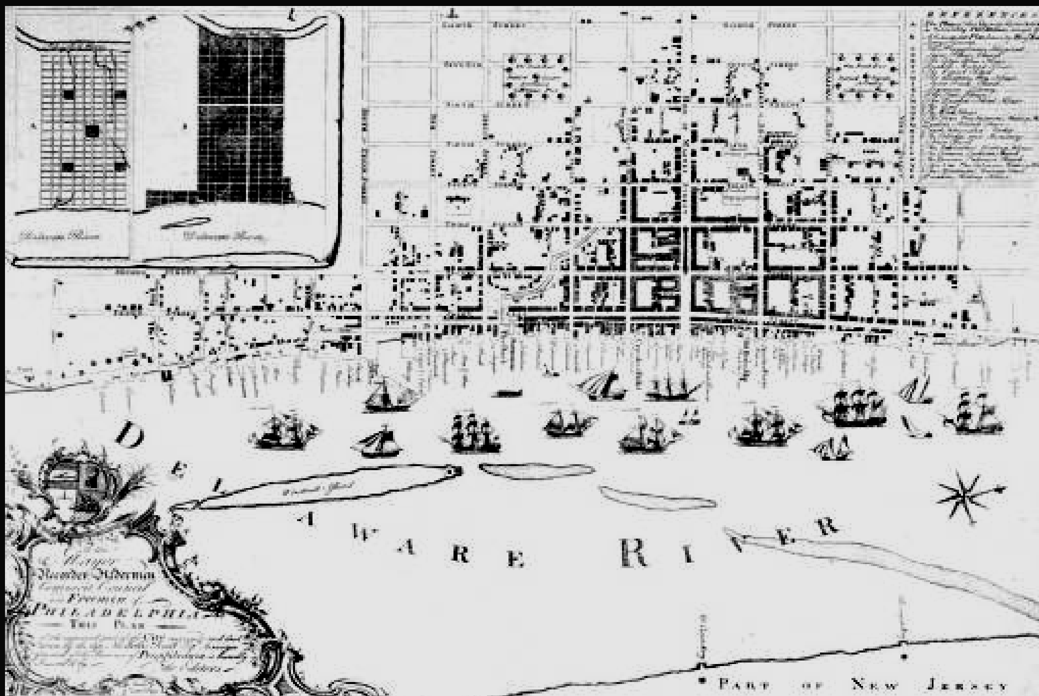
Tidal River:
- 4th largest US urban center
- world's largest freshwater port
- 70% of east coast oil
- Major industry buildup

Lower Estuary:
- Water fowl, finfish, shellfish
- Horseshoe crab population



Seat of the Nation
History as a "Working River"

DK 5



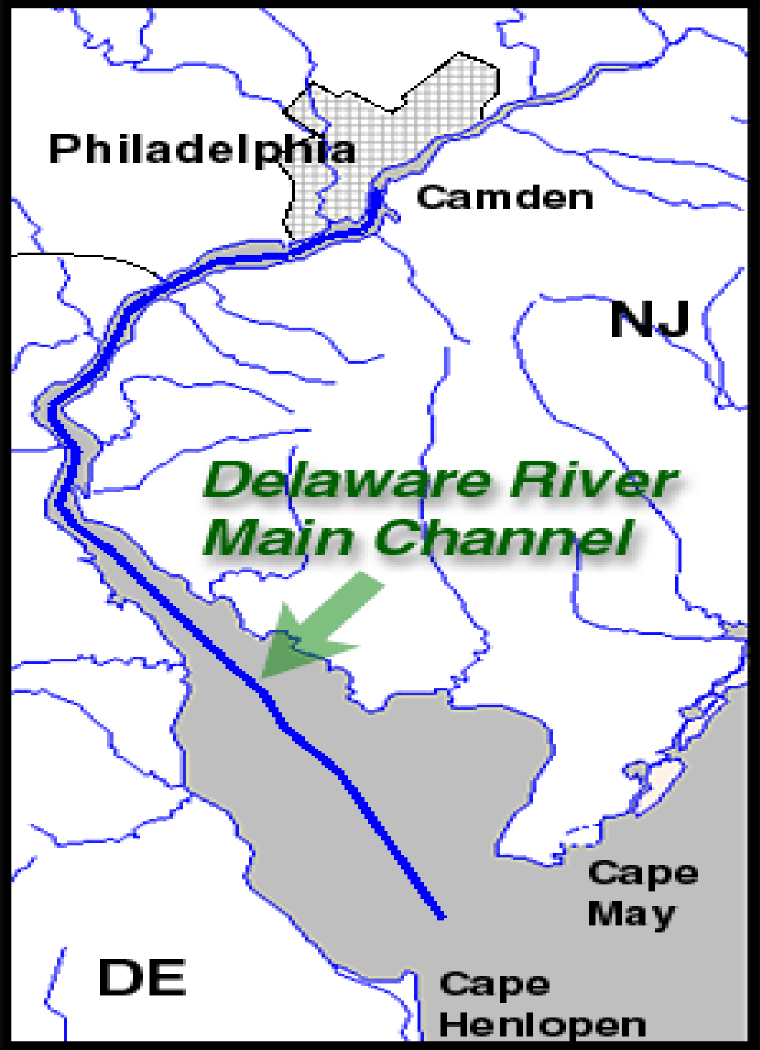
1762 map showing Philadelphia on the Delaware River

Slide from Jonathan Sharp (UDel)

Facts & Figures – Ports

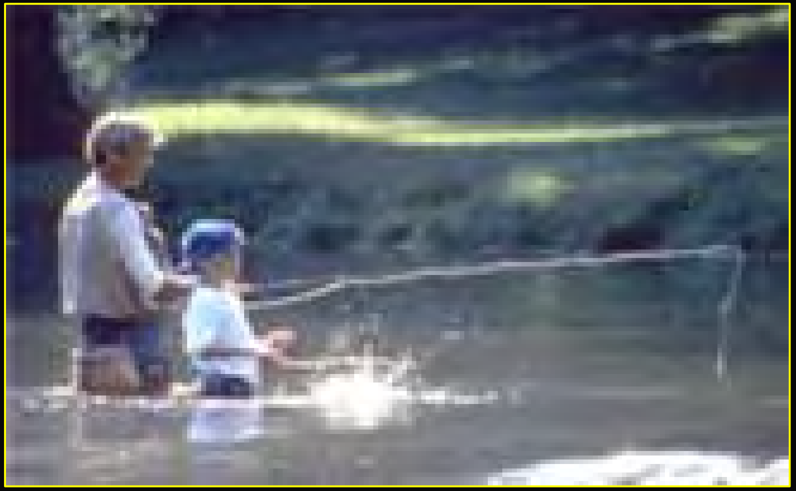
DK 6

- Largest Freshwater Port in World
- 3,000 vessels per year
- Largest port in U.S. for crude oil imports, 75% of east coast
- Largest North American port for steel, paper, and meat imports
- $19 billion in annual revenue



Slide adapted from USCG 2005

Also a "Living River"



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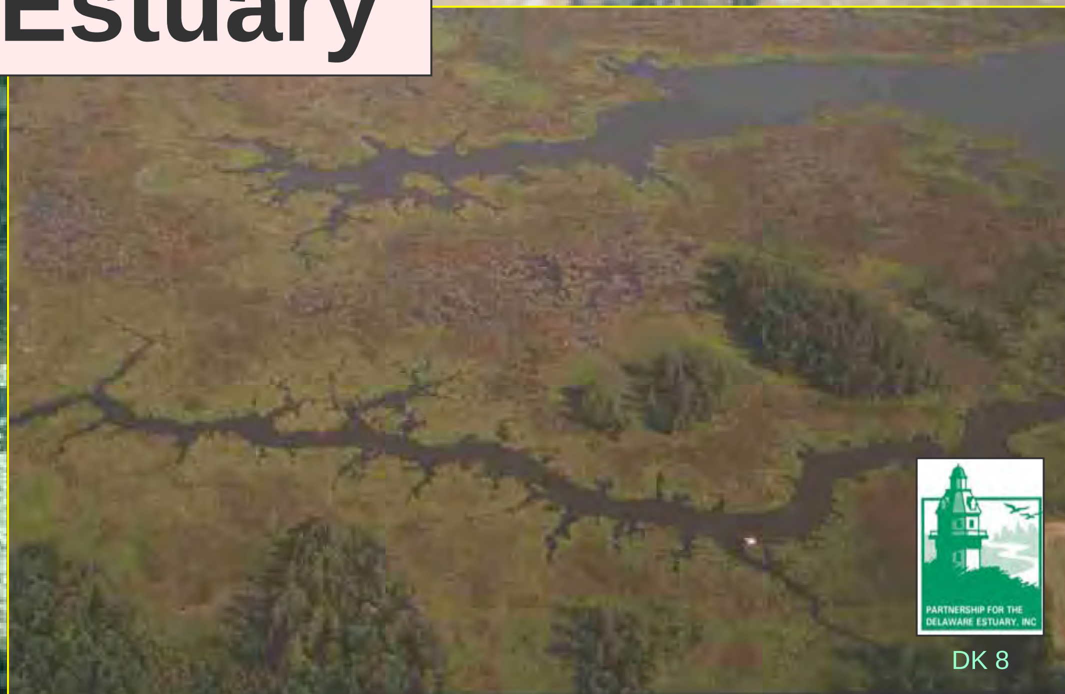
Delaware Estuary



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VOLUME 17 ✲ ISSUE 2 ✲ WINTER 2007

ESTUARY NEWS

NEWSLETTER OF THE PARTNERSHIP FOR THE DELAWARE ESTUARY: A NATIONAL ESTUARY PROGRAM

Climate Change Hits Home

By Kathy Klein, Executive Director, Partnership for the Delaware Estuary

As I was driving to work one recent morning, thinking about writing this article and listening to National Public Radio, I learned that the Bulletin of Atomic Scientists has concluded that the threat posed by climate change is second only to that posed by nuclear weapons. Although I am actually relieved that climate change is finally getting the attention it deserves, I am also keenly aware that time continues to tick away as world leaders and other policymakers explore ways to address global warming and its environmental impacts.

Being the visual person that I am, I can't seem to forget the recent image in the media of a lone polar bear floating on a piece of ice that had broken off the Arctic icecap as a result of melting. What most people do not realize, however, is you do not have to go to the Arctic to see the results of global warming. For many years, scientists in the Delaware Estuary have noted the dieback of upland

tant to realize, however, that there are small steps each one of us can take in our daily lives that, when multiplied, can make a meaningful impact.

One of these small steps is the use of compact florescent light bulbs (CFLs). CFLs use up to 75 percent less energy than regular incandescent light bulbs while lasting approximately eight times longer, and this results in less production of greenhouse gas emissions, air pollution, and toxic waste. The average CFL will save its owner at least $55 in energy costs over its lifetime. If every U.S. household replaced one bulb with a CFL, it would have the same impact as removing 1.3 million cars from the road.

I love a challenge and I hope you do too. Therefore, I would like to challenge the readers of "Estuary News" to make the switch at home, in at least one light fixture, from an incandescent light bulb to a CFL. If you already use CFLs in your home, why not make the

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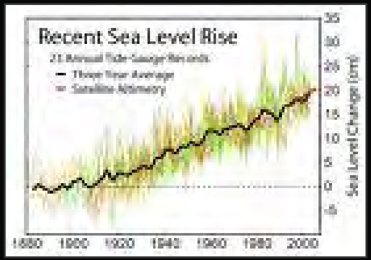
Climate Change in the Delaware Estuary

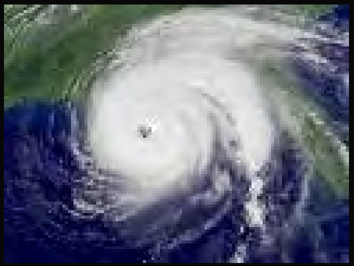
1. Likely Physical Changes

Temp

Salinity



Sea Level Rise



Storms

2. Example Effects on Resources

Uplands

Marshes

Bivalves

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Climate model results for the watershed of the Delaware Estuary

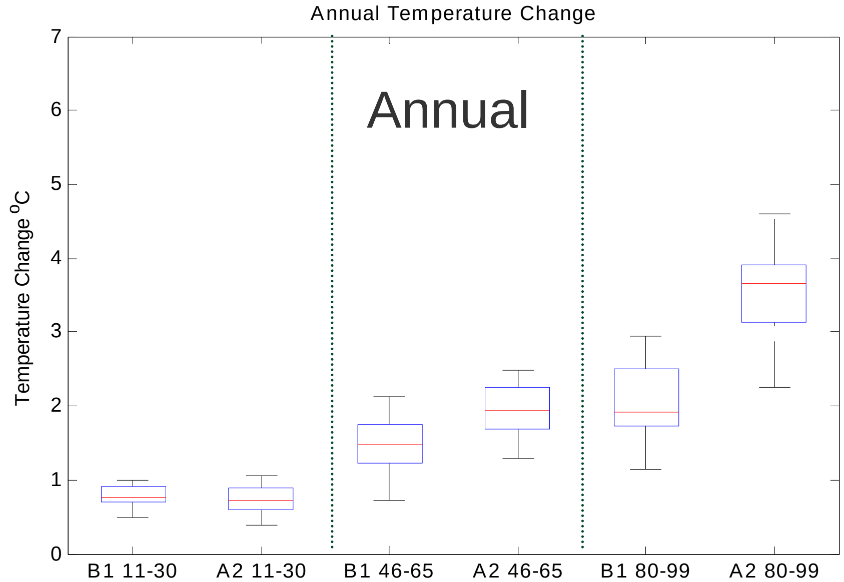
Raymond Najjar
Department of Meteorology
The Pennsylvania State University
May 2009

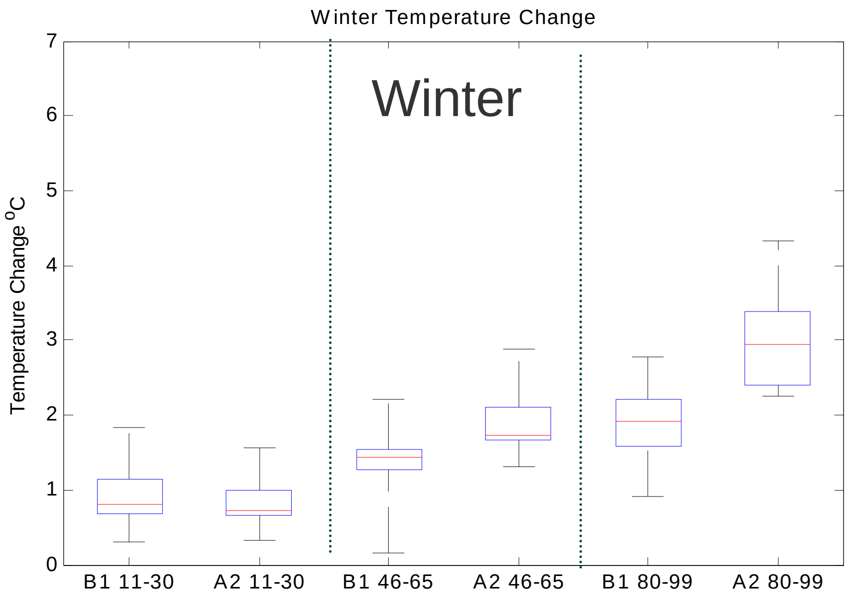
21st Century Climate Projections

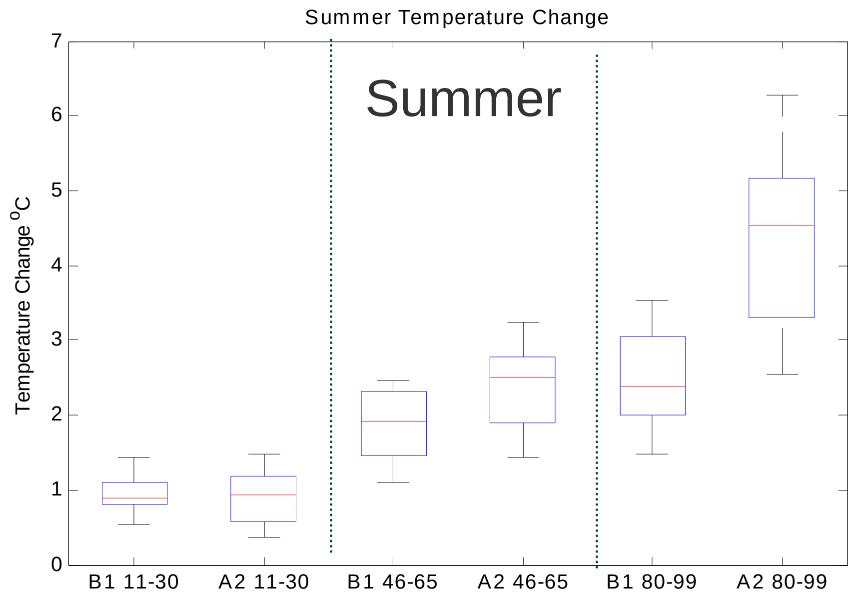
- Projections shown as changes with respect to 1980-1999 for three future time periods: 2011-2030 (early century), 2046-2065 (mid century), and 2080-2099 (late century).
- B1 (lower emissions) and A2 (higher emissions) scenarios are shown.
- Changes shown using box-and-whisker plots, which present 14-model maximum, minimum, median, 25th percentile, and 75th percentile.

Temperature change

- More warming in summer than winter
- Scenario differences minor until late century







***R. Najjar, PSU** – Draft not for distribution*

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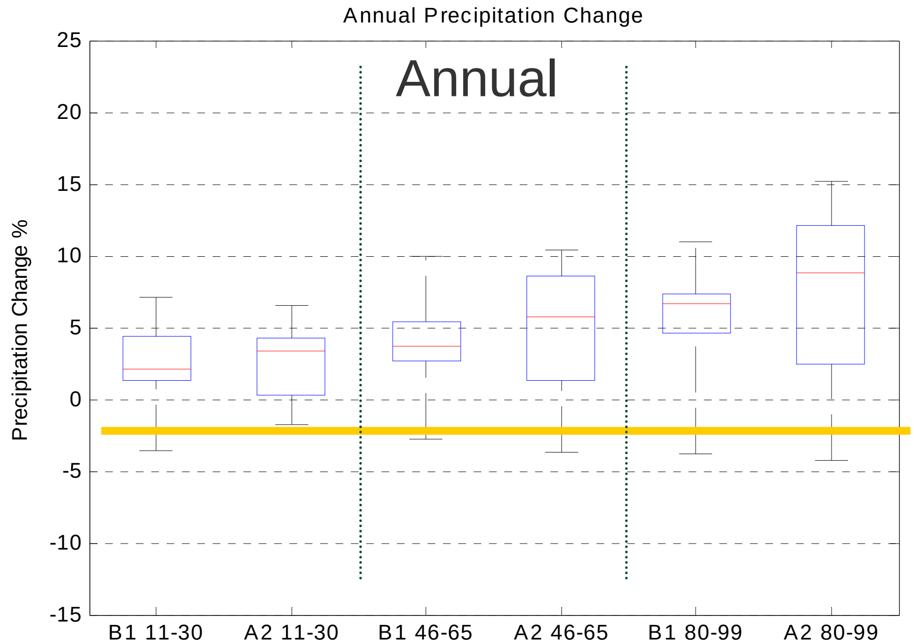
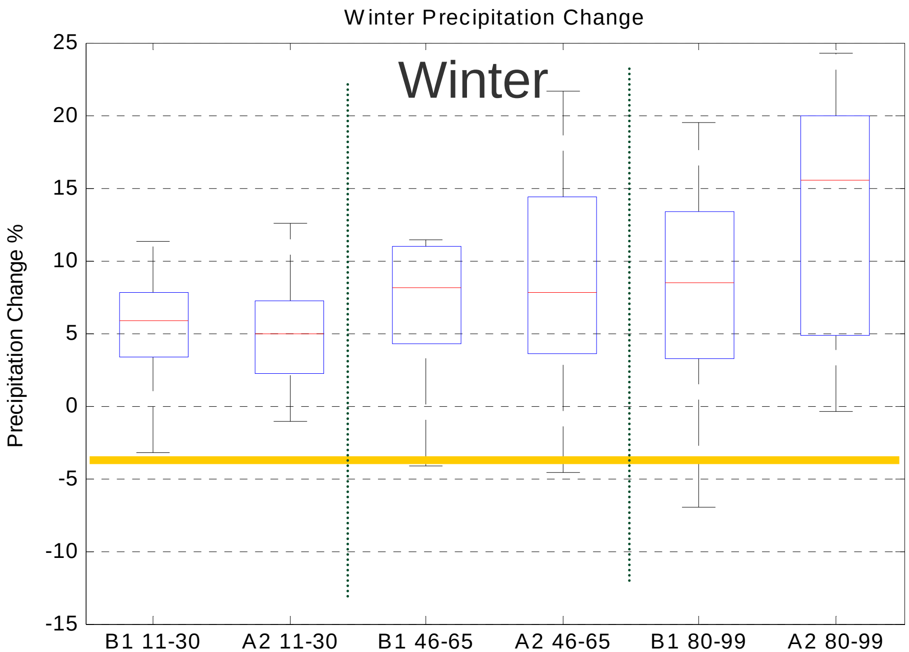
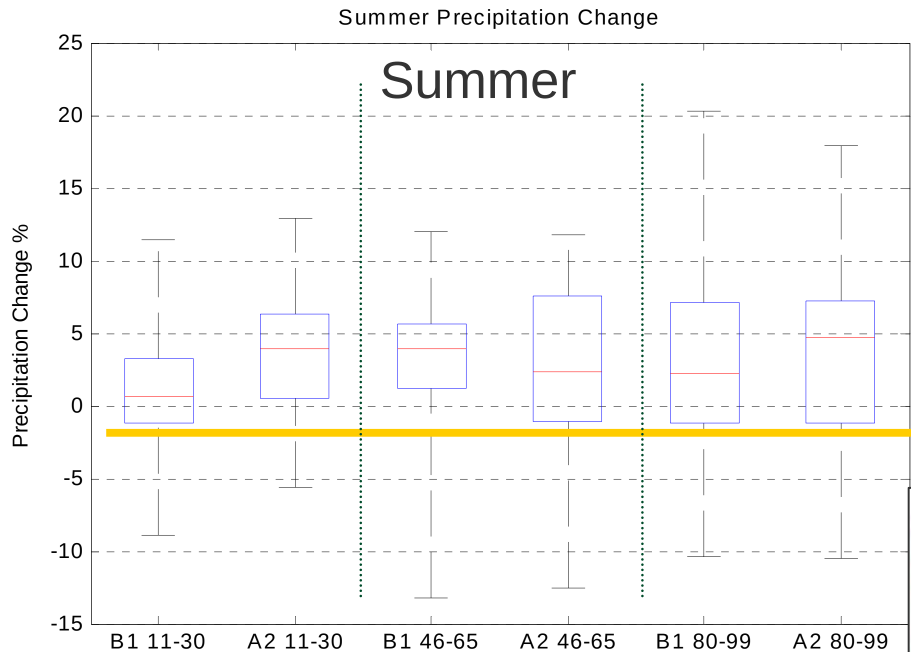
Precipitation change

- Most models predict annual precipitation increase
- Greater increase and agreement among models in winter than summer
- Less agreement among models for precipitation change than for temperature change







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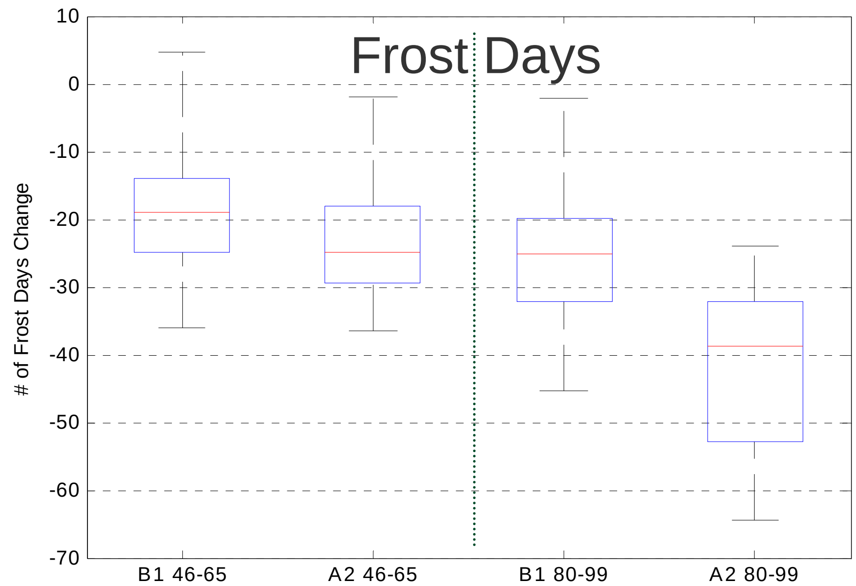
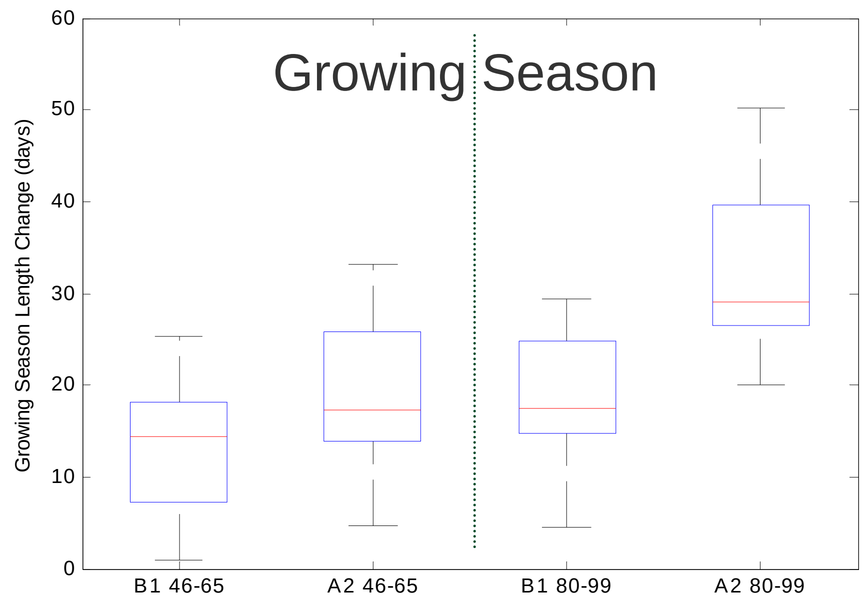
***R. Najjar, PSU** – Draft not for distribution*

Annual frost days and growing season length changes



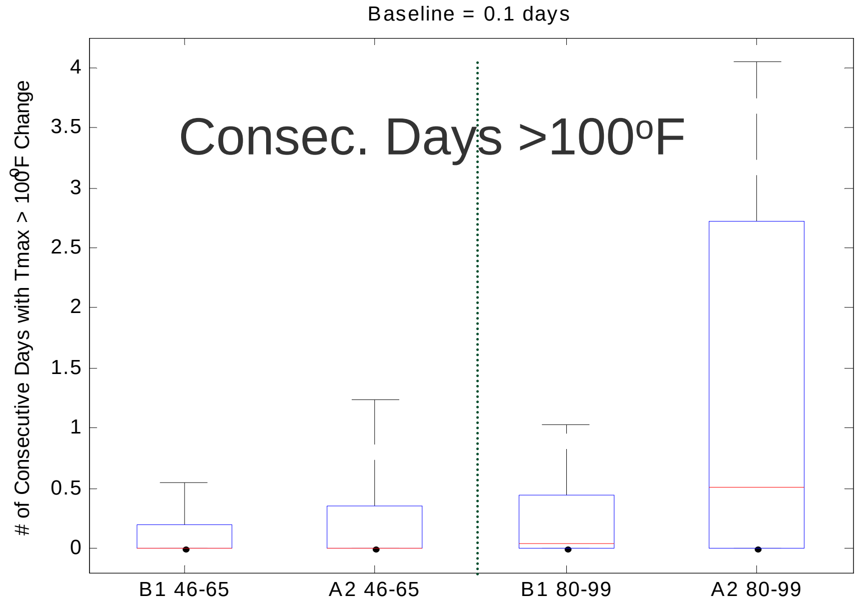


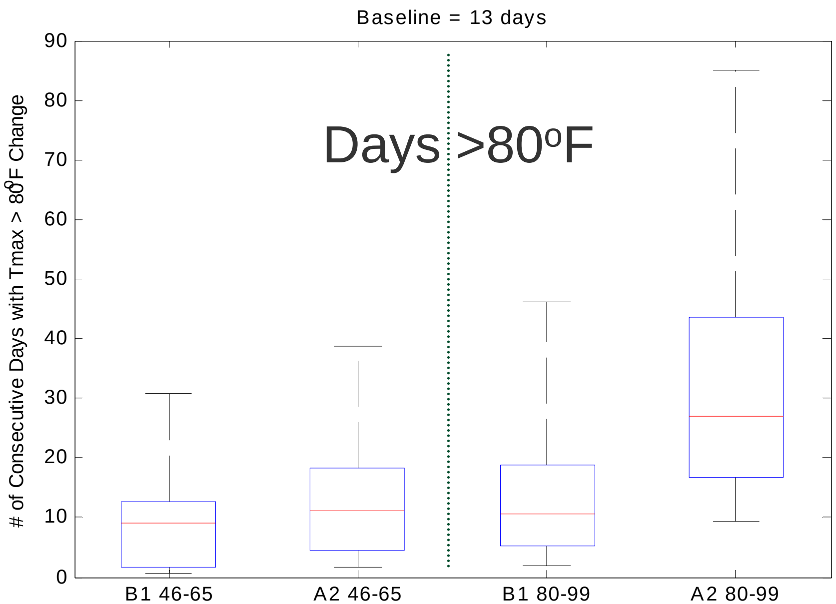
- Warmer spring and fall means fewer frost days and longer growing seasons

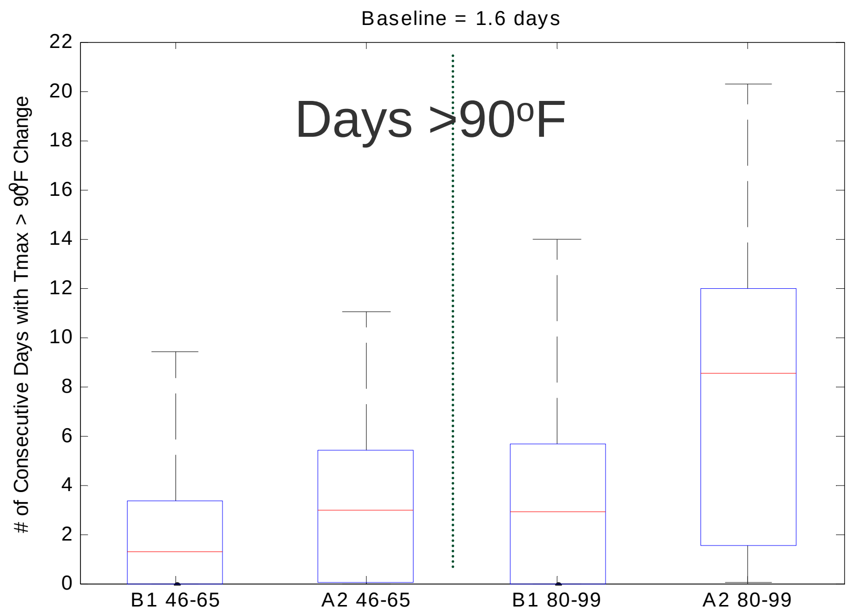
***R. Najjar, PSU** – Draft not for distribution*

Changes in heat waves

- All models project increases in heat waves
- Large spread among models







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***R. Najjar, PSU** – Draft not for distribution*

Summary of climate projections (Najjar)

- Early-century results independent of emissions scenario—means that some additional human-induced climate change is unavoidable
- All models warm
- Precipitation projected to increase, particularly in winter and spring
- Extreme precipitation and extreme heat are projected to increase

Climate Change in the Delaware Estuary

1. Likely Physical Changes

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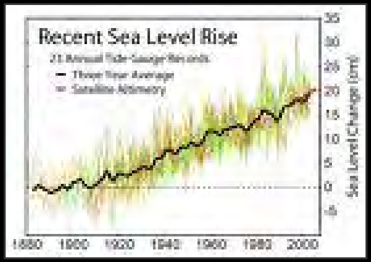
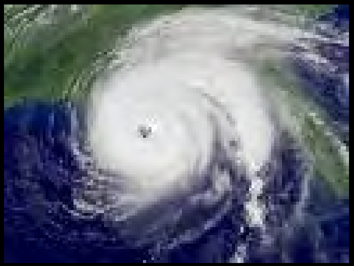


Sea Level Rise



Storms

2. Effects on Resources ?

Uplands

Marshes

Bivalves

Climate Change in the Delaware Estuary


VOLUME 17 • ISSUE 2 • WINTER 2007

ESTUARY NEWS

NEWSLETTER OF THE PARTNERSHIP FOR THE DELAWARE ESTUARY: A NATIONAL ESTUARY PROGRAM

Climate Change Hits Home

Natural Resource Patterns

- **Disruption** – species or community effects
- **Disconnects** – de-coupling ecological interactions
- **Thresholds** – non-linear bio responses
- **Synergisms** – climate effects + other changes

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Disruptions

Global Example: Species Range Shifts

Table 2 Recent latitudinal and altitudinal range shifts

Species*	Location	Observed changes	Climate link
Treeline	Europe, New Zealand	Advancement towards higher altitudes[87–89]	General warming
Arctic shrub vegetation	Alaska	Expansion of shrubs in previously shrub-free areas[90]	Environmental warming
Alpine plants	European Alps	Elevational shift of 1–4 m per decade[24]	General warming
Antarctic plants and invertebrates	Antarctica	Distribution changes[91]	Liquid water availability and increased temperature
Zooplankton, intertidal invertebrate and fish communities	Californian coast, North Atlantic	Increasing abundance of warm-water species[92,37,93,94]	Warmer shoreline ocean temperature
39 butterfly species	North America and Europe	Northward range shifts up to 200 km over 27 years[25,95]	Increased temperatures
such as Edith's Checkerspot butterfly (*Euphydryas editha*)	Western United States	124 m upward and 92 km northward shift since the beginning of the twentieth century[25,26]	
Lowland birds	Costa Rica	Extension of distribution from lower mountain slopes to higher areas[38]	Dry season mist frequency
12 bird species	Britain	18.9 km average range movement northwards over a 20-year period[96]	Winter temperatures
Red fox (*Vulpes vulpes*), Arctic fox (*Alopex lagopus*)	Canada	Northward expansion of red fox range and simultaneous retreat of Arctic fox range[97]	General warming

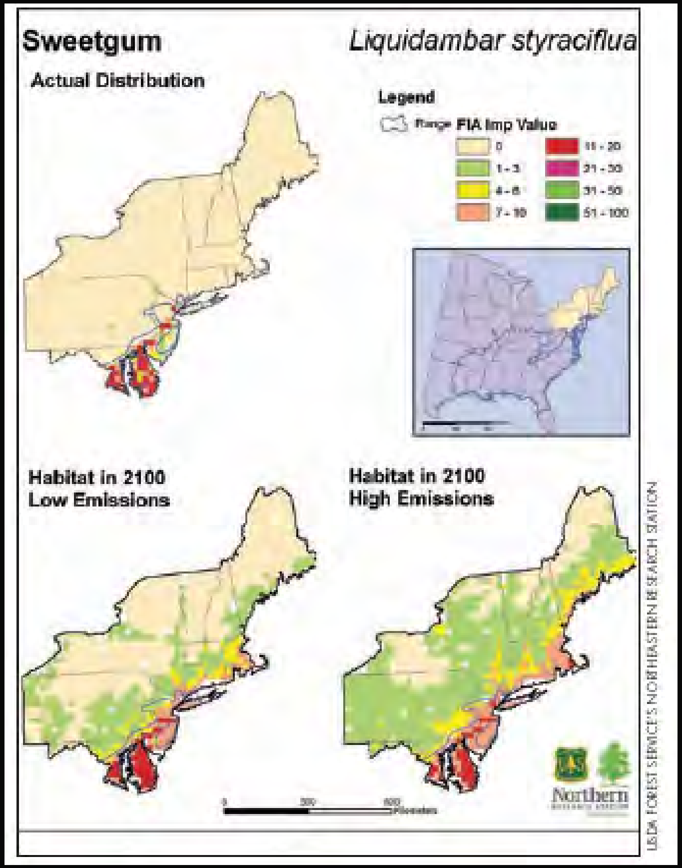
* Where possible, numbers of species which showed a response to climate change are given.

Walthe et al. 2002 Nature

Plus - species do not move as coherent assemblages (i.e. Some ranges shift faster than others)

Slide from Carlos Duarte

Regional Example: Species Range Shifts

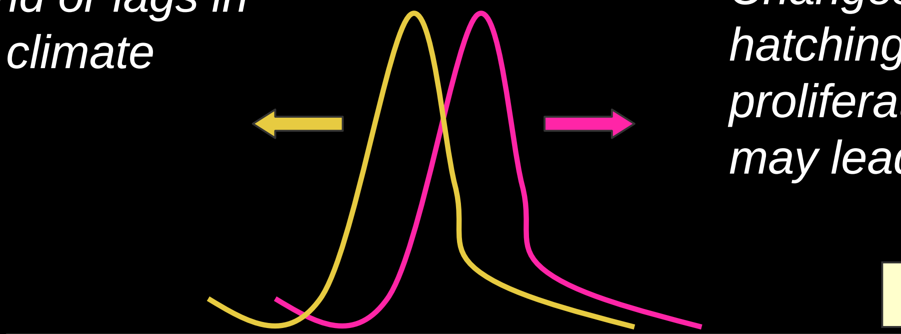


Opportunistic Invasive Species

Disconnects – Decoupled Interactions

Mismatches in Food Webs and Cooperative Networks

Changes in phenology and or lags in range displacement with climate change



Changes in the timing of fish hatching relative to the proliferation of their predators may lead to population collapse

Slide from Carlos Duarte

Other Hypothetical Non-Linear Responses:

Decoupling of Horseshoe Crab Spawning and Shorebird Migration

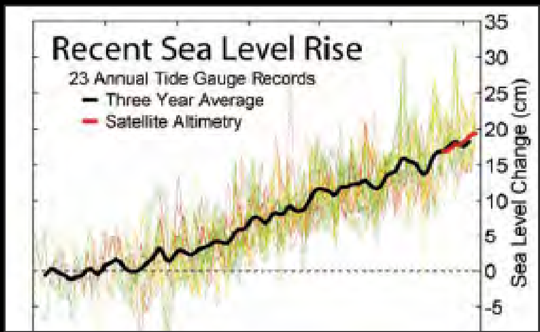
Website slides are from the Delaware Shorebird Project and the Horseshoe Crab Conservation Network

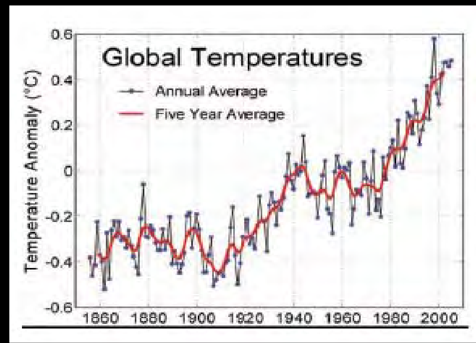
Thresholds (Non-linear Responses)

Hypoxia triggers abrupt changes and massive mortality

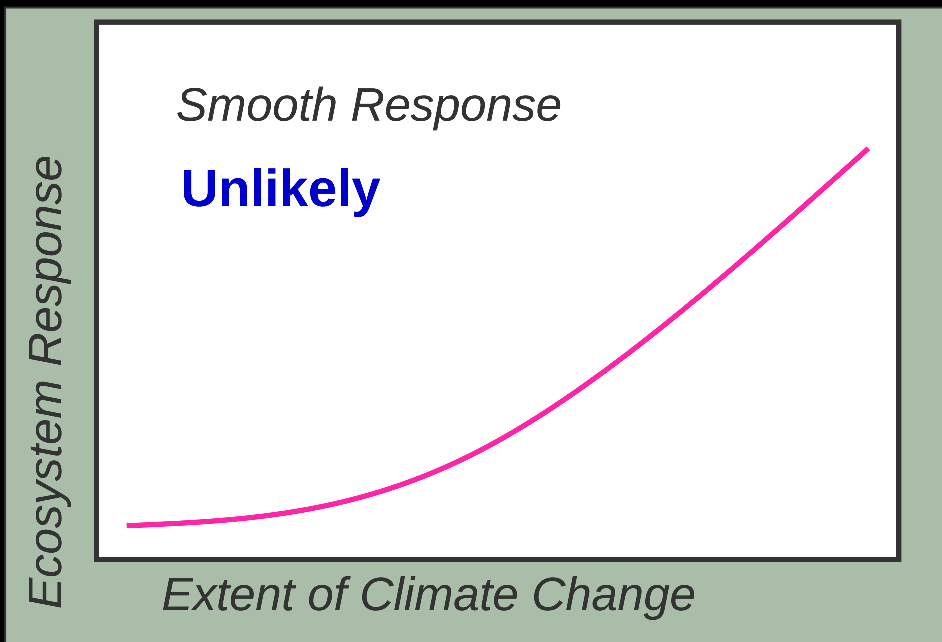
Slide from Carlos Duarte

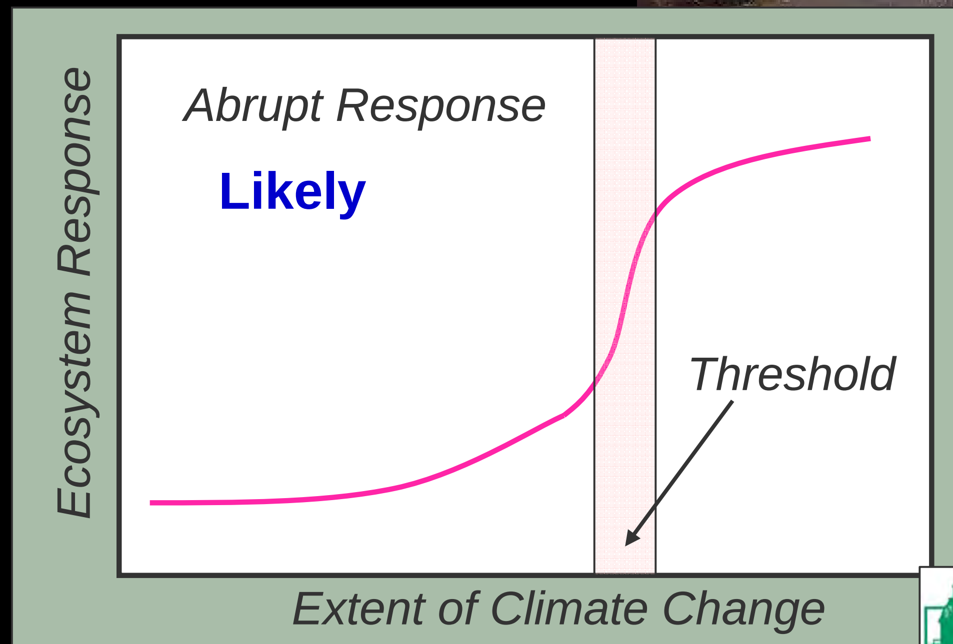
Thresholds – Non-linear Responses





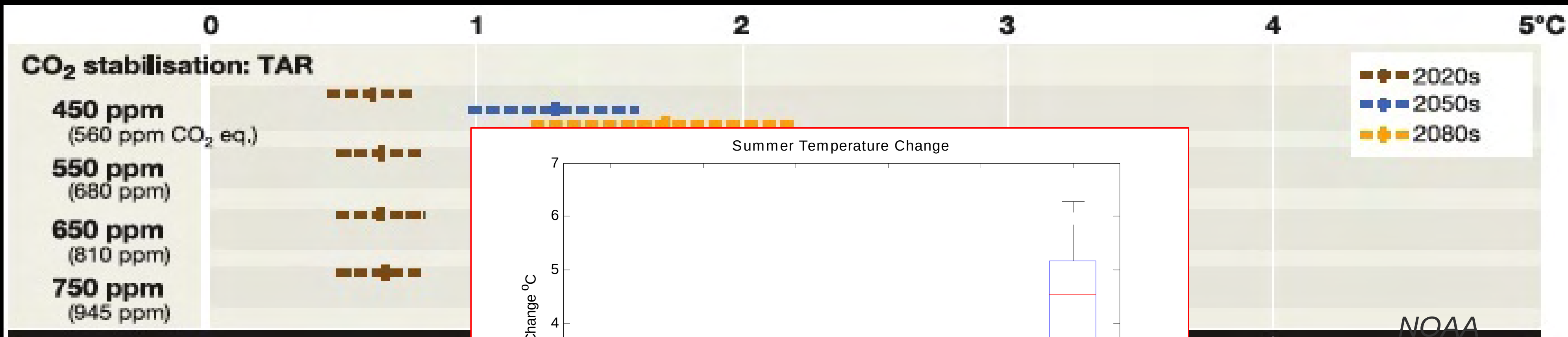
Tolerance Limits Breached

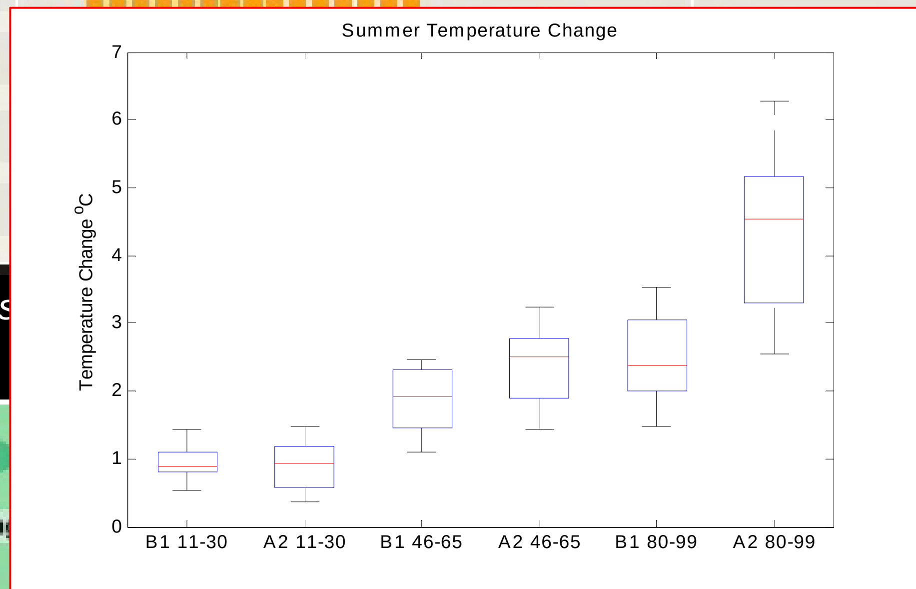




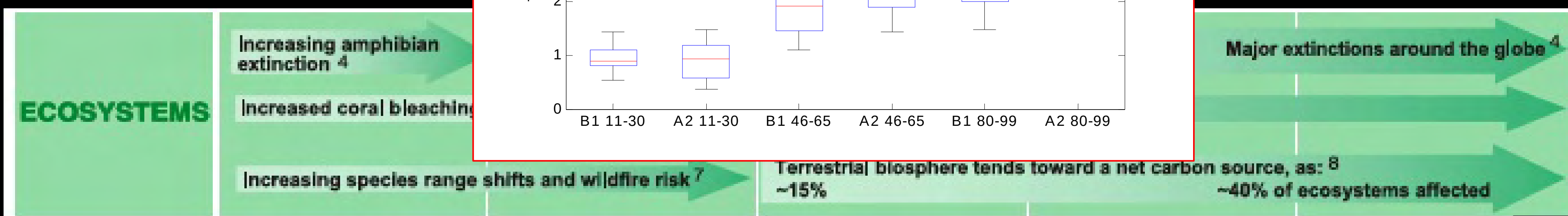
Slide adapted from Carlos Duarte

Species Extinction is an Abrupt, Irreversible Change





Impacts of Climate Change on Ecos



Yohe et al. IPCC (2007)

Slide adapted from Carlos Duarte

Other Scaling Problems: The Impact of Temperature Rise on Respiration and Heterotrophic Metabolism

Calculated using Metabolic models, a 4 ºC warming is predicted to result in a 20% increase in net primary production but a 43% increase in oxygen consumption

Effects are expected to be most severe in coastal ecosystems

NPP ↑ 20%
Resp ↑ by 43%

Seagrass Meadows

Harris, Nixon and Duarte, 2006. Estuaries and Coasts 29: 343–347

Slide from Carlos Duarte

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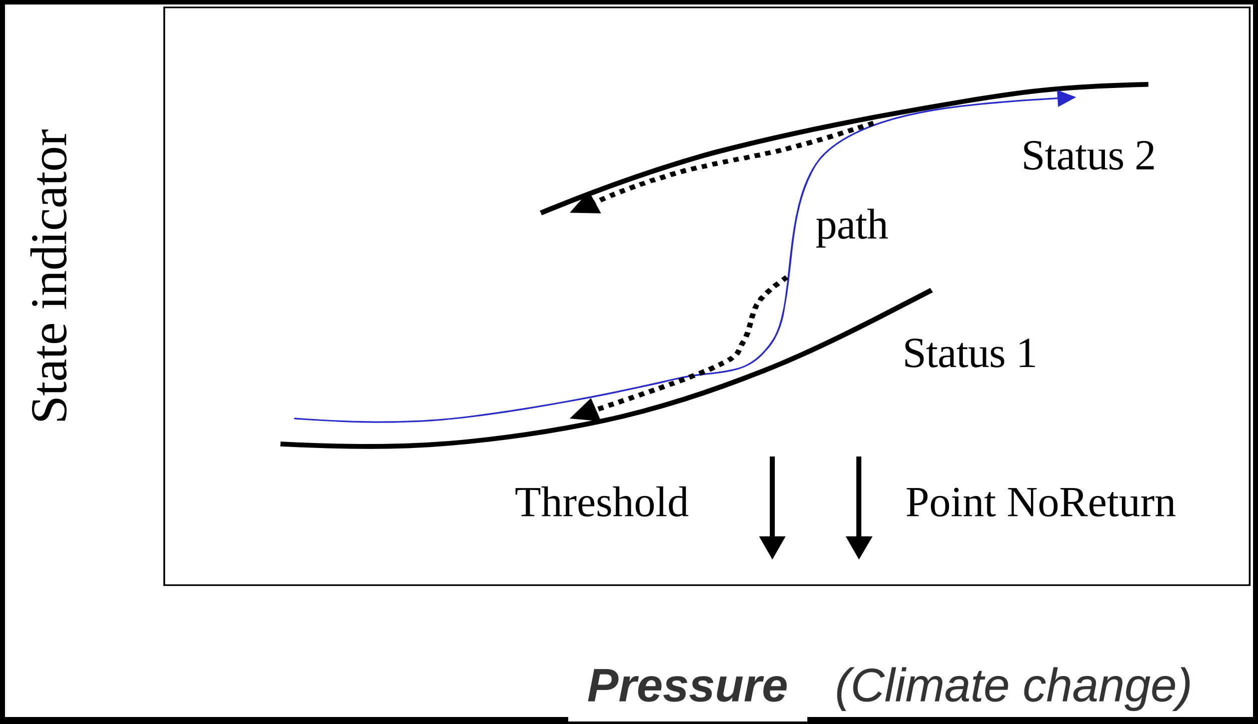
Ecological Thresholds

Slide from Carlos Duarte

DK 29

- Non linear shifts in **ecosystem** status
- Tipping points or breaking points of the system
- Once breached, ”recovery” may be slow or unlikely

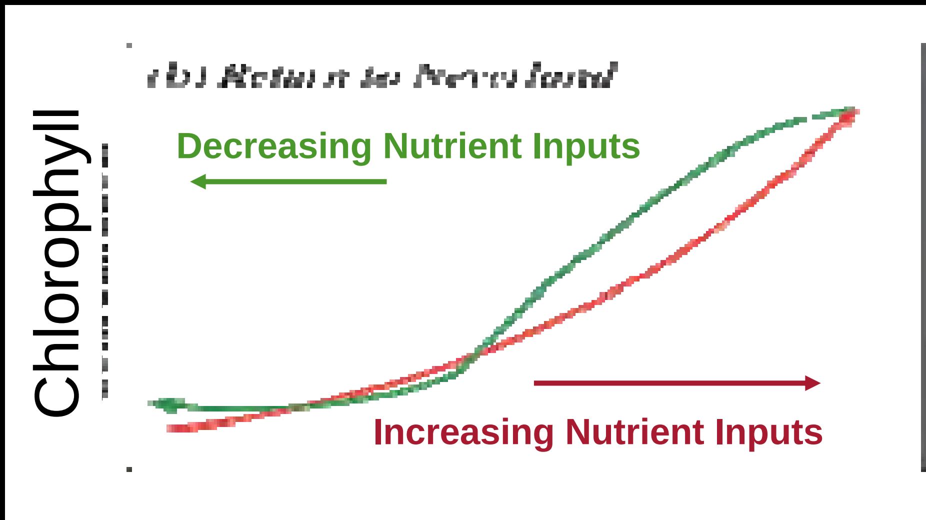


Knowing where these tipping points are will be extremely valuable to set policy targets (Climate-driven Thresholds)

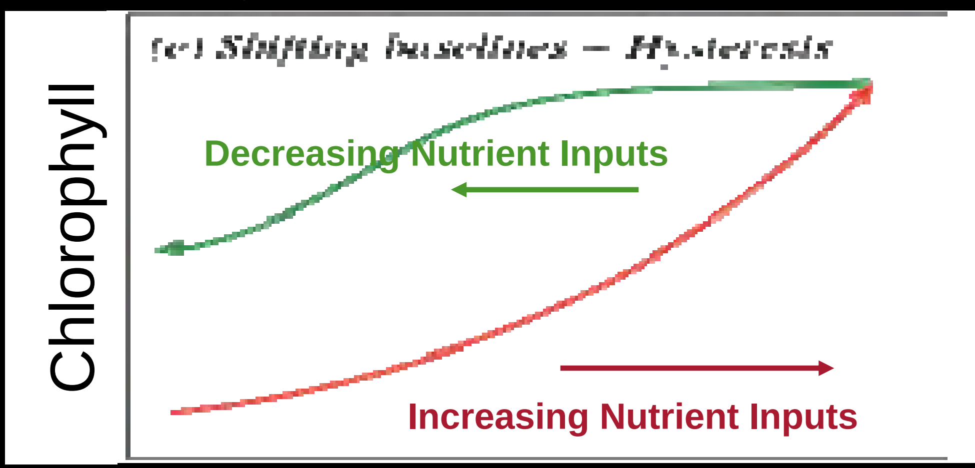
Example – Nutrients

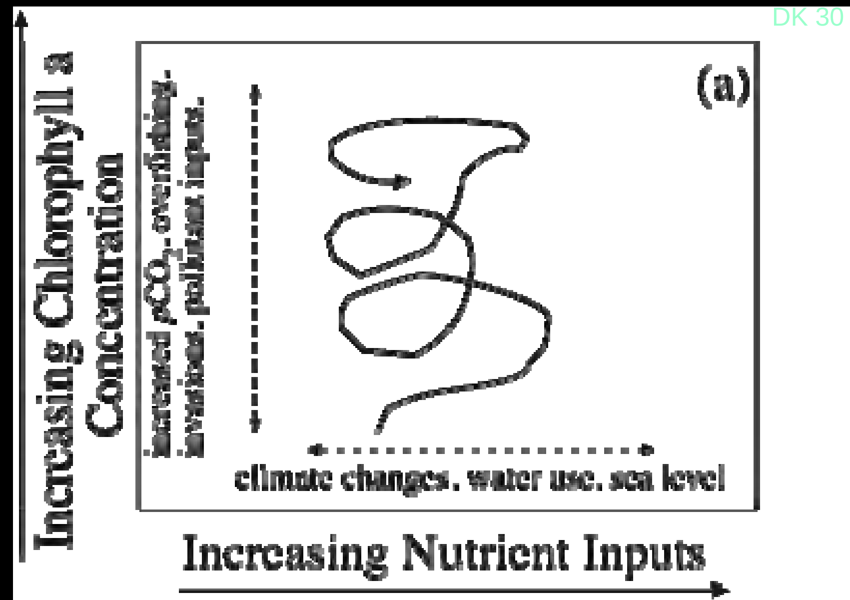
Duarte et al. (submitted)

The Expectation



The Reality





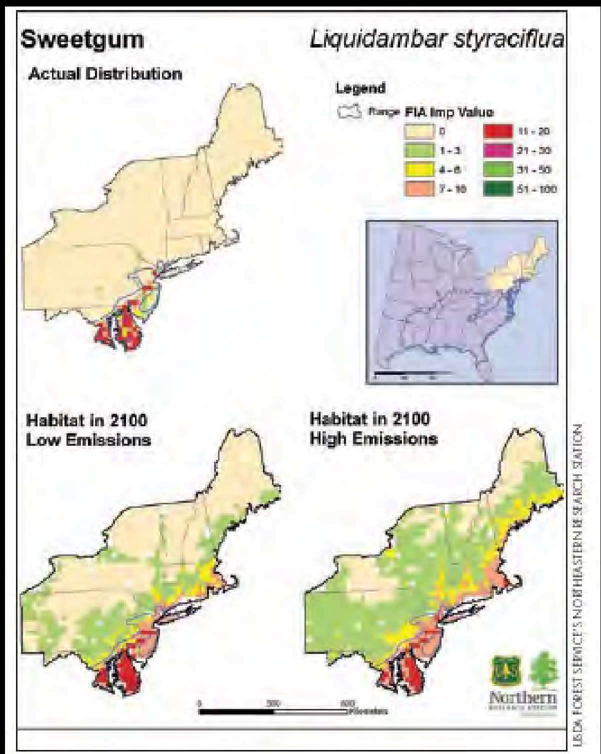
Ecosystem Trajectories Rarely Reverse Course

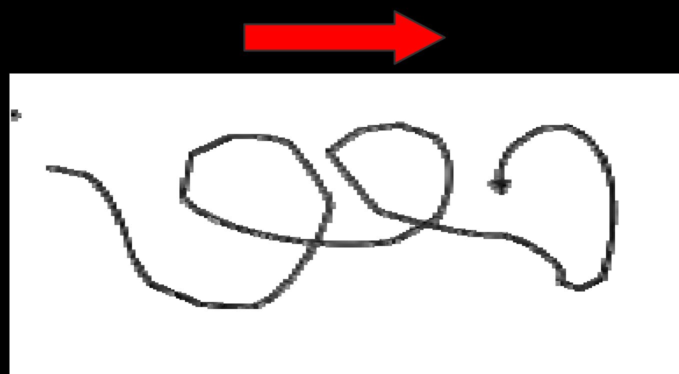
"Reference Values" are Dynamic

New Buffers Become Established to Reinforce New Steady States

<u>Lesson</u>: "Restore" for the Future

- ***Forecast future sustainable states***
- ***Targeted restoration and climate adaptation***





Synergisms – Climate & Other Changes Together

THE ROYAL SOCIETY

Received 24 July 2002
Accepted 28 October 2002
Published online 3 February 2003

Climate change and habitat destruction: a deadly anthropogenic cocktail

J. M. J. Travis

"… The interaction between climate change and habitat loss might be disastrous. During climate change, the habitat threshold occurs sooner. Similarly, species suffer more from climate change in a fragmented habitat."

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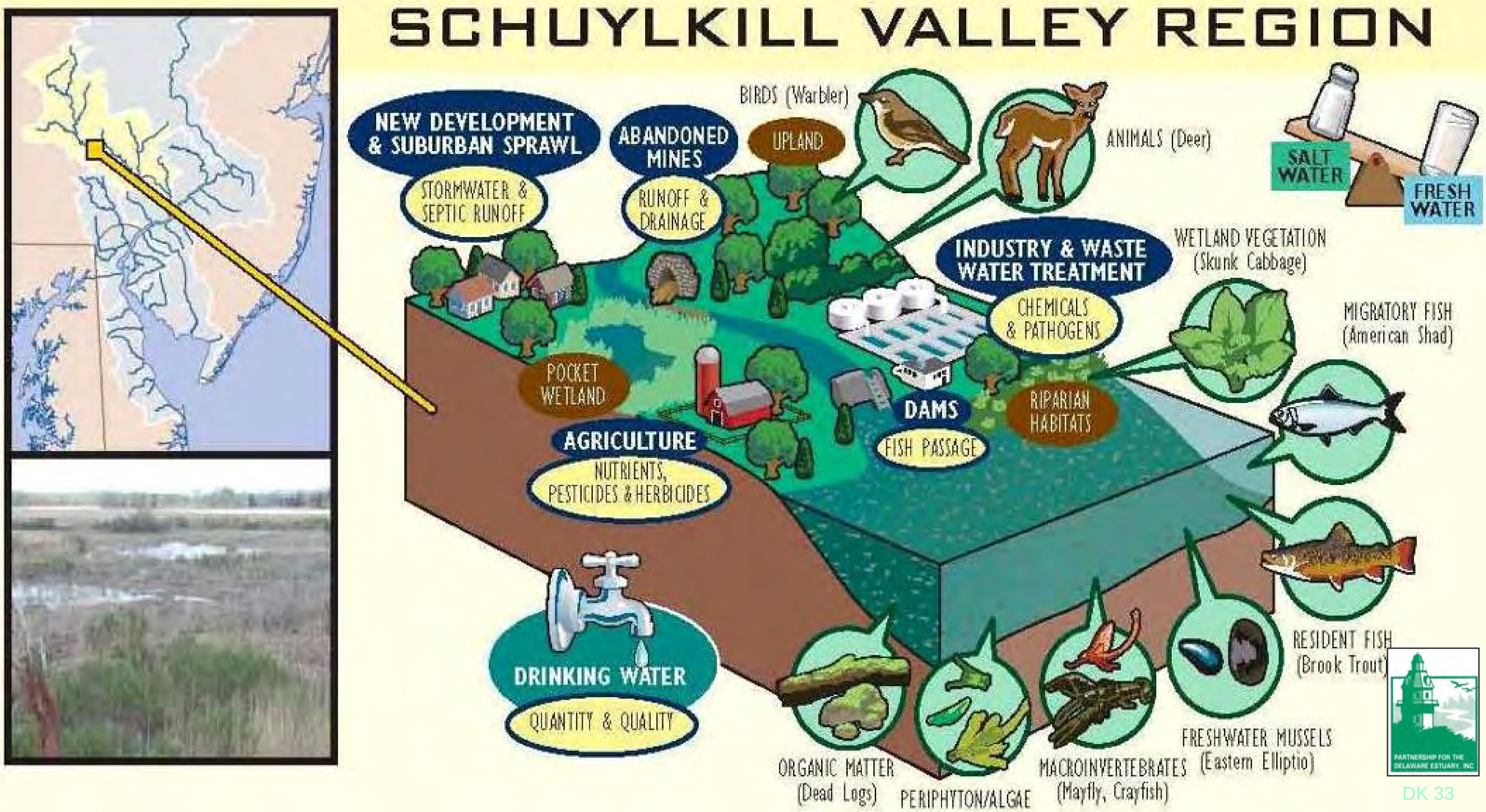
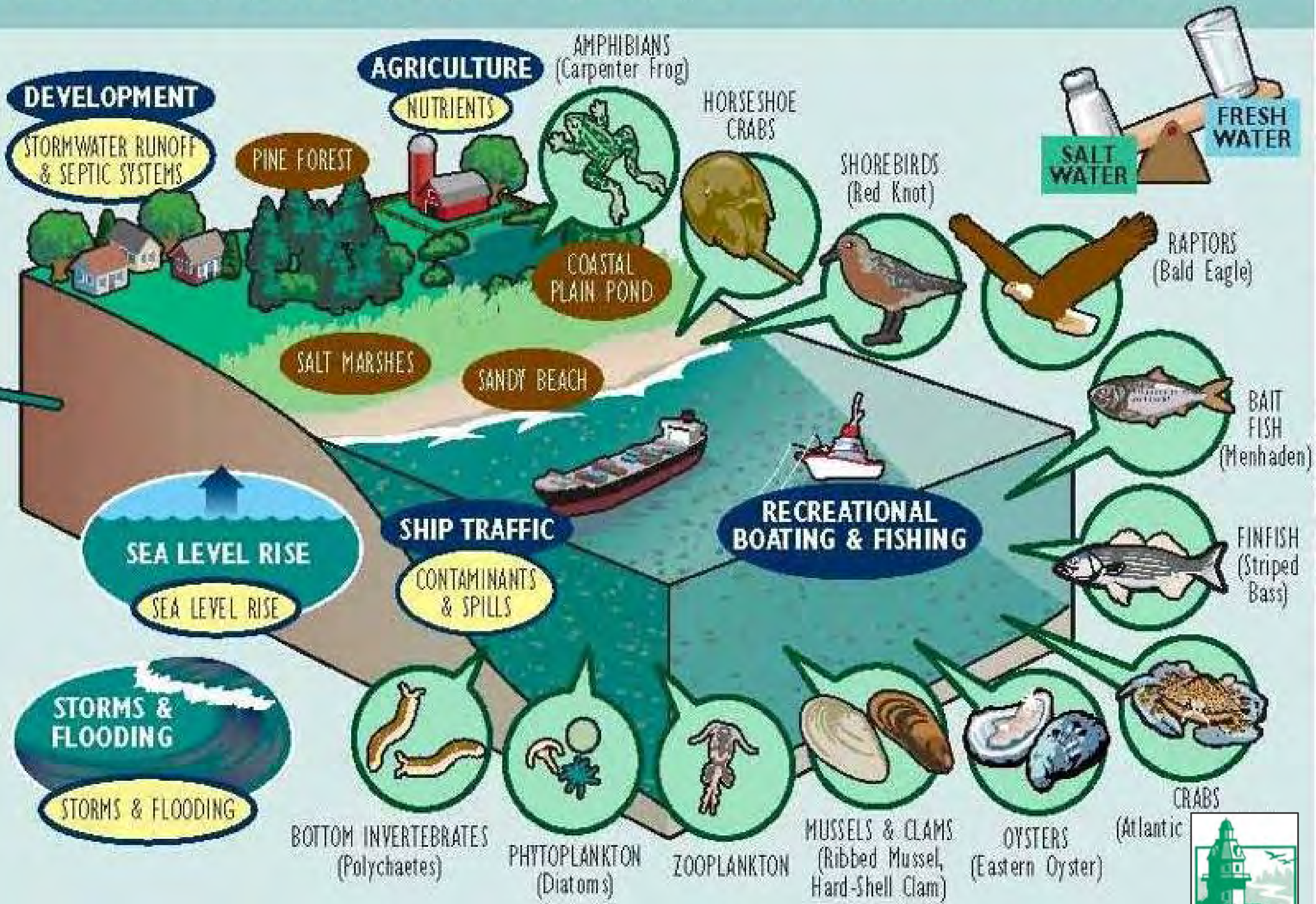
Management Challenges – Complexity



DELAWARE BAY REGION



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Hot Topics

DK 35

- Ecological Flows
- Land Use Change
- LNG Terminal
- Spills, NRDA
- Dredging
- Withdrawals
- Inundation, SLR
- Horseshoe Crabs, Red Knots
- Emerging Pollutants

11/27/2004

Management Challenges

- **Disruption** – species or community effects
- **Disconnects** – de-coupling ecological interactions
- **Thresholds** – non-linear bio responses
- **Synergisms** – climate effects + other changes

→ Complexity

Climate Change Adds Complexity to an Already Complex, Changing Landscape

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White Paper Technical Needs

1. **Contaminants** (forms, sources, fates & effects for different classes)
2. **Tidal Wetlands** (status, trends and relative importance of different types)
3. **Ecologically Significant Species & Critical Habitats** (shellfish, horseshoe crabs)
4. **Ecological Flows** (effects of flow changes on salt balance & biota)
5. **Physical-Chemical-Biological Linkages** (e.g., sediment budgets, toxics & biota)
6. **Food Web Dynamics** (key trophic connections among functional dominant biota)
7. **Nutrients** (forms, concentrations and balance of macro- and micronutrients)
8. **Ecosystem Functions** (assessment and economic valuation of ecosystem services)
9. **Habitat Restoration and Enhancement** (science & policy)
10. **Invasive Species** (monitoring, management & control)

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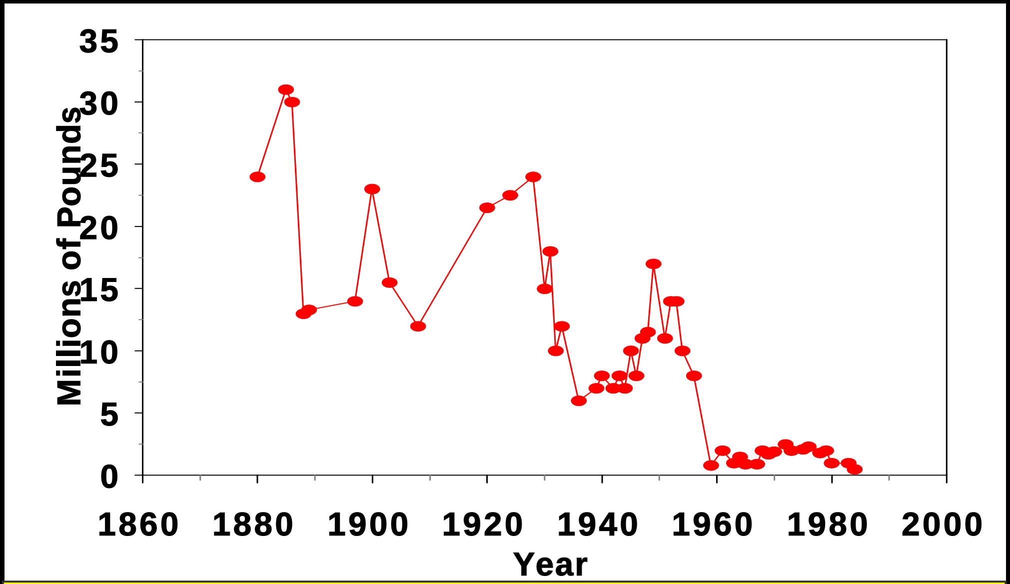
Bivalves

Oyster Trends



Oyster landings in Delaware Bay: 1880 - 1980s

http://www.epodunk.com/cgi-bin/genInfo.php?locIndex=25475

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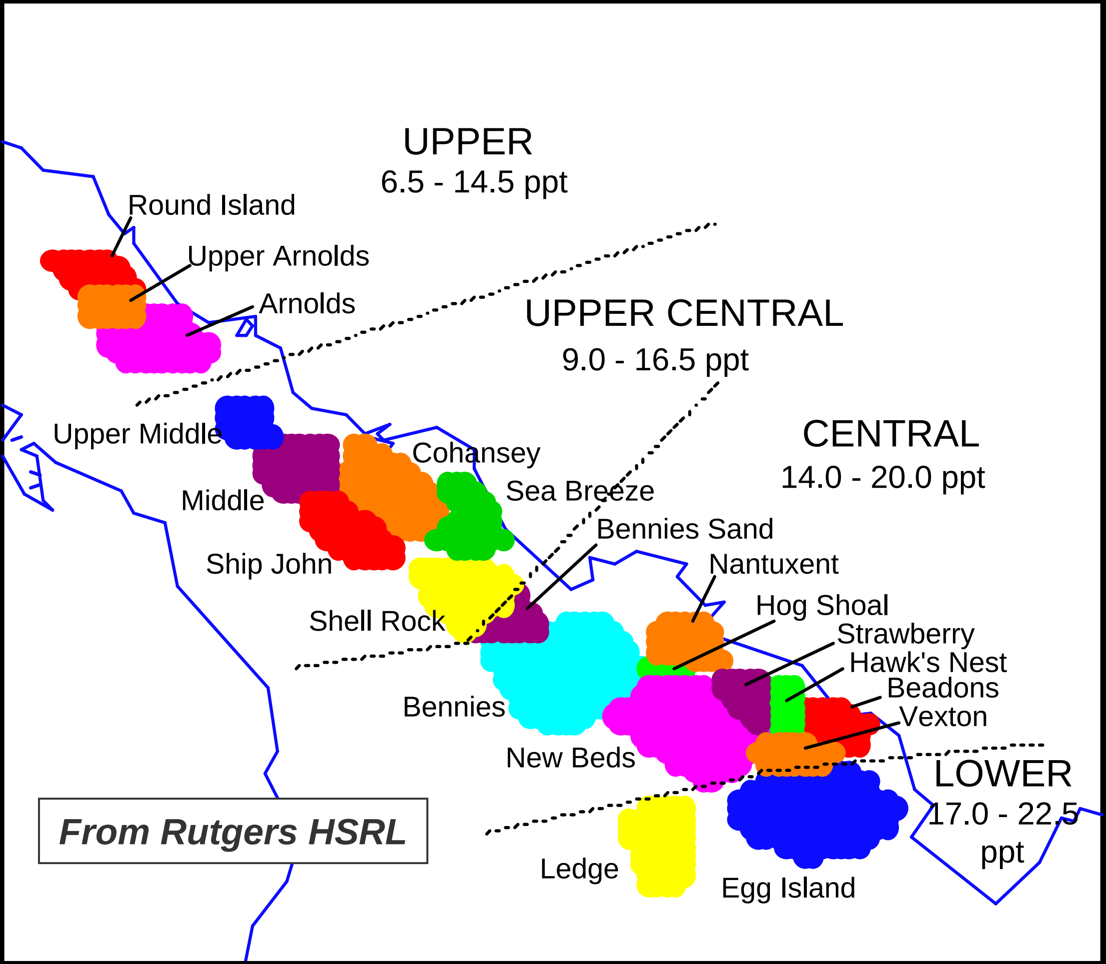
Example: Oysters

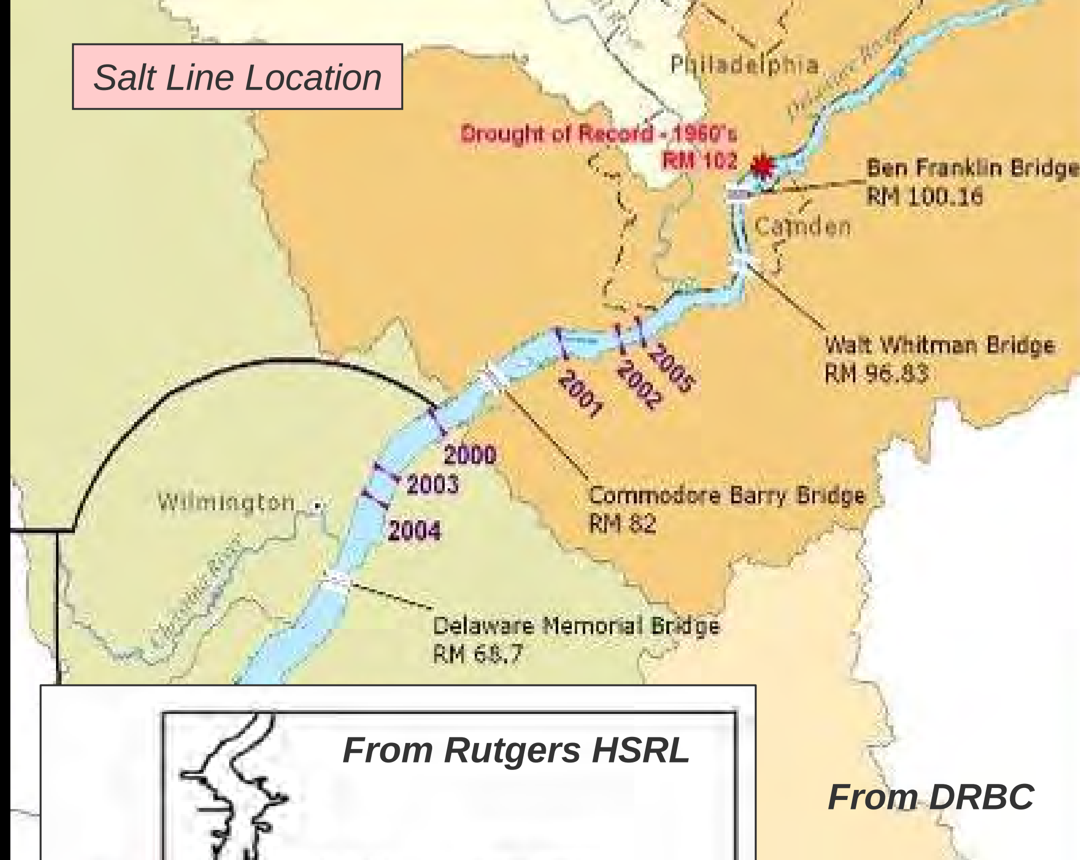


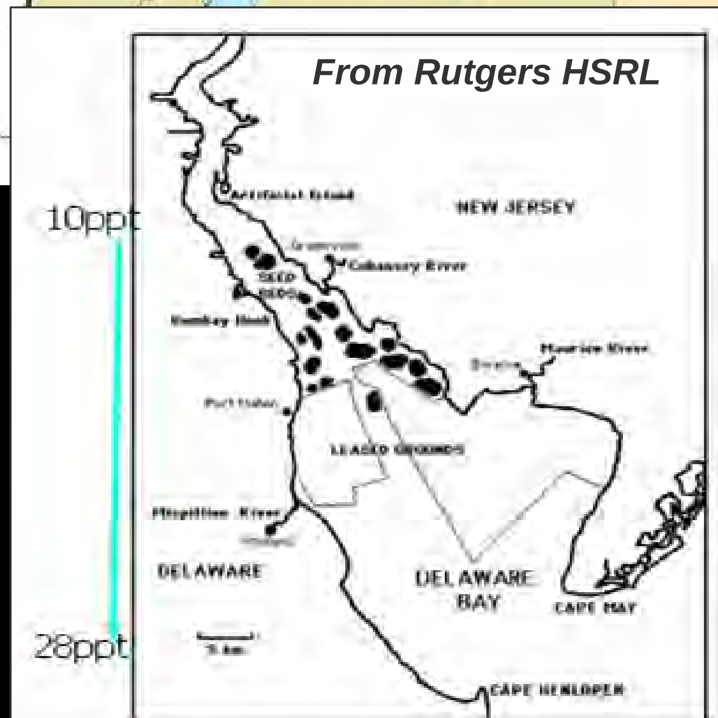
From Rutgers HSRL

Oyster Disease, Salinity & Climate Change

www.livingclassrooms.org/lbo/dermo/oyster2.jpg

Rutgers: “A 2 parts per thousand increase in salinity over the seed beds may push the oysters past a point of no return”

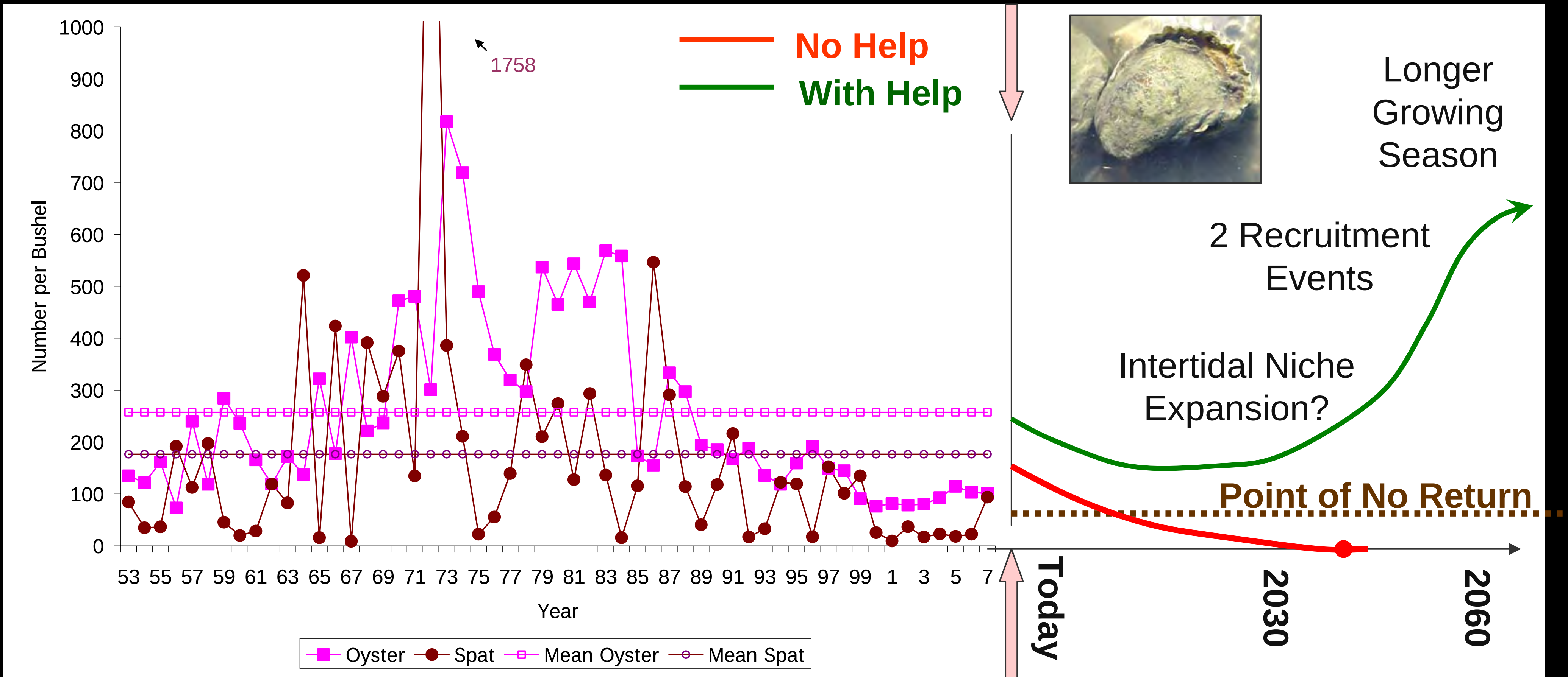




Oyster Management

Can they maintain (or be maintained) until they might see more optimal conditions?

DK 41



Historical data from Rutgers Haskin Shellfish Laboratory

Oyster Reef Revitalization

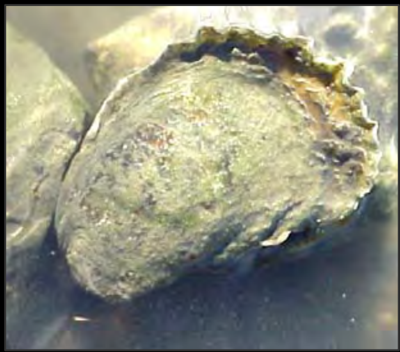
PARTNERSHIP FOR THE DELAWARE ESTUARY, INC

Bivalves of the Delaware

11 Other Species of Freshwater Unionid Mussels

Elliptio complanata

Geukensia demissa



Crassostrea virginica

Corbicula fluminea

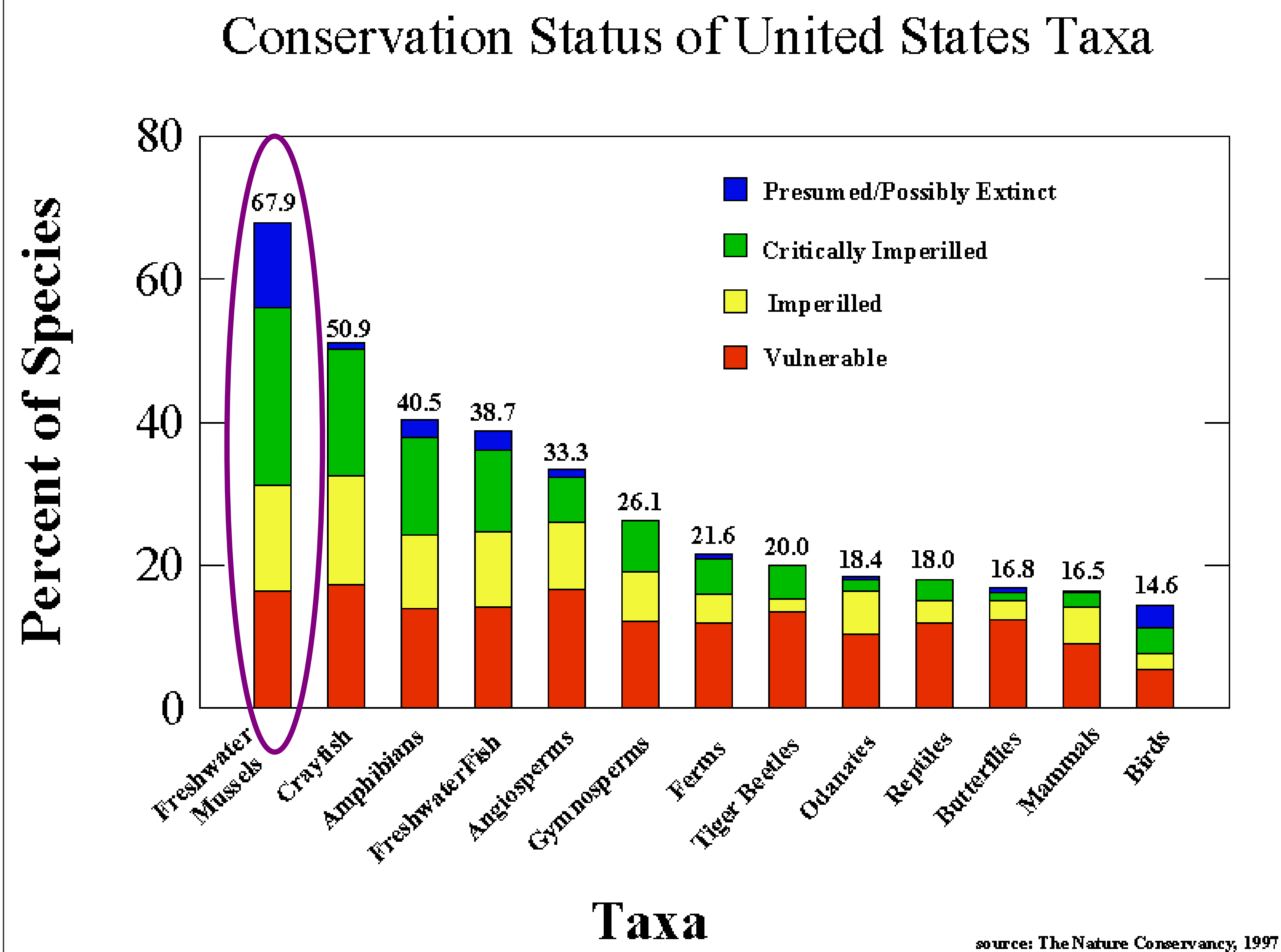
Rangia cuneata

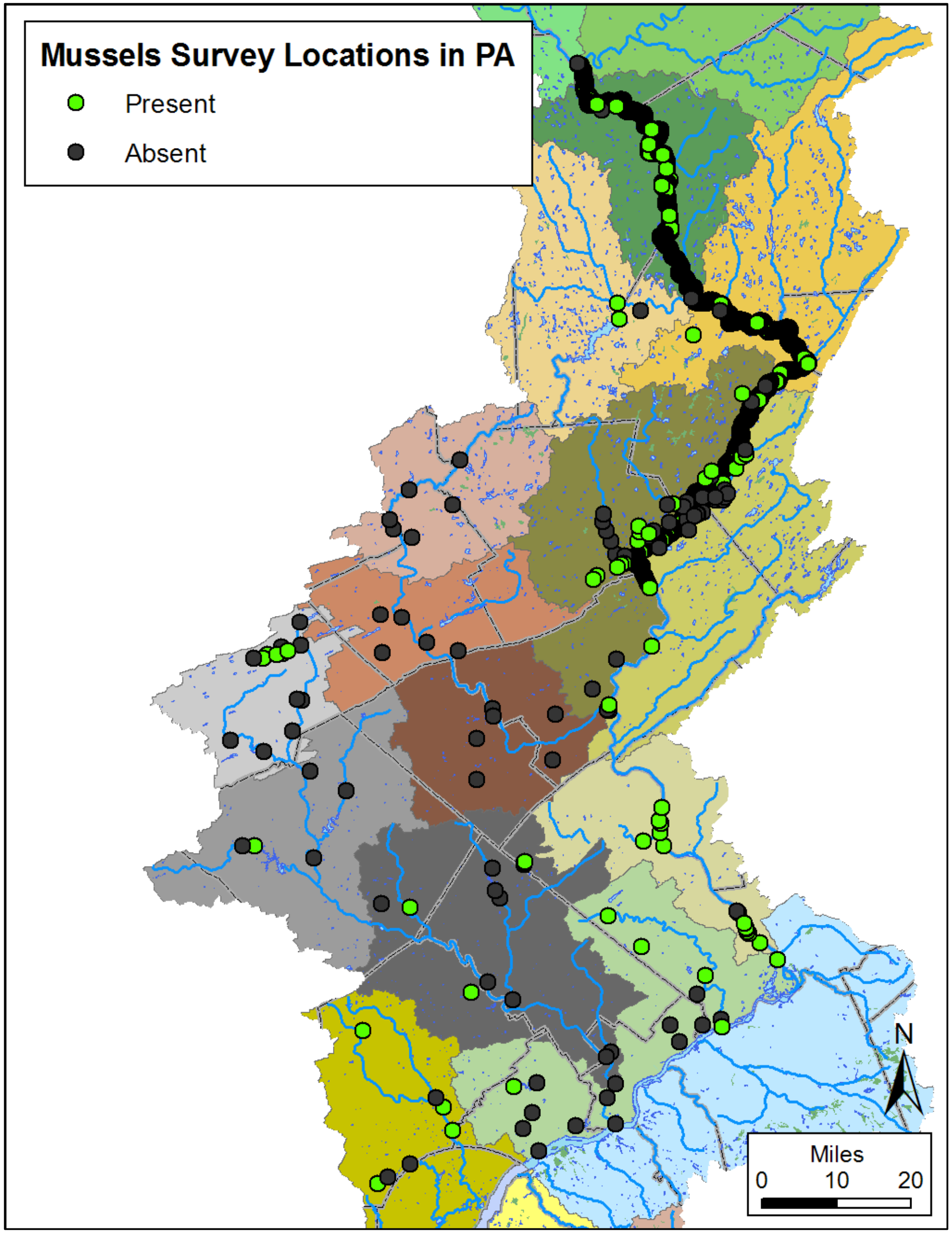
Mya arenaria

Mytilus edulis

Ensis directus

Mercenaria mercenaria


Conservation Status of United States Taxa
Percent of Species
80
60
40
20
0
Presumed/Possibly Extinct
Critically Imperilled
Imperilled
Vulnerable
67.9
50.9
40.5
38.7
33.3
26.1
21.6
20.0
18.4
18.0
16.8
16.5
14.6
Freshwater Mussels
Crayfish
Amphibians
Freshwater Fish
Angiosperms
Gymnosperms
Ferns
Tiger Beetles
Odanates
Reptiles
Butterflies
Mammals
Birds
Taxa
source: The Nature Conservancy, 1997



PARTNERSHIP FOR THE DELAWARE ESTUARY, INC

Lower Delaware Watershed

DK 46

Patchy, Impaired

Elliptio complanata

Rare

Strophitus undulatus

Extirpated

Alasmidonta heterodon

		State Conservation Status		
Scientific Name	**Scientific Name**	**DE**	**NJ**	**PA**
ALASMIDONTA HETERODON	DWARF WEDGEMUSSEL	Endangered	Endangered	Critically Imperiled
ALASMIDONTA UNDULATA	TRIANGLE FLOATER	Extirpated ?	Threatened	Vulnerable
ALASMIDONTA VARICOSA	BROOK FLOATER	Endangered	Endangered	Imperiled
ANODONTA IMPLICATA	ALEWIFE FLOATER	Extremely Rare	no data	Extirpated ?
ELLIPTIO COMPLANATA	EASTERN ELLIPTIO	common	common	Secure
LAMPSILIS CARIOSA	YELLOW LAMPMUSSEL	Endangered	Threatened	Vulnerable
LAMPSILIS RADIATA	EASTERN LAMPMUSSEL	Endangered	Threatened	Imperiled
LASMIGONA SUBVIRIDIS	GREEN FLOATER	no data	Endangered	Imperiled
LEPTODEA OCHRACEA	TIDEWATER MUCKET	Endangered	Threatened	Extirpated ?
LIGUMIA NASUTA	EASTERN PONDMUSSEL	Endangered	Threatened	Critically Imperiled
MARGARITIFERA MARGARITIFERA	EASTERN PEARLSHELL	no data	no data	Imperiled
PYGANODON CATARACTA	EASTERN FLOATER	no data	no data	Vulnerable
STROPHITUS UNDULATUS	SQUAWFOOT	Extremely Rare	Species of Concern	Apparently Secure

VOLUME 18 • ISSUE 3 • SUMMER 2008
PDE REPORT NO. 08-01

ESTUARY NEWS

A PUBLICATION OF THE PARTNERSHIP FOR THE DELAWARE ESTUARY: A NATIONAL ESTUARY PROGRAM

SPECIAL ISSUE

State of the Delaware Estuary 2008

By Jennifer Adkins, Executive Director, Partnership for the Delaware Estuary

Every three to five years, the Partnership for the Delaware Estuary works with outside experts to take a comprehensive look at the health of the Delaware Estuary and its watershed. This helps the National Estuary Program track the progress it is making implementing its long-term "Delaware Estuary Comprehensive Conservation and Management Plan." The results are presented here, for 2008, as a special issue of "Estuary News."

The Delaware River's dual identity as both a living river and a working river makes it an Estuary of many contrasts. On one hand it is a principal corridor for commerce that has sustained our region since America's Industrial Revolution, and it continues to be a major strategic port for national defense. On the other hand, it provides a wealth of natural and living resources, such as drinking water for millions of people, extensive tidal marshes that sustain vibrant ecosystems, and world-class habitats for horseshoe crabs, migratory shorebirds and more.

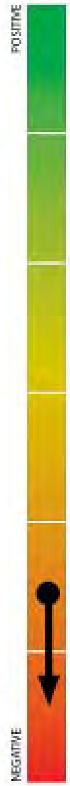
Given these contrasts, it should be no surprise that the 2008 State of the Estuary Report tells a story of mixed environmental conditions. In some ways, the Delaware Estuary is healthier than ever before, thanks largely to improvements in wastewater treatment and laws enacted over time. The condition of some species, like bald eagles and striped bass, for example, have remained stable or improved. Unfortunately, the status of other species appears to be getting worse. The total population of Atlantic sturgeon may number less than 1,000 — perhaps even less than 100. Freshwater mussels and brook trout now appear to be absent from much of the region's non-tidal waterways.

The Delaware Estuary has many important features that set it apart from other American estuaries. These include its freshwater tidal reach and extensive tidal marshes, which serve as the "kidneys" and "fish factories" of the Estuary. Less than five

continued on page 2

This report is being issued as a special summer edition of "Estuary News," as well as technical report number 08-01 of the Partnership for the Delaware Estuary. Additional supporting materials like references can be found at www.DelawareEstuary.org, and a list of key definitions can be found on page 34. This assessment complements the State of the Basin Report, which is currently being developed by a team led by the Delaware River Basin Commission (DRBC) that also includes the Partnership. For information on that report, please call the DRBC at (609) 883-9500.

Freshwater Mussels



INDICATOR DESCRIPTION: Freshwater mussels are filter-feeding bivalve mollusks that live in lakes, rivers, and streams. Similar to oysters, freshwater mussels benefit water quality, enrich habitats, and furnish other important ecosystem functions. Unlike marine species, freshwater mussels grow more slowly, live longer (50 years or more), and have complicated reproduction strategies dependent on fish hosts. Therefore, freshwater mussels cannot rebound quickly after they become impaired.

Behold the squawfoot mussel, or *Strophitus undulatus*, one of the many once-abundant filter-feeders that is currently in decline in the Delaware Estuary's streams and rivers.

As they are sedentary creatures that filter large amounts of water, freshwater mussels are sensitive indicators of water quality and habitat conditions. Consequently, they lay claim to being the most imperiled taxonomic group in the nation. These long-lived animals are often unable to recolonize their habitats following disturbances due to their complicated life history. The status of freshwater mussels provides different environmental information than macroinvertebrates, the latter of which are good indicators of short-term changes in conditions. The health, reproductive status, population abundance, and species diversity of the mussel assemblage therefore represents an excellent bioindicator of watershed conditions over long periods of time.

Common Name	Scientific Name	State Conservation Status		
		DE	NJ	PA
Dwarf Wedgemussel	*Alasmidonta heterodon*	Endangered	Endangered	Critically Imperiled
Triangle Floater	*Alasmidonta undulata*	Extirpated	Threatened	Vulnerable
Brook Floater	*Alasmidonta varicosa*	Endangered	Endangered	Imperiled
Alewife Floater	*Anodonta implicata*	Extremely Rare	No Data	Extirpated ?
Eastern Elliptio	*Elliptio complanata*	Common	Common	Secure
Yellow Lampmussel	*Lampsilis cariosa*	Endangered	Threatened	Vulnerable
Eastern Lampmussel	*Lampsilis radiata*	Endangered	Threatened	Imperiled
Green Floater	*Lasmigona subviridis*	No Data	Endangered	Imperiled
Tidewater Mucket	*Leptodea ochracea*	Endangered	Threatened	Extirpated ?
Eastern Pondmussel	*Ligumia nasuta*	Endangered	Threatened	Critically Imperiled
Eastern Pearlshell	*Margaritifera margaritifera*	No Data	No Data	Imperiled
Eastern Floater	*Pyganodon cataracta*	No Data	No Data	Vulnerable
Squawfoot	*Strophitus undulatus*	Extremely Rare	Species of Concern	Apparently Secure

This chart shows the state conservation status of freshwater mussel species that were historically documented from the Delaware Estuary and River Basin. Gray-shaded cells indicate that these mussels may never have been found in that state. Note the different status descriptions used among the three states.

TRENDS: The most recent comprehensive mussel survey in the region was conducted in Pennsylvania between 1909 and 1919. Even by that time, dams and water-quality degradation may have impaired mussel communities. Nevertheless, the study provided an excellent benchmark for gauging mussel losses for the past 90-plus years. State surveys and recent anecdotal information suggest that all native mussel species in the region are impaired to some degree, with most being severely depressed or extirpated altogether.

STATUS: North America has the world's greatest diversity of native freshwater mussels (more than 300 species), however, more than 75 percent have special conservation status. The leading causes of mussel decline are habitat and water-quality degradation. For example, dams that block fish passage can affect reproduction, gene flow, and may prevent recolonization from adjacent tributaries following disturbance. Of the 12 or more native species in the Delaware Estuary Watershed, even the most common mussel is patchy in abundance and may not be successfully reproducing across much of its range.

ACTIONS AND NEEDS: More proactive monitoring is needed to assess the species presence and population health of freshwater mussels across the entire Delaware River Basin. Improved coordination and data sharing among states and the Partnership for the Delaware Estuary would greatly facilitate indicator development and watershed restoration planning.

Fast Fact

The Partnership for the Delaware Estuary is currently devising methods to reintroduce mussels into waterways where they once flourished, like the Brandywine River, Chester Creek and White Clay Creek.

Bivalve Natural Capital

Five Reasons Why We Should Care

1. Biodiversity

DK 49

Species Loss:

↓ Intrinsic Losses

↓ Niches Filled

↓ Human Health

2. Commercial Value

DK 50

Shellfisheries
Jewelry
Pearl Shell Industry

3. Cultural-Historical

Native American Uses
Waterman Lifestyle
Ecotourism

PARTNERSHIP FOR THE DELAWARE ESTUARY, INC

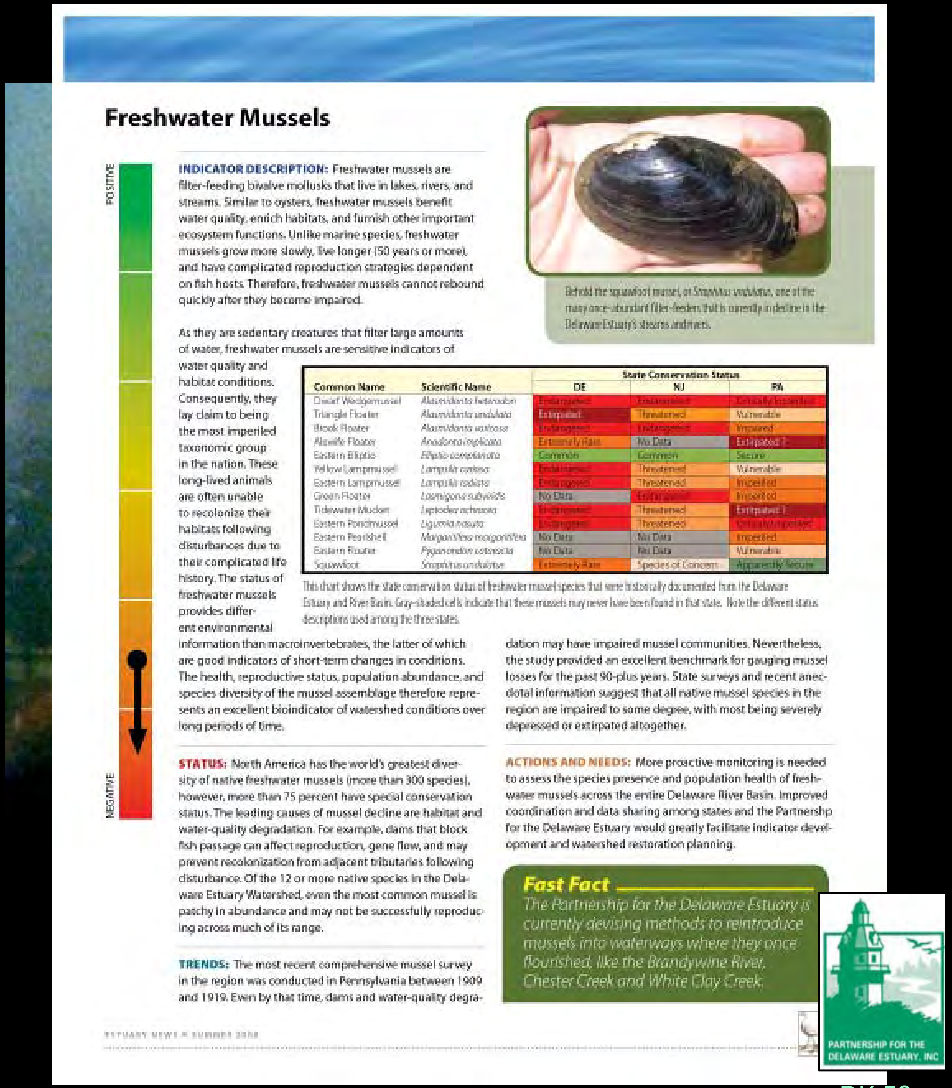
4. Bioindicator Value

International Mussel Watch

Freshwater Caging Studies

Contaminant and Site-Specific Testing, Monitoring

Tributary and Regional Bioassessment



Freshwater Mussels

POSITIVE

NEGATIVE

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ESTUARY NEWS ★ SUMMER 2008

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5. Biomass (Populations)

Biomass Loss:

↓ EcoServices

↓ Fish & Wildlife

↓ Human Health

CTUIR Freshwater Mussel Project


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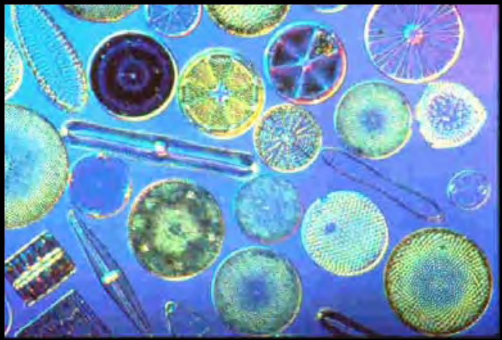
DELAWARE ESTUARY, INC

Ecosystem Engineers

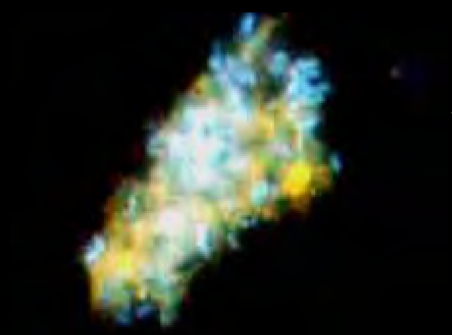
Water Quality & Grazing Impacts of Populations

Pennate Diatoms

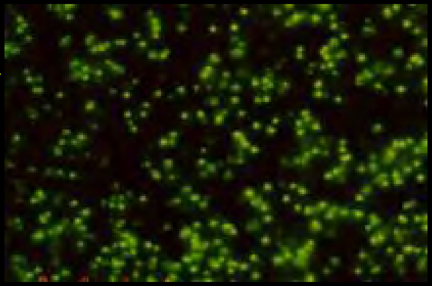
Phytoplankton



Centric Diatoms



Detritus Complex



Bacteria

Heterotrophic Protists

Mussels Are Habitat INITIATIVE
Restoring Our Nation's Water Quality

Clean Water

Slide from R. Neves, VA Tech

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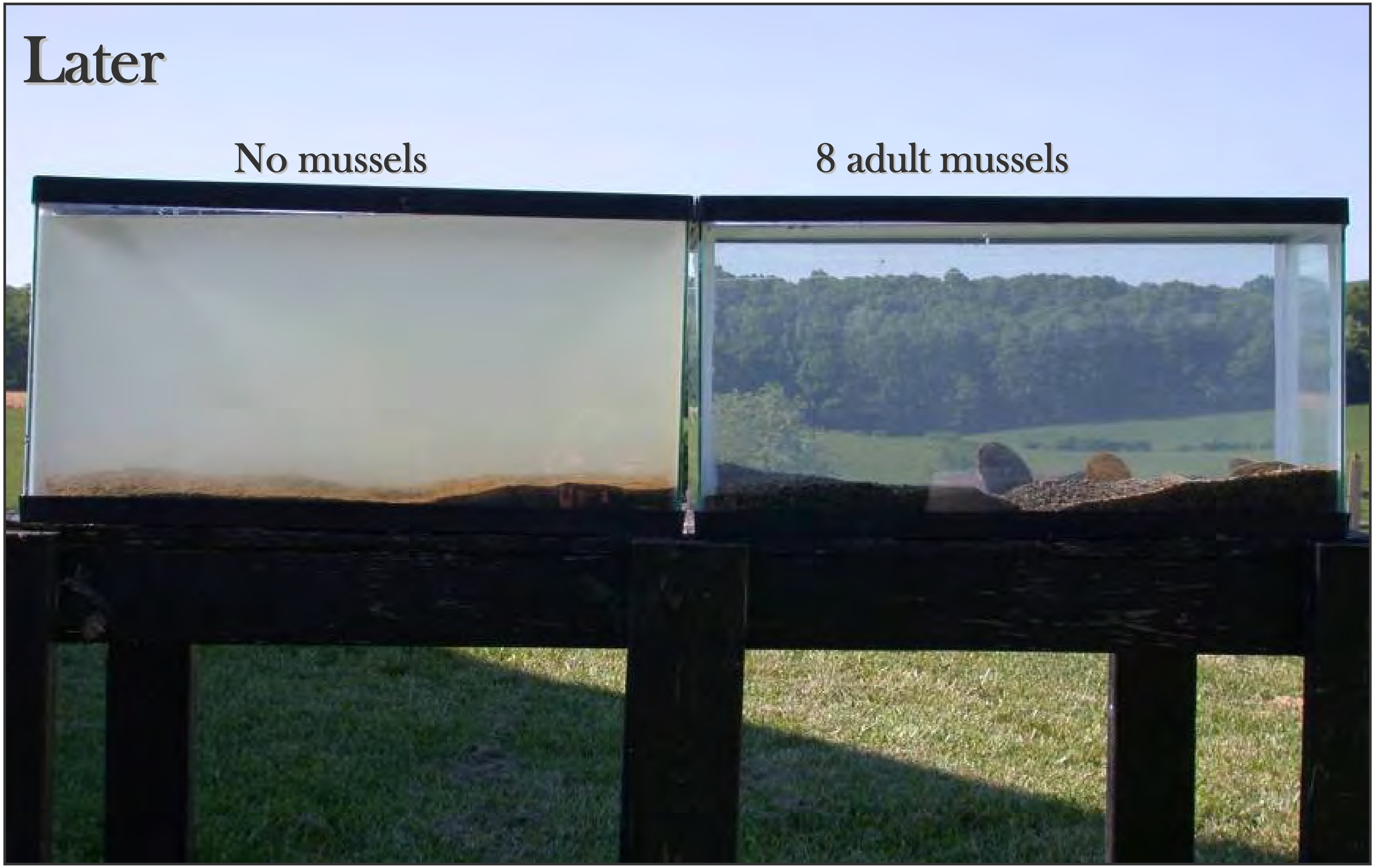
Mussels Are Habitat INITIATIVE
Restoring Our Nation's Water Quality

Biofiltration Potential



Slide from R. Neves, VA Tech

Brandywine River, PA

Elliptio complanata

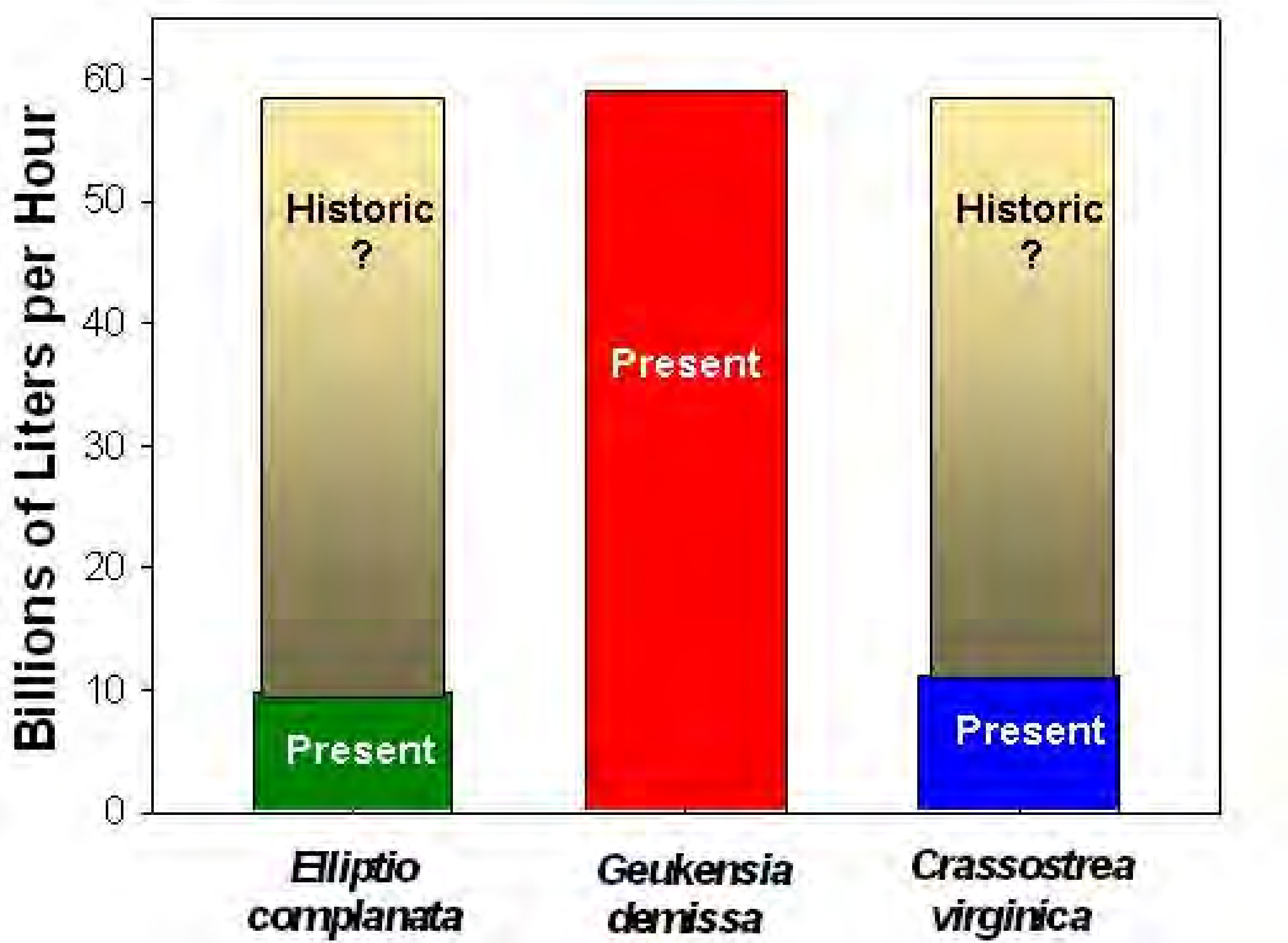
Delaware Estuary Marshes

Geukensia demissa

Delaware Bay Oysters

Crassostrea virginica

Water Processing Potential



Bivalve Ecological Services

1. Structure

↑ Habitat Complexity

↑ Binding of Bottom

↑ Bottom Turbulence

2. Function

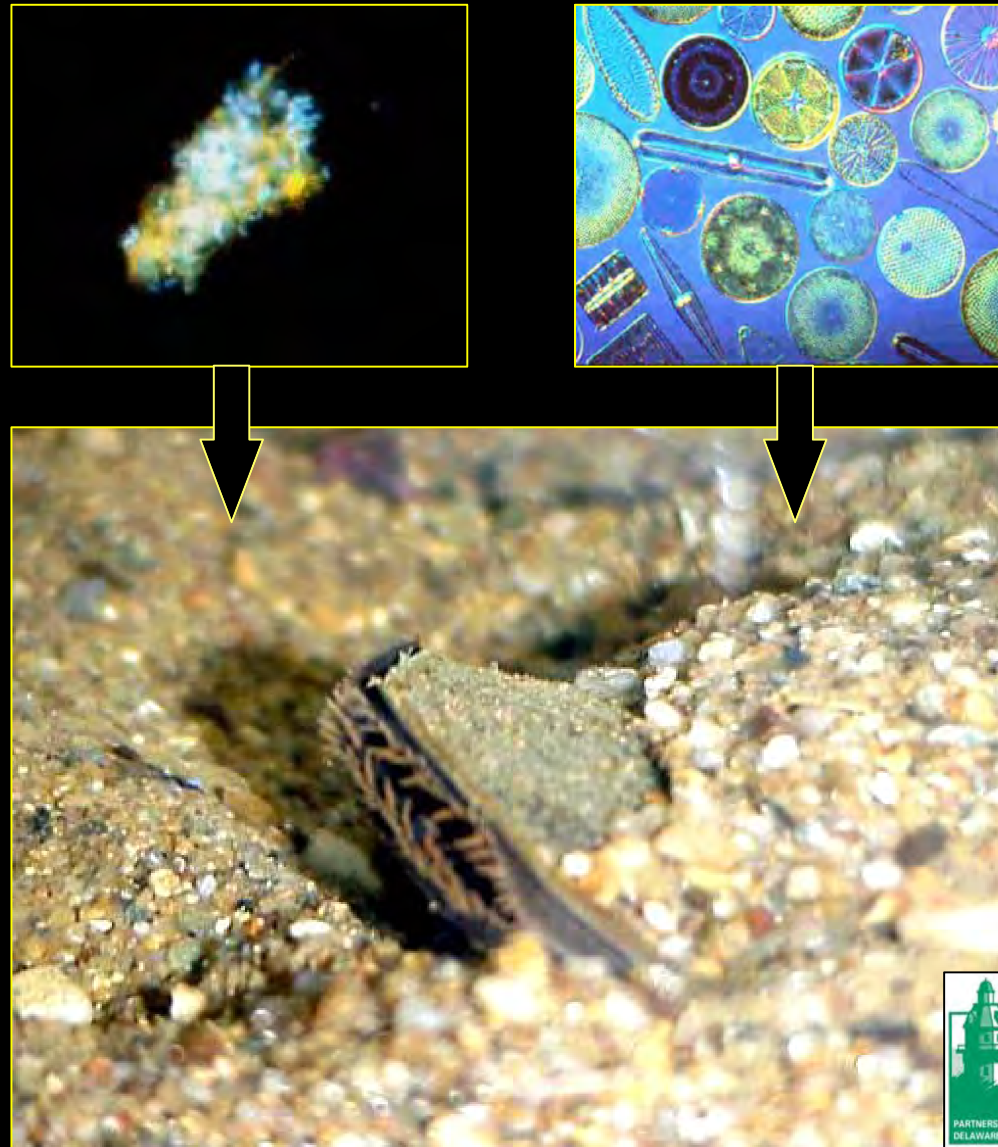
↓ Suspended Particulates

↓ Particulate N, P

↑ Light

↑ Sediment Enrichment

↑ Dissolved Nutrients



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Importance of Shellfish to the Delaware Estuary Watershed

			Oysters *Crassostrea virginica*	**Marsh Mussels** *Geukensia demissa*	**FW Mussels** *Elliptio complanata*
Natural Capital Value	**Commercial**	***Dockside Product + Secondary Value***	✓✓✓		✓
	Ecological	***Structural Habitat*** biological hot spots, bottom-binding	✓✓	✓✓	✓✓
		Prey	✓	✓	✓
		Biofiltration top-down grazing, TSS removal, light)	✓✓	✓✓✓	✓✓
		Biogeochemistry enrichment/turnover, benthic production	✓	✓	✓
		Shoreline Protection - nearshore reefs	✓		
		Shoreline Stabilization - living edges	✓	✓✓	
	Cultural-Historical	***Waterman Lifestyle, Ecotourism***	✓✓		
		Native American - jewelry, dietary staple	✓		✓✓
	Bioindicator	***Watershed Indicators*** hallmark resource status/trends	✓✓	✓	✓
		Site-specific Bioassessment NS&T, caged sentinels	✓	✓	✓✓
	Conservation	**Biodiversity** fw mussels most critically impaired biota			✓✓✓

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Importance of Tidal Wetlands

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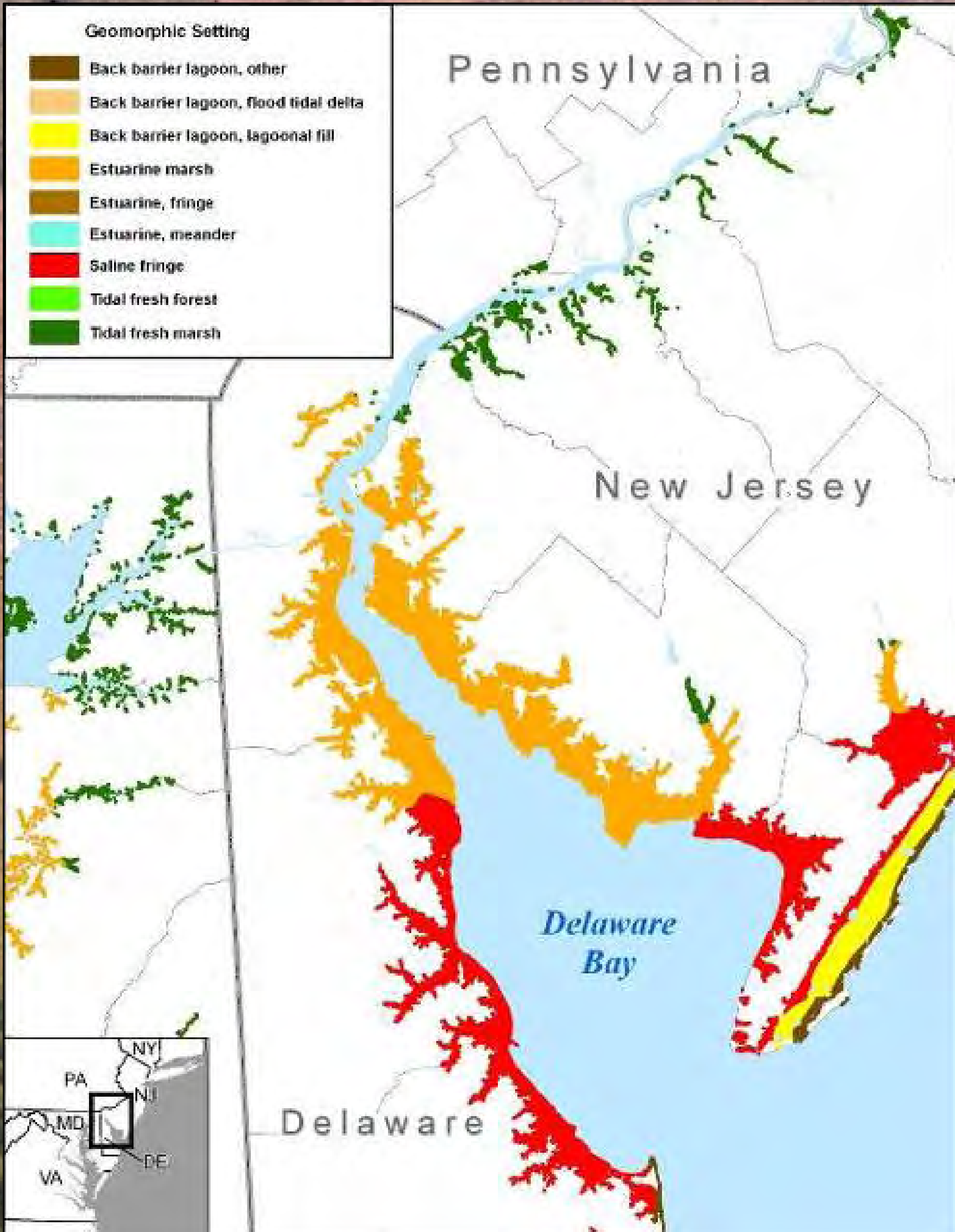
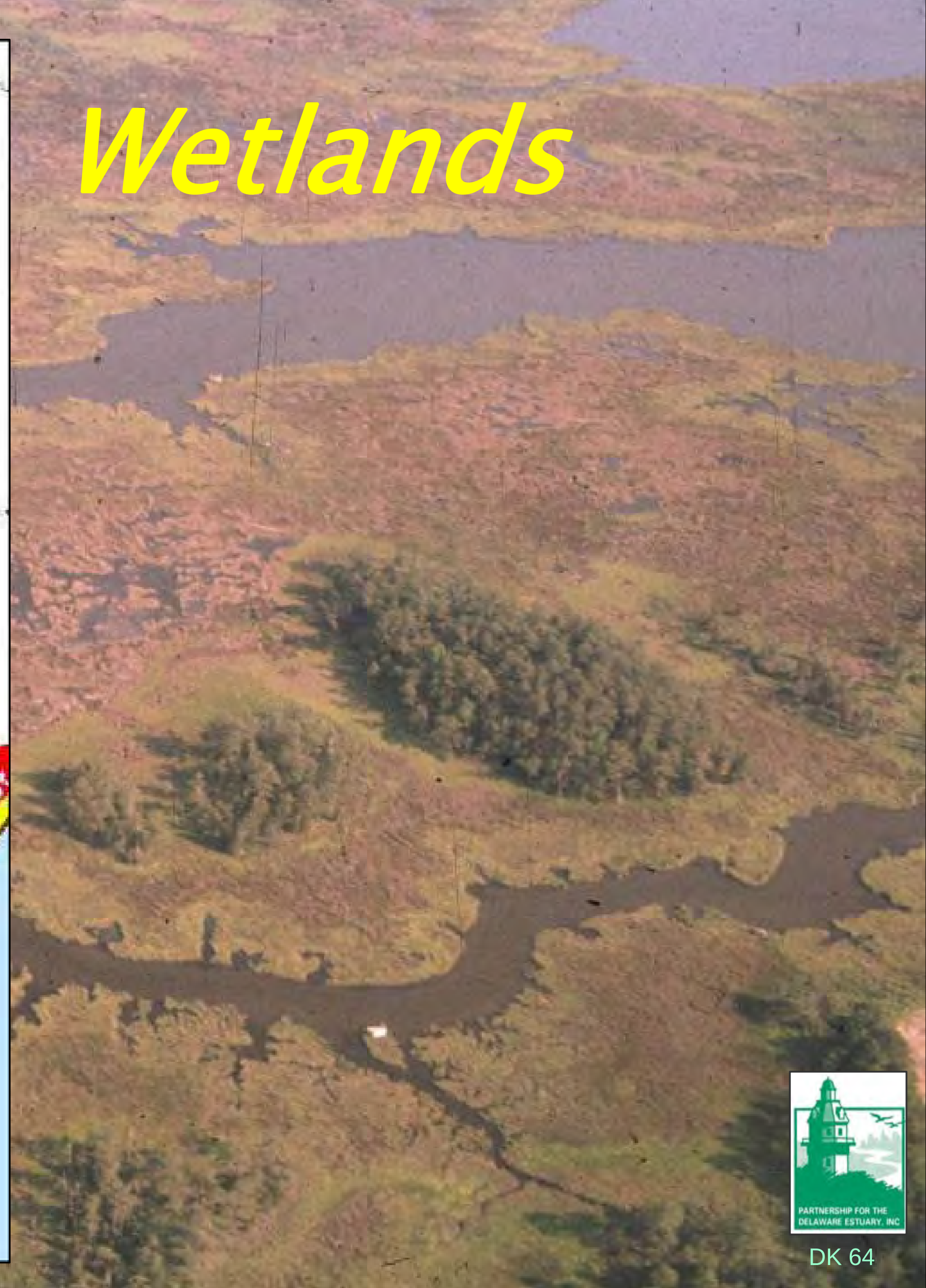
Wetlands



Geomorphic Setting
Back barrier lagoon, other
Back barrier lagoon, flood tidal delta
Back barrier lagoon, lagoonal fill
Estuarine marsh
Estuarine, fringe
Estuarine, meander
Saline fringe
Tidal fresh forest
Tidal fresh marsh
Pennsylvania
New Jersey
Delaware Bay
Delaware
NY
PA
NJ
MD
DE
VA



Tidal Wetlands

A Signature Trait of System

- Near Contiguous Band
- Diverse: *Freshwater Tidal Marshes*
  Brackish Marshes
  Salt Marshes

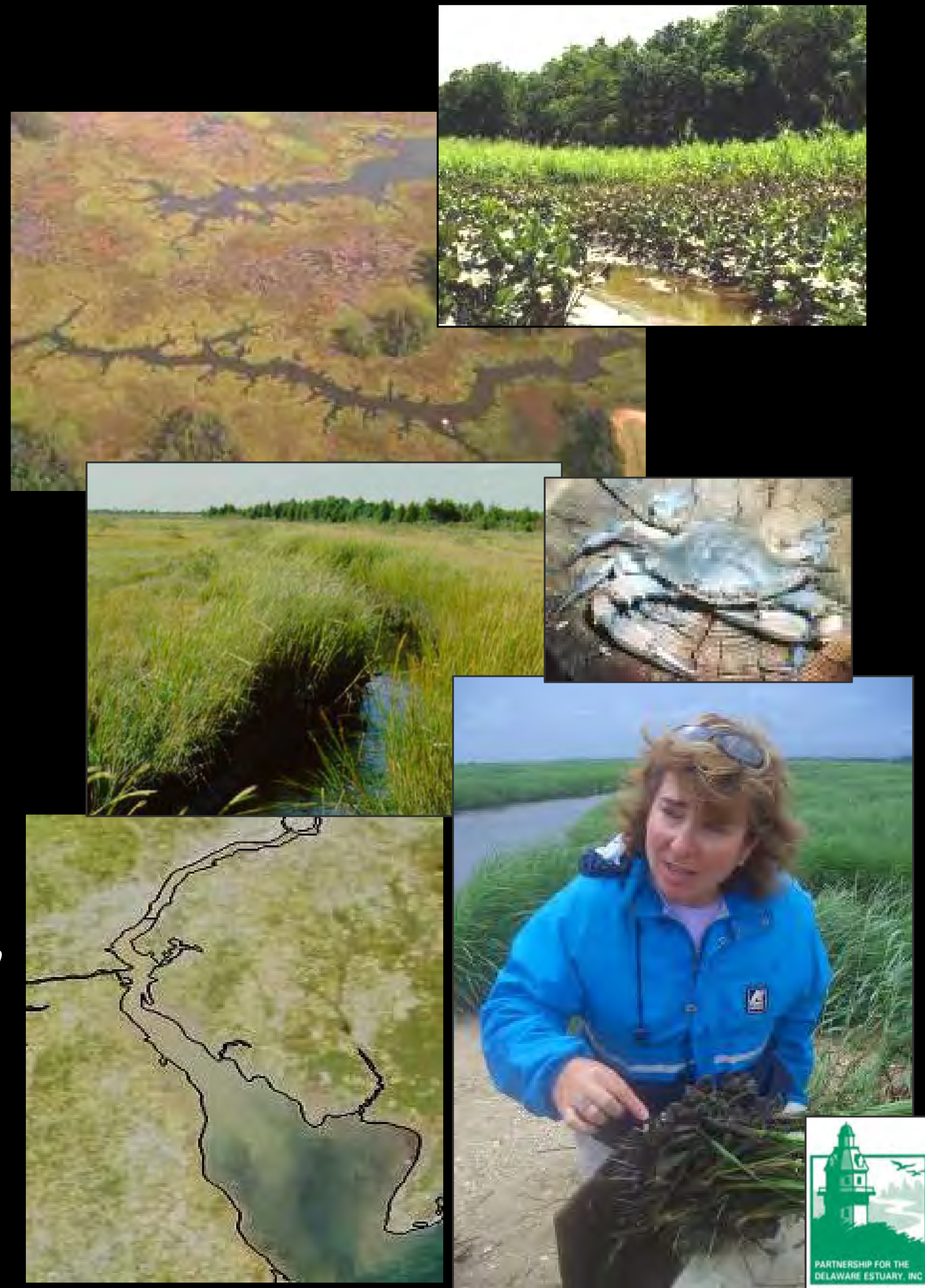
<u>Ecological Values</u>:

Structural

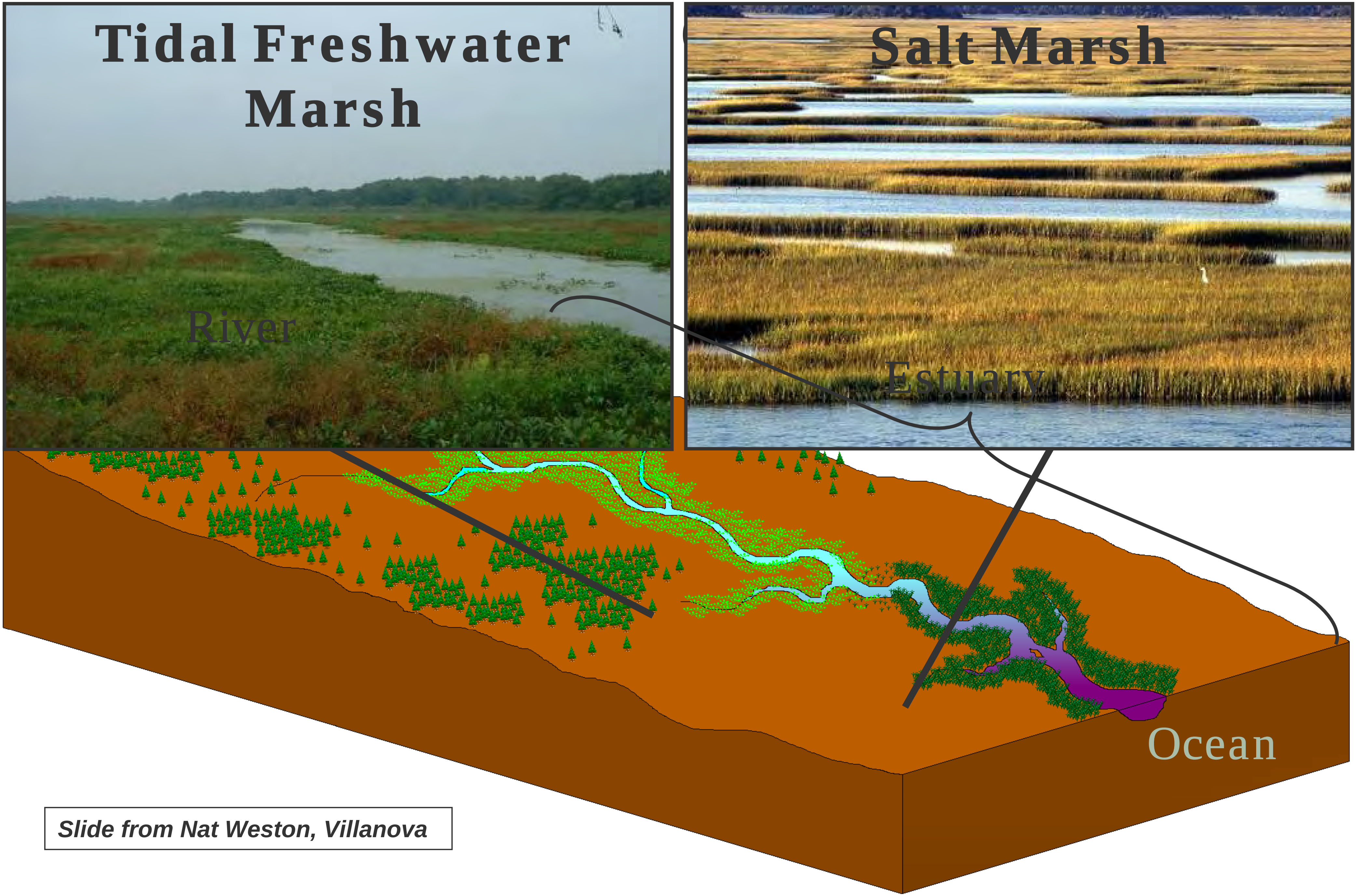
biodiversity
habitat for fish and wildlife
nurseries for imperiled taxa

Functional

food web
water quality
flood protection



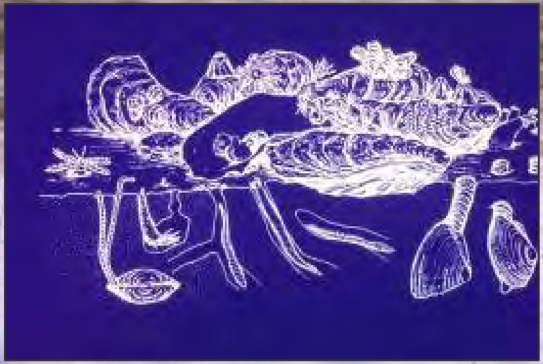
Rutgers University


Tidal Freshwater Marsh
Salt Marsh
River
Estuary
Ocean
Slide from Nat Weston, Villanova


Tidal Range up to 9'
Salinity <0.5 ppm
PARTNERSHIP FOR THE DELAWARE ESTUARY, INC
DK 67

Delaware Estuary *Spartina* Marsh

High Production



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Nursery Habitat

Recreation

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Ecosystem Services e.g., Carbon Sequestration

Some Literature

Temperate wetlands accumulate 1.42 tons C ha^{-1} yr^{-1}

Wetlands represent the largest terrestrial biological C pool, and thus play an important role in global carbon cycles

Wetland soils have the highest average organic carbon followed by forest soils; agricultural soils are >20 fold less carbon rich

Since agricultural soils have lower organic C than wetlands, conversion of ag lands to wetlands may enhance CS

Tidal Wetlands

A Signature Trait of the Ecosystem

Ecological Values:

Structural

habitat for fish and wildlife
nurseries for imperiled taxa

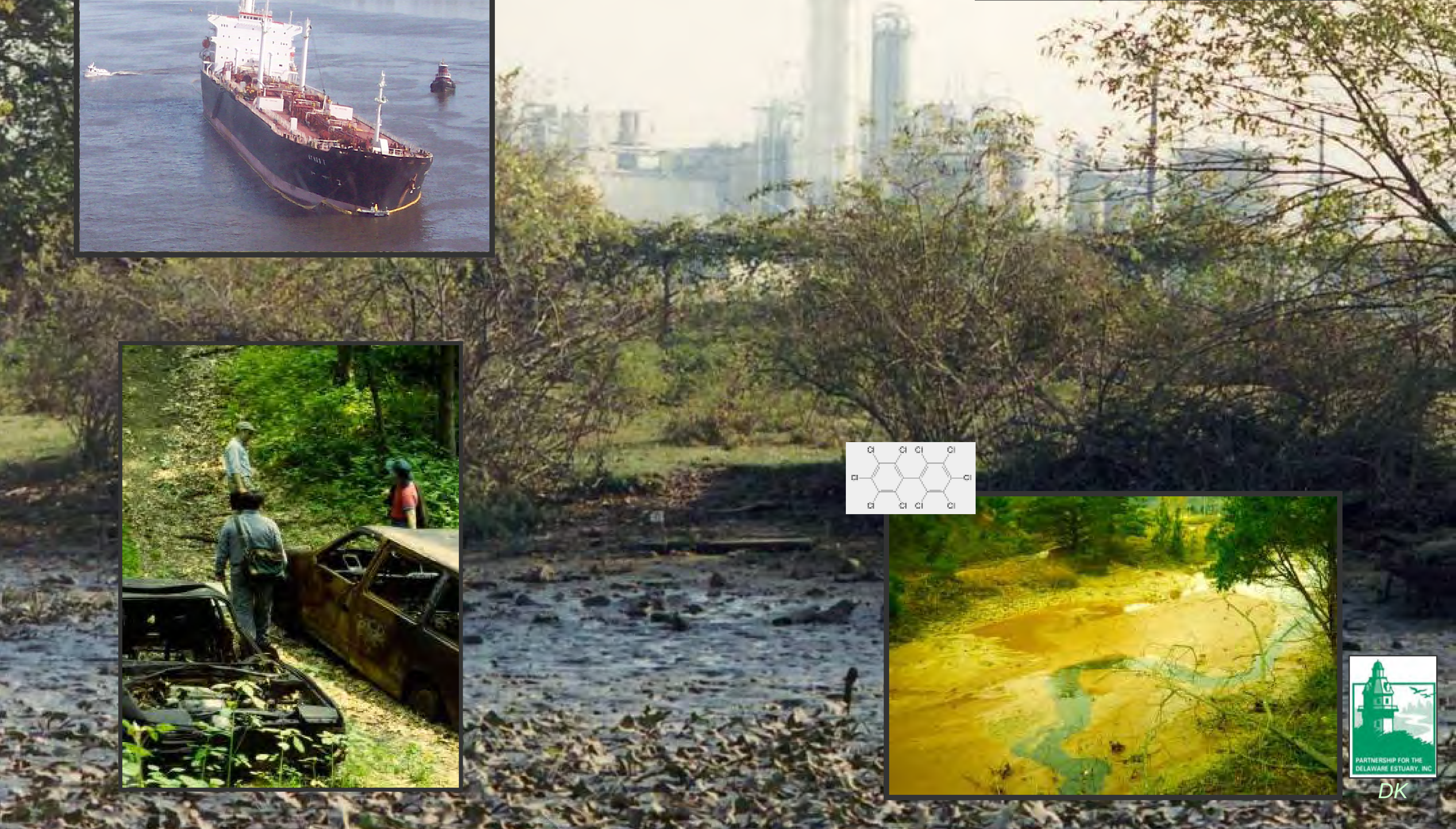
Functional

food web
water quality
flood protection

Concerns:

Degradation

Degradation



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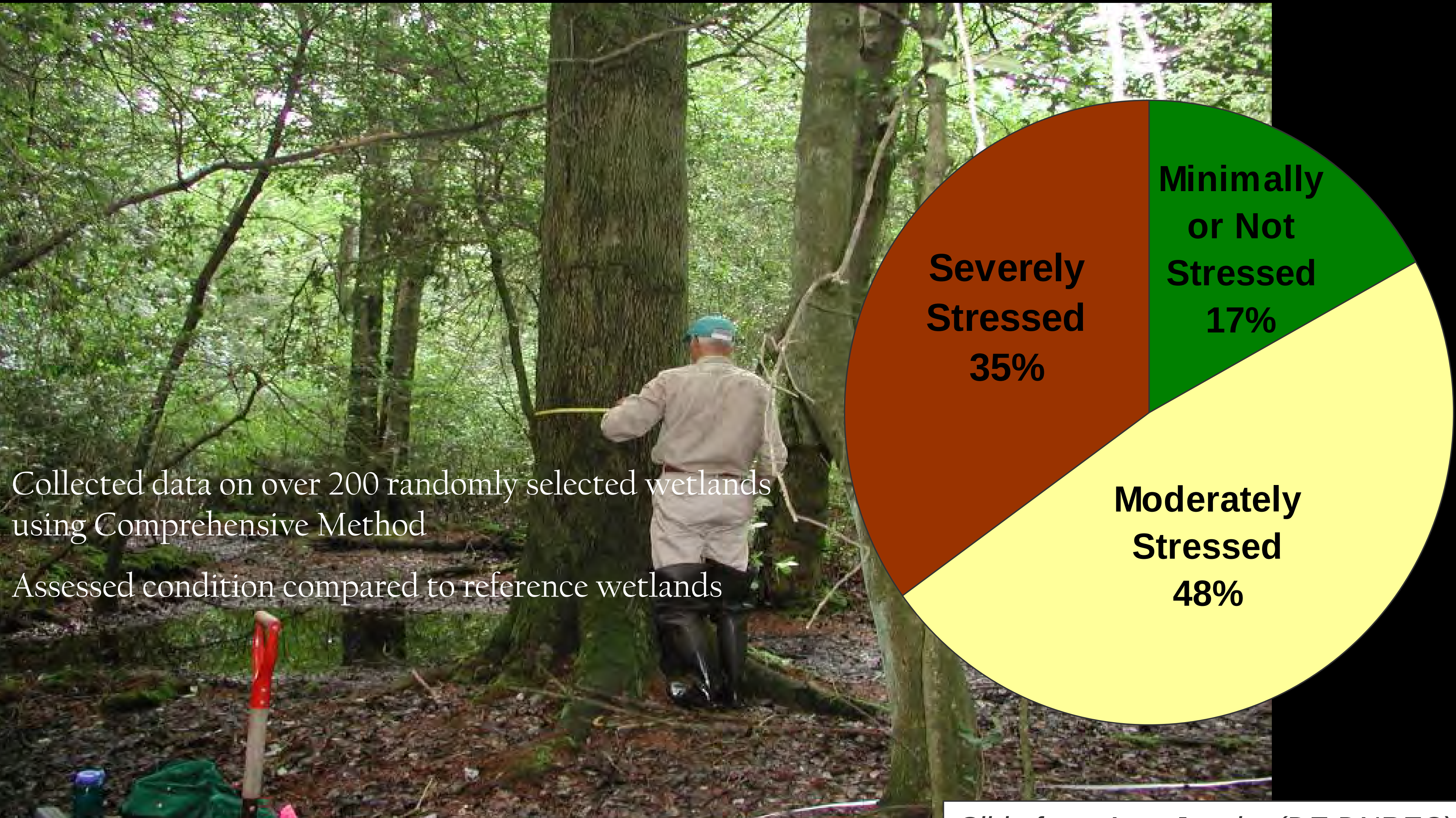
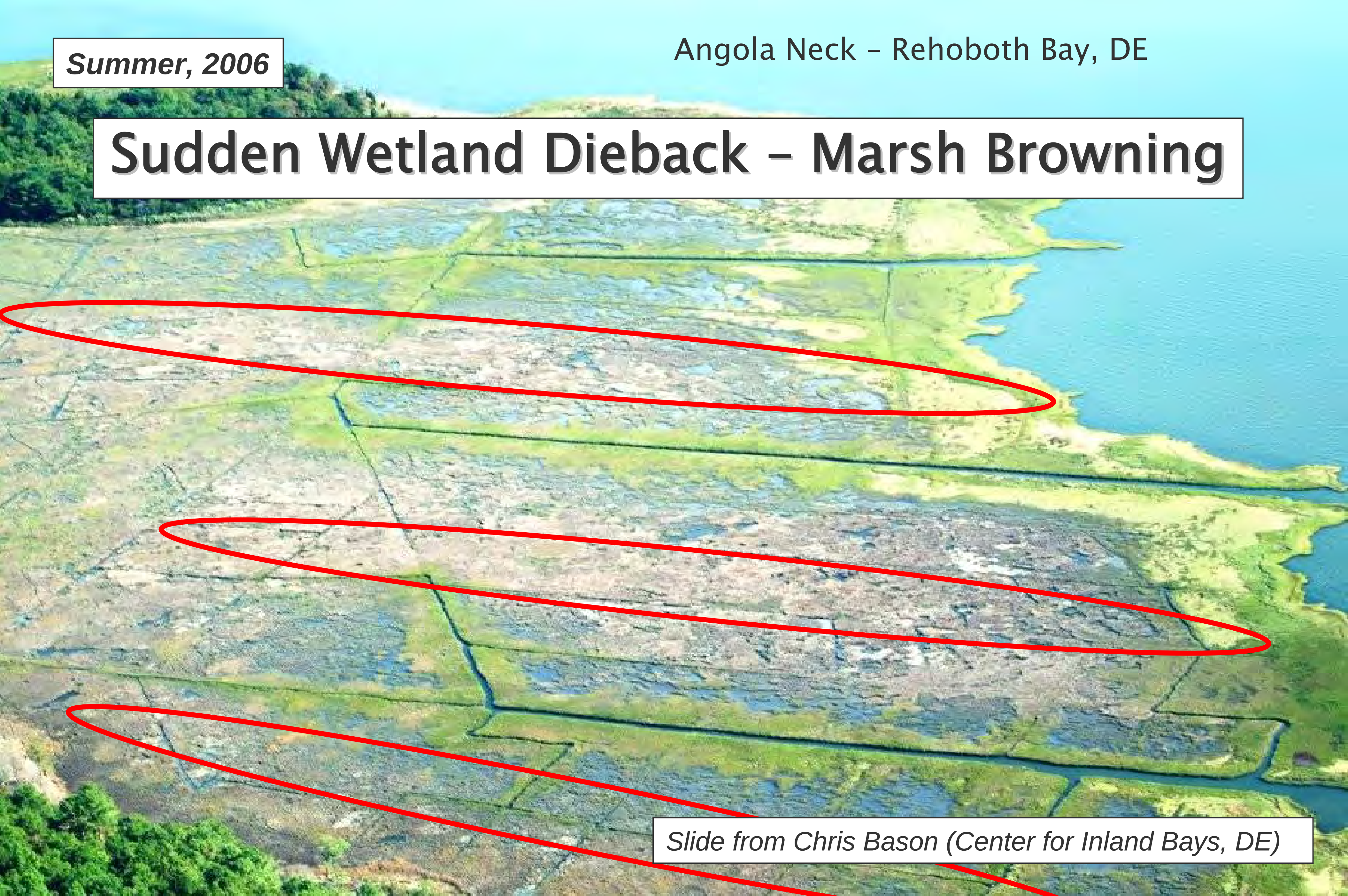
DK

Condition of non tidal wetlands in the Nanticoke River watershed



Slide from Amy Jacobs (DE DNREC)


Summer, 2006
Angola Neck – Rehoboth Bay, DE
Sudden Wetland Dieback – Marsh Browning
Slide from Chris Bason (Center for Inland Bays, DE)

Tidal Wetlands

Ecological Values:

Structural
habitat
Functional
food web
water quality
flood protection

Concerns:
Degradation

Conversion & Loss

Freshwater Tidal Wetland Acreage

Past and Present

Pre-Settlement *?*

1973 (Patrick et al.) *2310 ha*

1981 (NWI) *9347 ha (all classes)*
597 ha (emergent)

1988 (Tiner & Wilen) *1000 ha*

New data soon (NWI, States, LU/LC)

Estimated < 5% remains

Tidal Wetlands

Ecological Values:

- Structural
  - *habitat*
- Functional
  - *food web*
  - *water quality*
  - *flood protection*

Concerns:

- Degradation
- Conversion & Loss
- Sea level rise

PARTNERSHIP FOR THE DELAWARE ESTUARY, INC

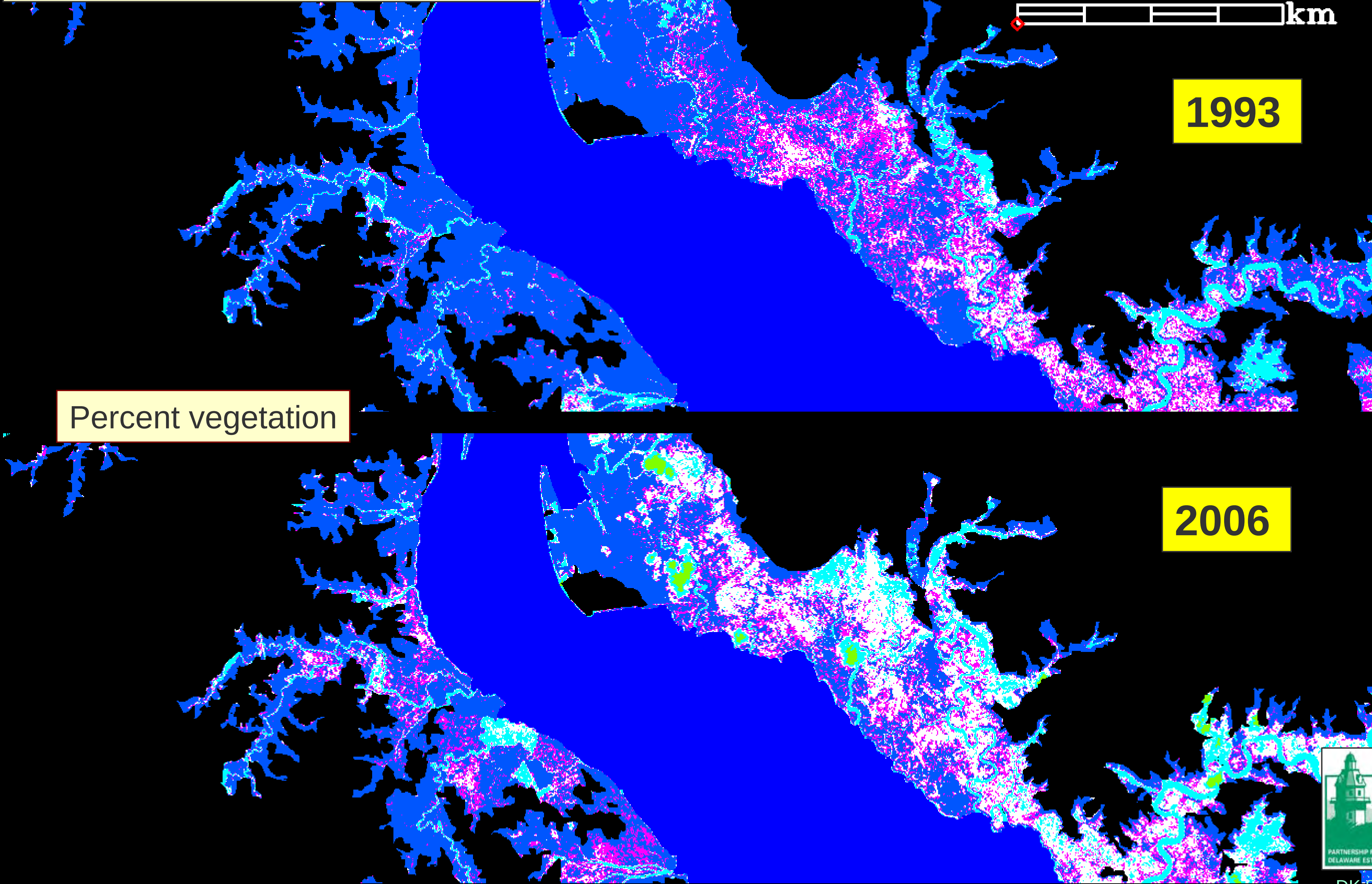
DK 80

Shoreline Erosion

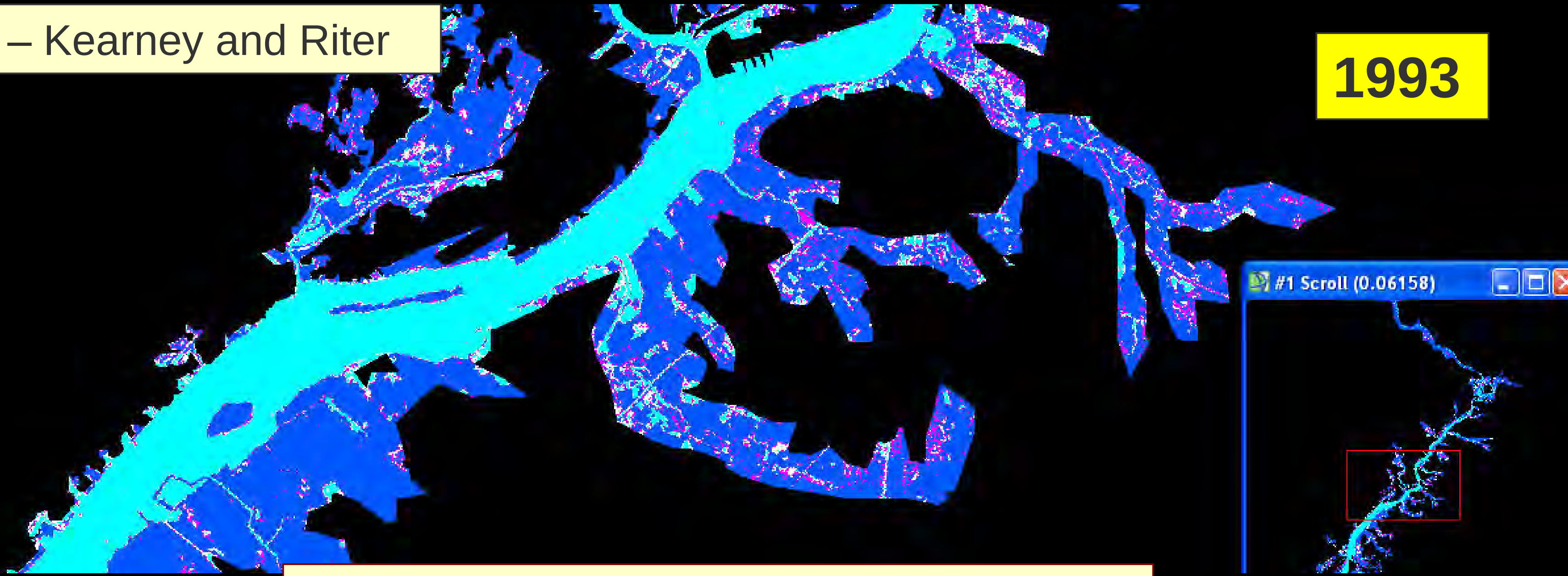
Courtesy D. Bushek, Rutgers

Courtesy J. Gebert, ACOE

Satellite Data – Kearney and Riter

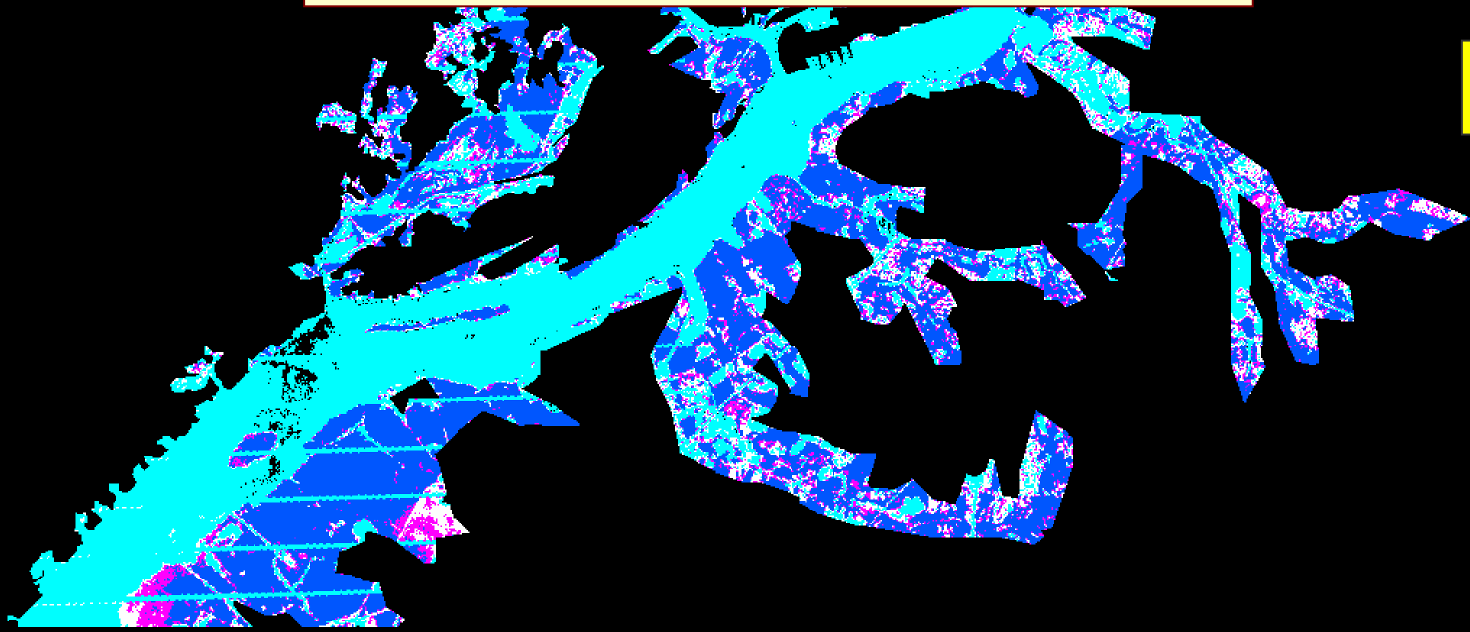


Satellite Data – Kearney and Riter



1993

Percent vegetation near Philadelphia airport



2006

Tidal Wetlands

Ecological Values:

Structural

habitat

Functional

food web

water quality

flood protection

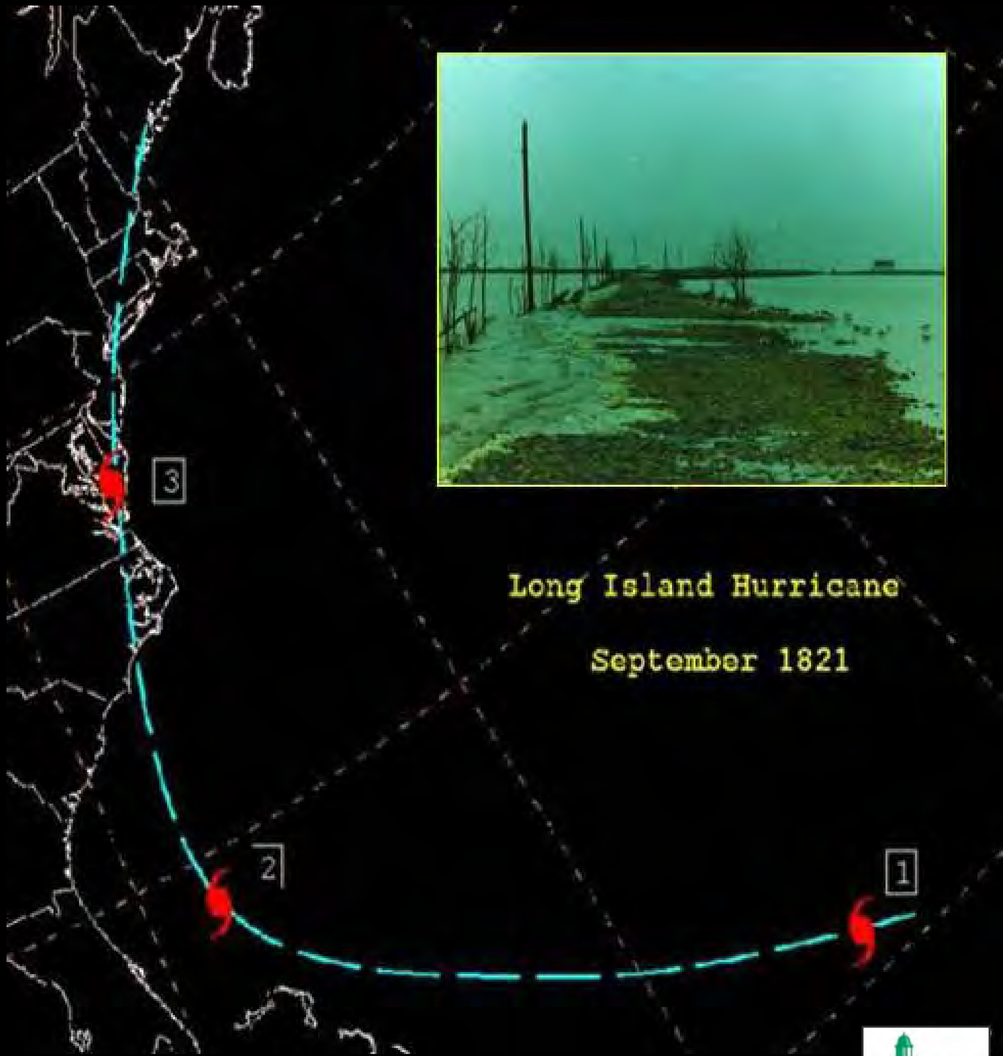
Concerns:

Degradation

Conversion & Loss

Sea Level Rise

Storms



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Tidal Wetlands

Ecological Values:

Structural
habitat
Functional
food web
water quality
flood protection

Concerns:
Degradation
Conversion and Loss
Sea Level Rise
Storms

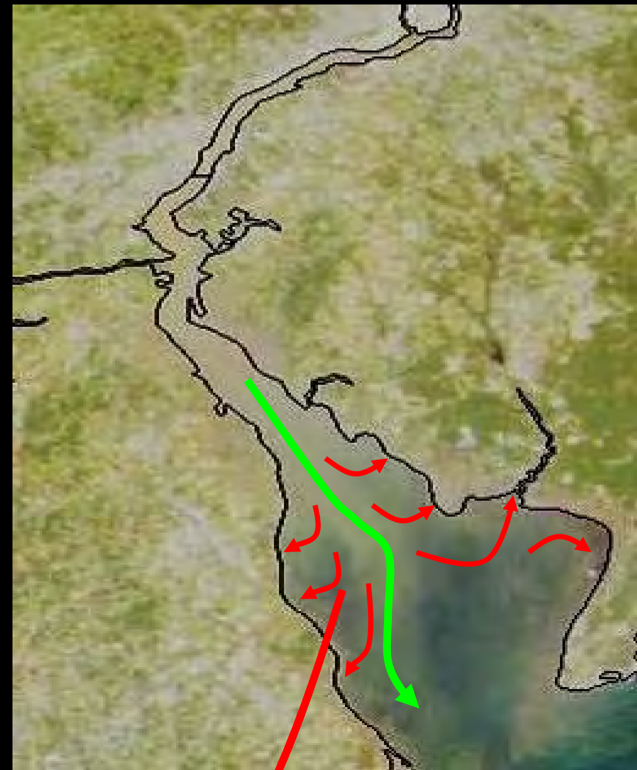
** Sediment budget

Tidal Wetlands

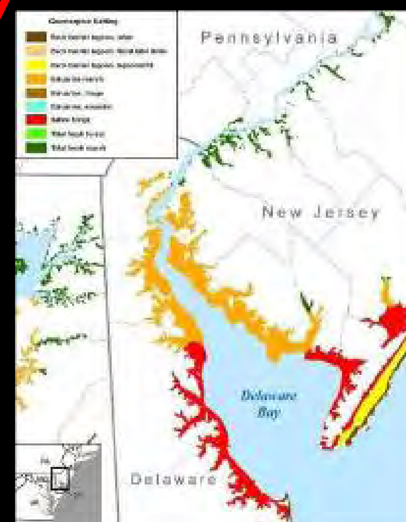
Concerns:

- Degradation
- Conversion and Loss
- Sea Level Rise
- Storms

Sediment budget

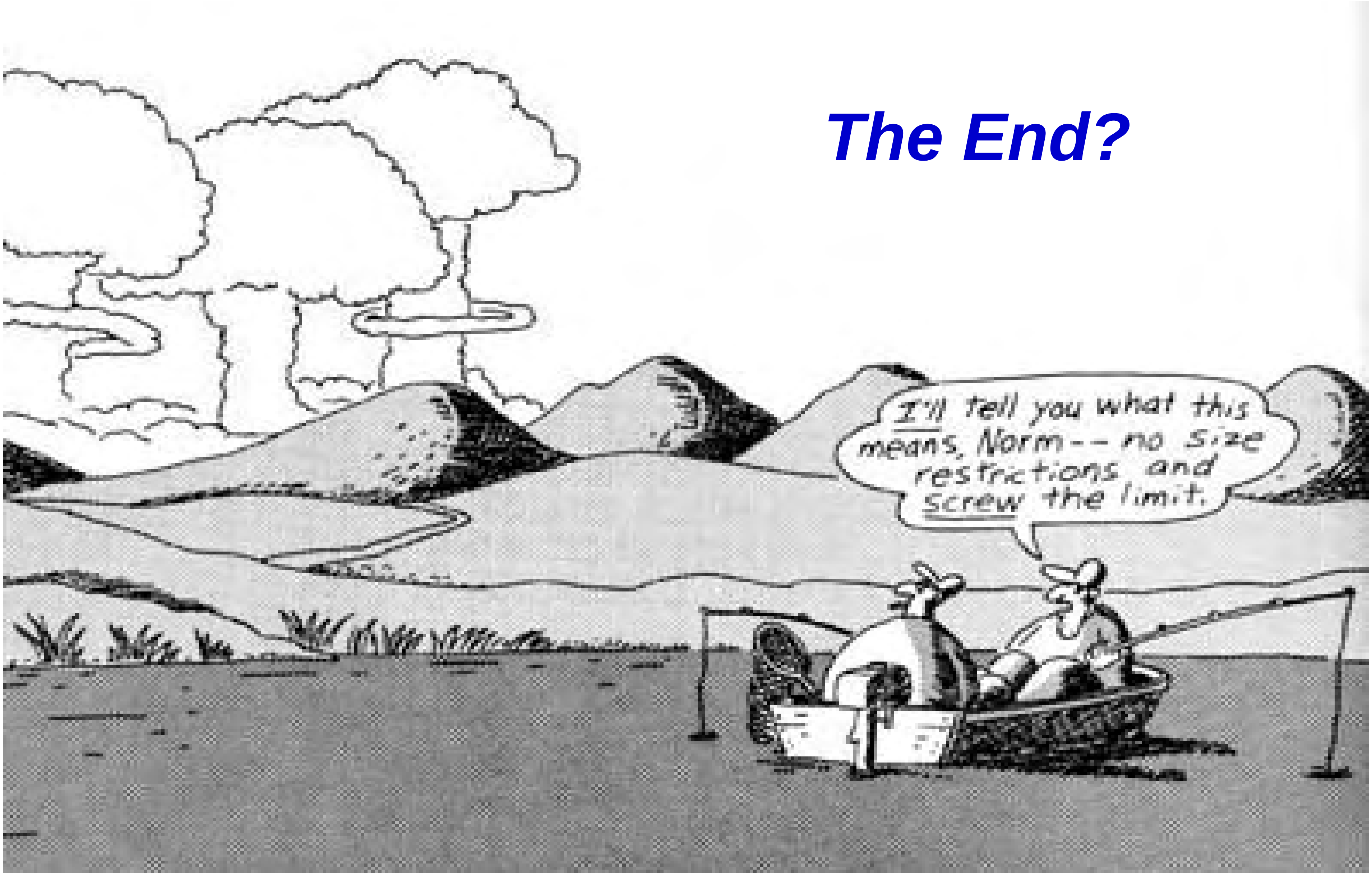


Living Shorelines 2008



DK 87

The End?



The Far Side by Gary Larson


Change Happens !
So what should we do?
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DK 89

Take Home: Predicting and Planning for the Future will Require an Understanding of Interactions , Climate + Other Changes

Sea level, salinity, temperature and suspended sediment are important environmental factors for biological communities such as oyster reefs and tidal marshes

Climate change will alter these environmental conditions

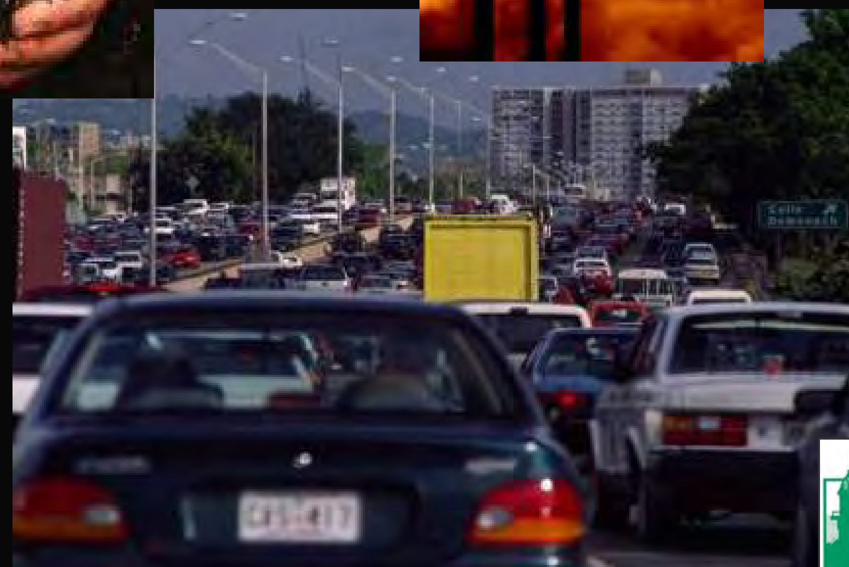
Land use change, channel deepening, and changes in freshwater inflow are also likely to alter these conditions

How will biological communities respond to the combined effects?

How will life sustaining resources and functions respond?

What Can We Do?

1. Mitigate – work to curtail climate change



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What Can We Do?

2. Protect and Conserve

Continue implementing sound management plans to safeguard ecosystem structure and function

What Can We Do?

3. Restore & Enhance

Restore or otherwise enhance ecosystem structure and function

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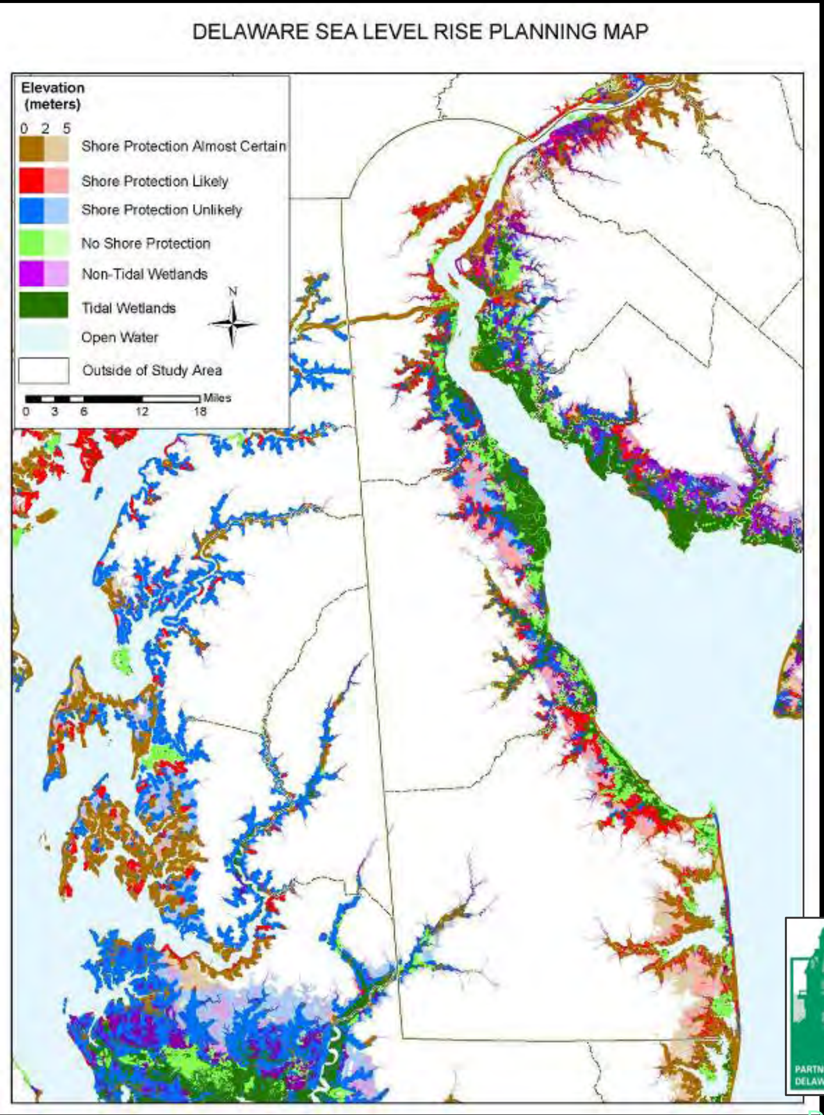
Restoration for the Future

Restore, conserve or otherwise enhance ecosystem structure and function, smartly



New Tactics: e.g. Living Shoreline Initiatives

Shellfish as Natural Breakwaters

- Reduce wave energy
- Trap silt
- Reduce bank erosion
- Protect salt marsh

Slide from Dave Bushek, Rutgers

Living Shorelines

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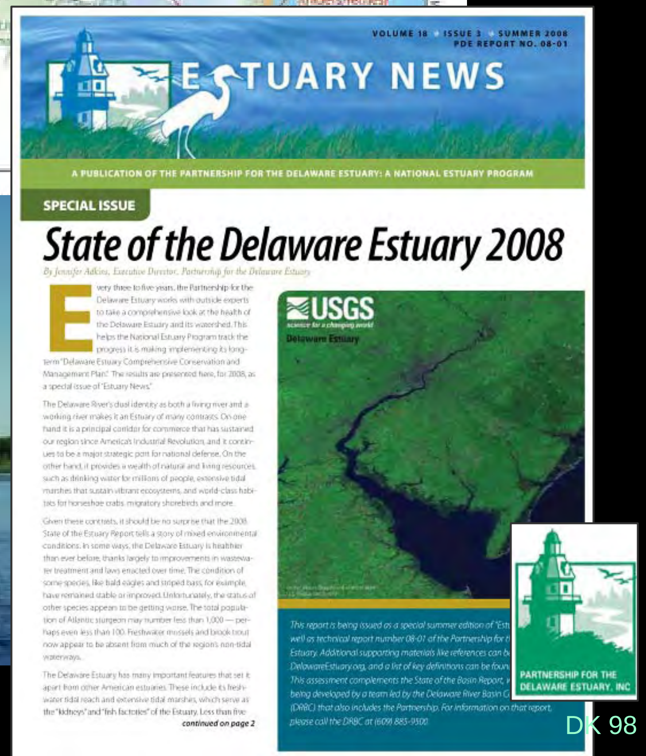
Examples

What Can We Do?

4. Monitor & Study

Continue to characterize how the system works and strengthen our monitoring infrastructure to better track status and change in ecosystem structure and function



What Can We Do?

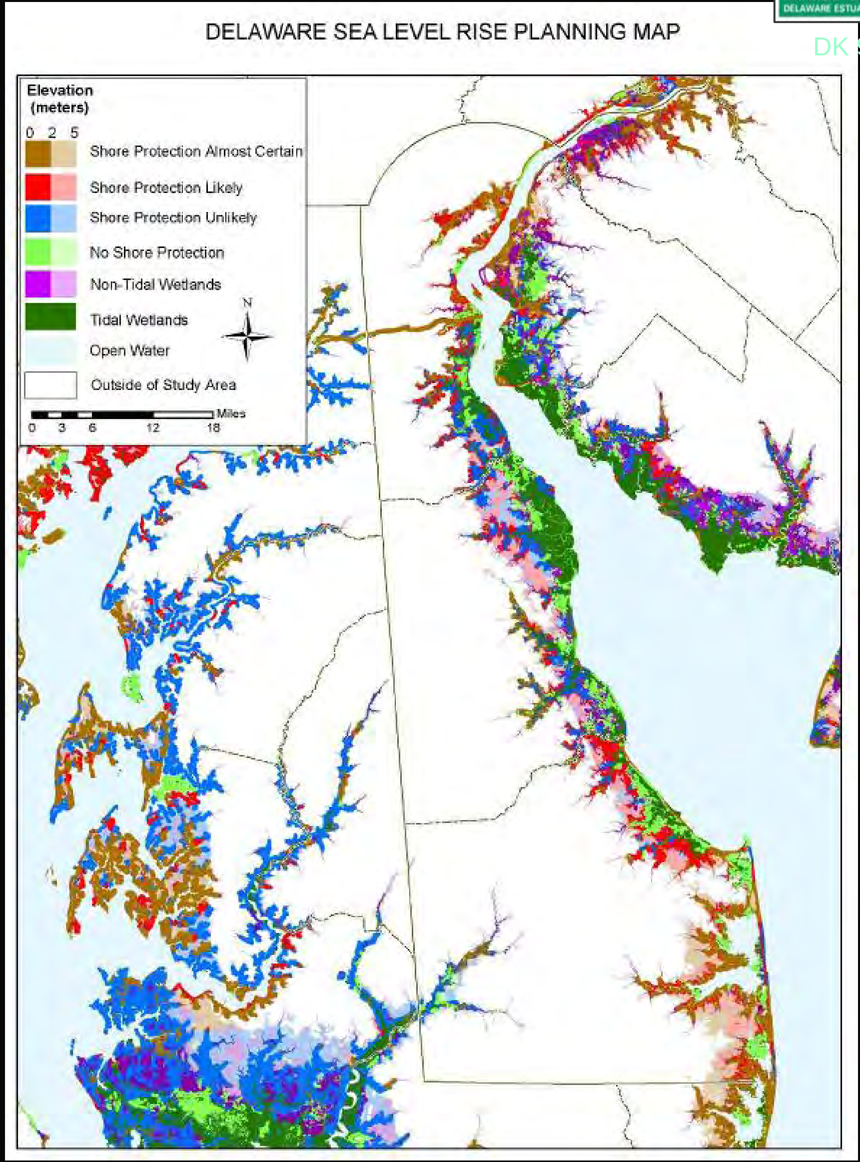
5. Adapt !

Strategic adjustments for climate change to maximize long-term ecosystem health and resiliency, as well as lives and livelihoods

Will Wetlands Be Converted to Open Water?								
Rate of Sea Level Rise	Blue	Red	Orange	Brown	Tan	Yellow	Light green	Dark green
Current rate	Yes	?	?	No	No	No	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No	No	No	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

e.g., Where will wetlands convert to open water, where can we save them?



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Plans for Adaptation Plans

High Need
Escalating Interest
New Programs
Still.. Little On-the-Ground Action

Recent CSO Survey:

- **80% of coastal states plan to develop sea level rise adaptation plans**
- **only 3 have made any progress**
- **no standard approach**
- **little federal coordination**

CLIMATE READY ESTUARIES
EPA

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Adaptation Planning *(in addition to mitigation)*

- **Vulnerability** – forecast and assess risks
- **Opportunity** – identify activities that can help offset vulnerabilities to key natural resources
- **Obstacles** – identify potential barriers to action (e.g., interstate cooperation, data comparability, etc.)
- **Adaptation Plan** – recommend actions for filling information needs, capitalizing on highest value opportunities, and overcoming obstacles

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So What Are We Doing?
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Priority
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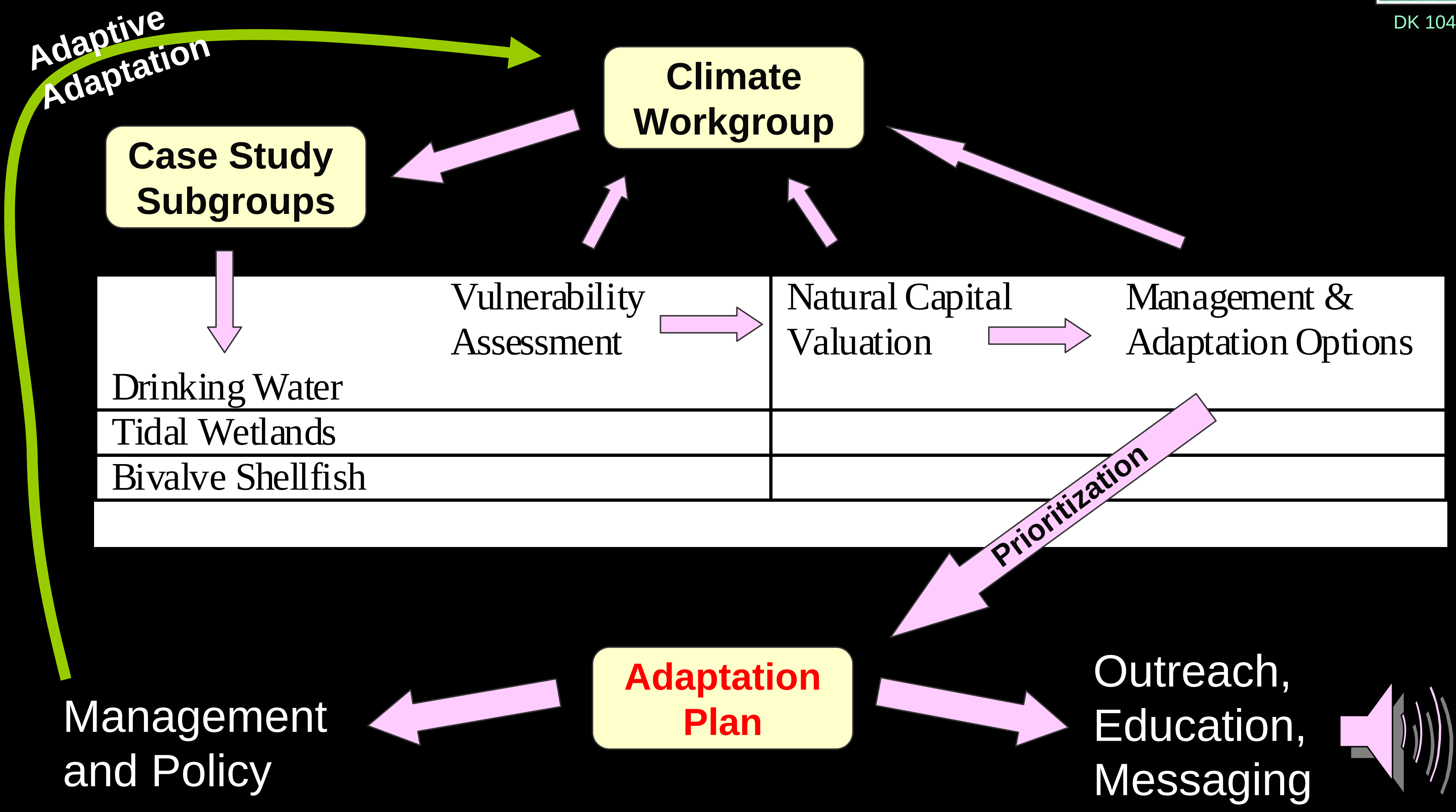
PDE Climate Ready Pilot

- **Goal** – perform a vulnerability assessment and draft adaptation plan for one or more case studies

- **Tasks**
  - Vulnerability/Risk Assessment - inventory threats to natural resources
  - Valuation - Assess natural goods and services that are at risk
  - Identify Options – **List** management response scenarios, including early warning monitoring needs, and **prioritize** adaptation options to safeguard or enhance resources at risk
  - Recommendations - Provide managers and policy-makers guidance on how to achieve greatest natural resource outcomes

PDE Climate Ready Approach

DK 104



Climate Adaptation Planning

ID Vulnerabilities

↓

Ecological Valuation

↓

Adaptation Options

↓

Recommendations and Reporting

Case Studies

Tidal Marshes

Bivalve Shellfish

Drinking Water

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Climate Adaptation Planning

ID Vulnerabilities

↓

Ecological Valuation

↓

Adaptation Options

↓

Recommendations and Reporting

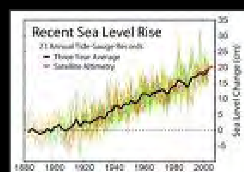
Work Groups

Climate Adaptation Work Group (CAWG)
STAC-affiliated; Chair: Dan Soeder

Tidal Wetland Sub-group
Velinsky & Kreeger

Shellfish Sub-group
Kraeuter & Kreeger

Drinking Water Sub-group
Connolly



Predications & Modeling Team
Najjar

Natural Capital Team
Cole

Climate Adaptation Planning

ID Vulnerabilities

↓

Ecological Valuation

↓

Adaptation Options

↓

Recommendations and Reporting

Case Studies

Tidal Marshes

Bivalve Shellfish

Drinking Water

Tidal Wetlands Adaptation Planning

<u>Goal</u>: Maximize long-term ecosystem health and resiliency

Will Wetlands Be Converted to Open Water?								
Rate of Sea Level Rise	(blue)	(red)	(orange)	(brown)	(tan)	(yellow)	(light green)	(dark green)
Current rate	Yes	?	?	No	No	No	No	No
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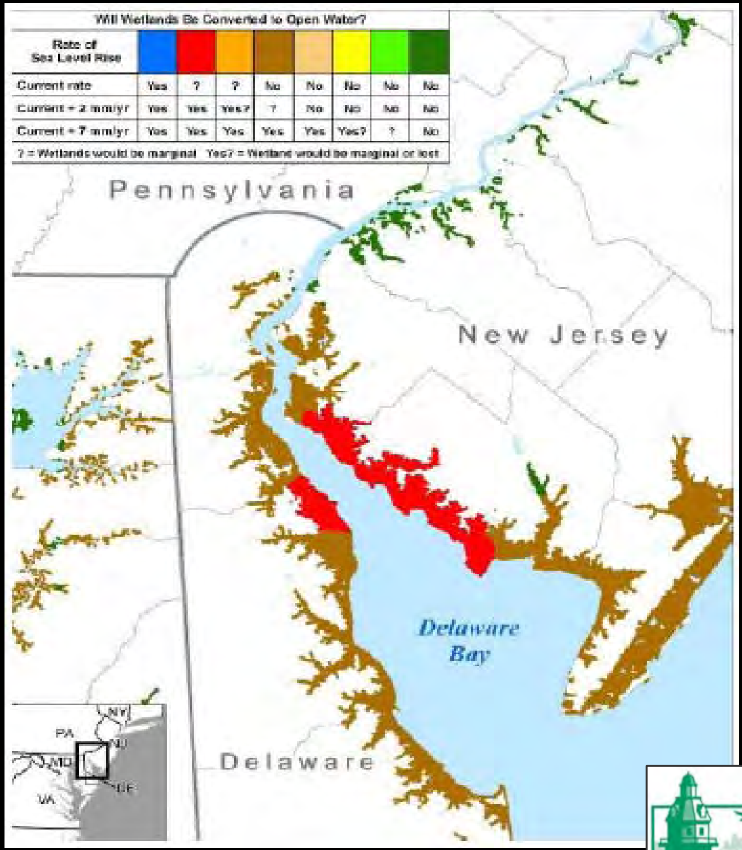


<u>Tough Choices</u>

- Where will wetlands will be converted to open water?
- Where can we save them ?
- Where is strategic retreat the best option?

Tidal marshes need to move:

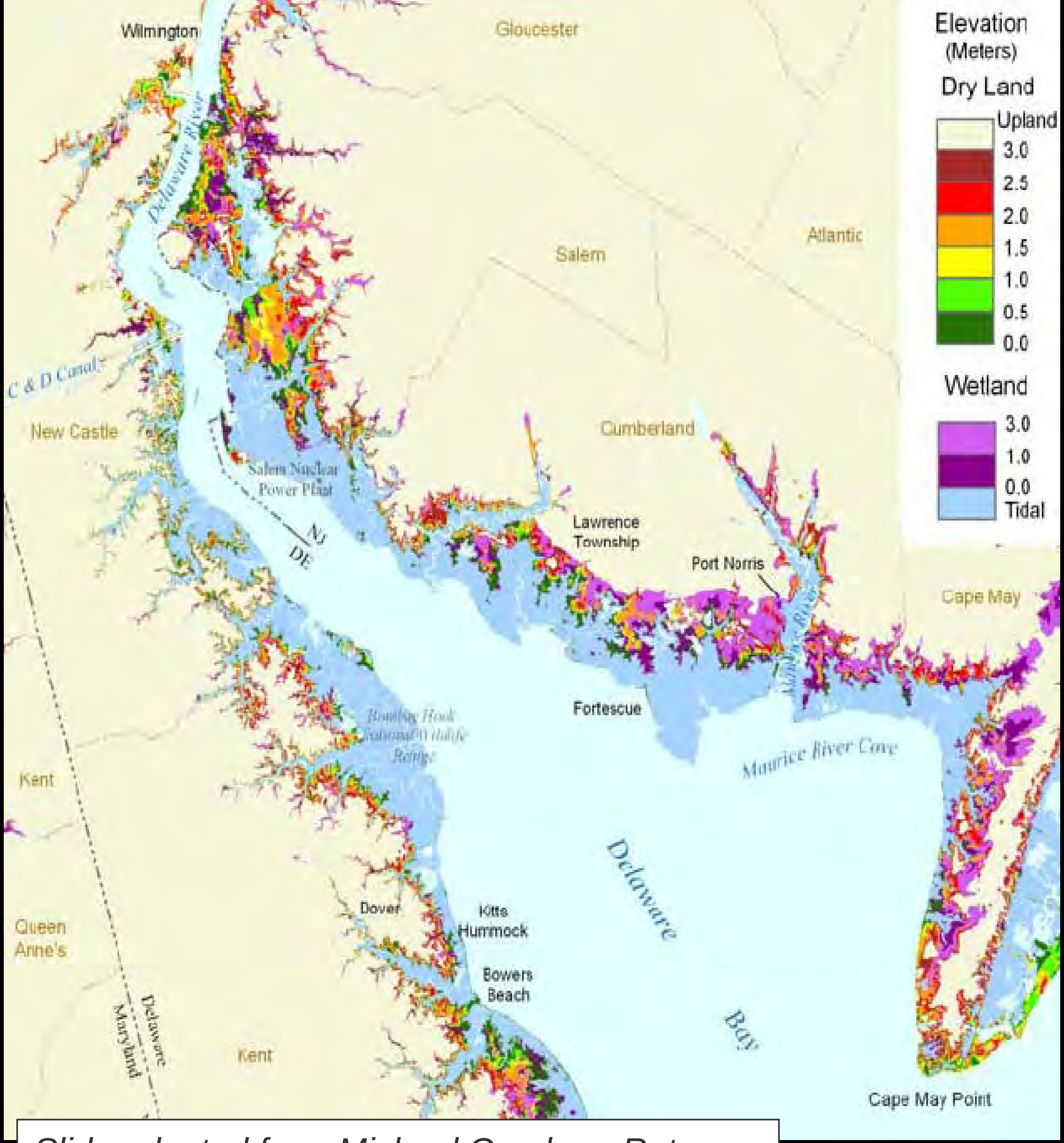
1) <u>horizontally</u>
(landward)

and/or

2) <u>vertically</u>
(to keep pace)

Can they do it?

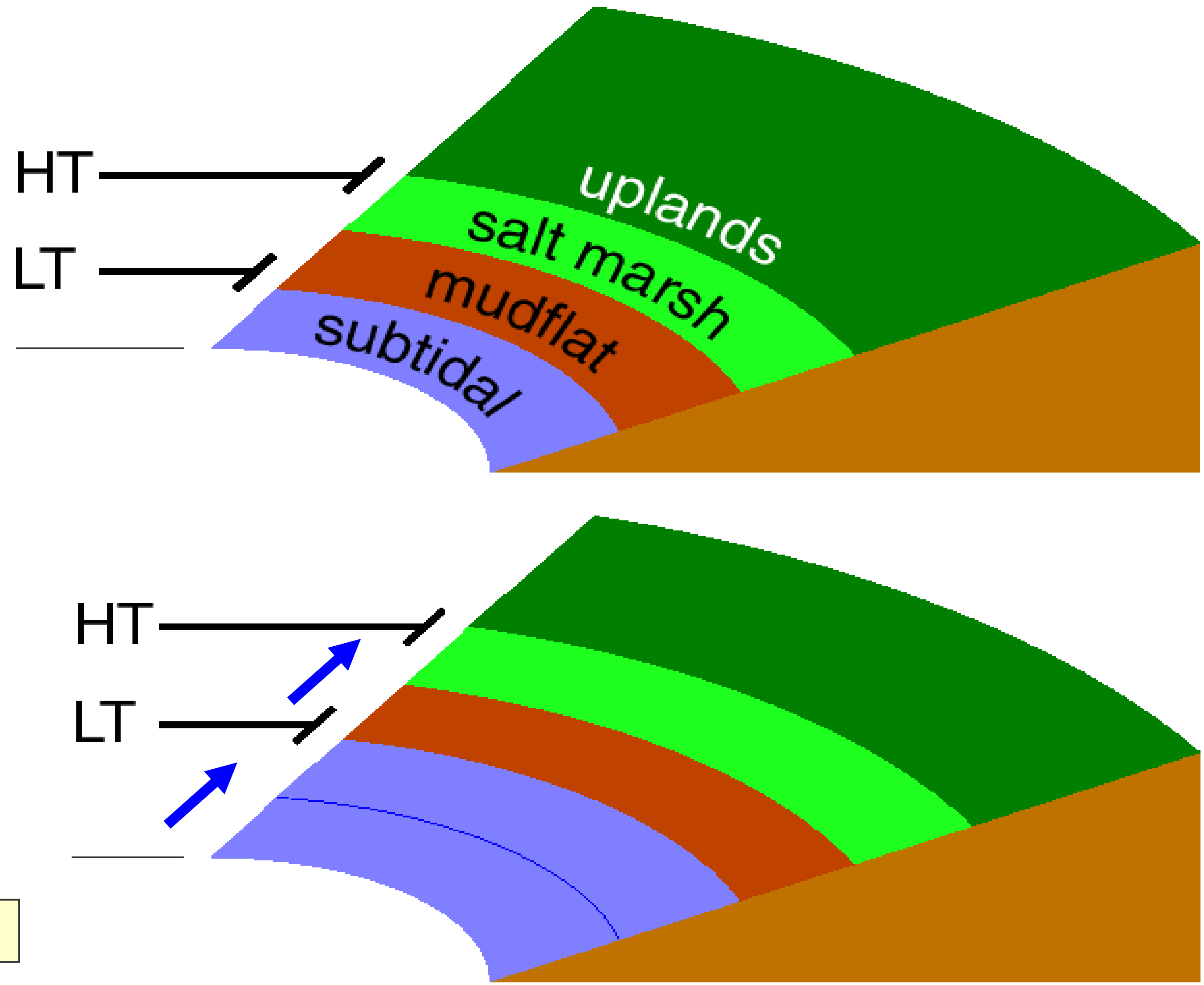
Where?



Slide adapted from Michael Craghan, Rutgers

SLR and Transgression

As sea-level rises, the environments shift with the changing flood conditions.

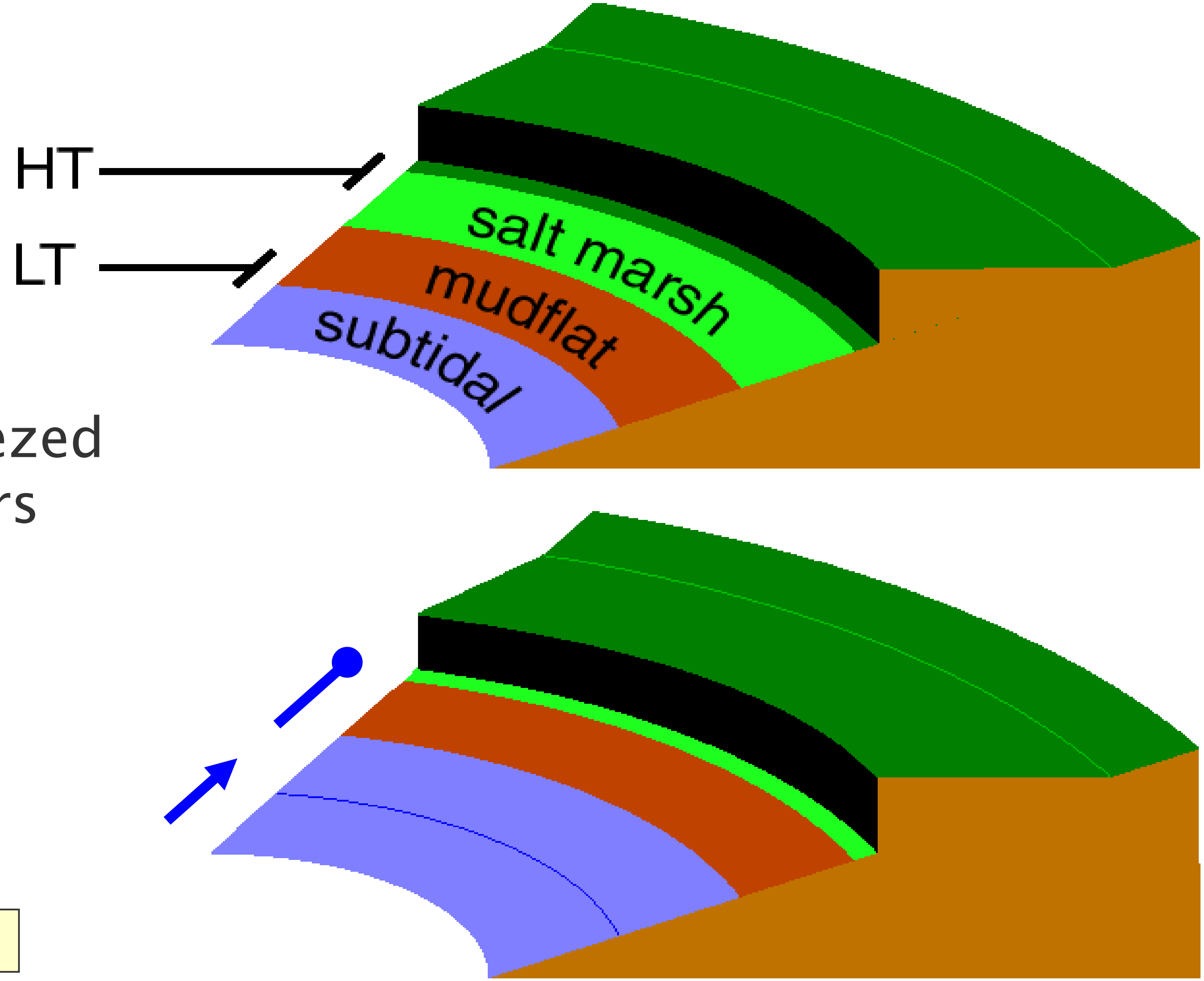


Slide from M. Craghon, Rutgers

The “coastal squeeze”

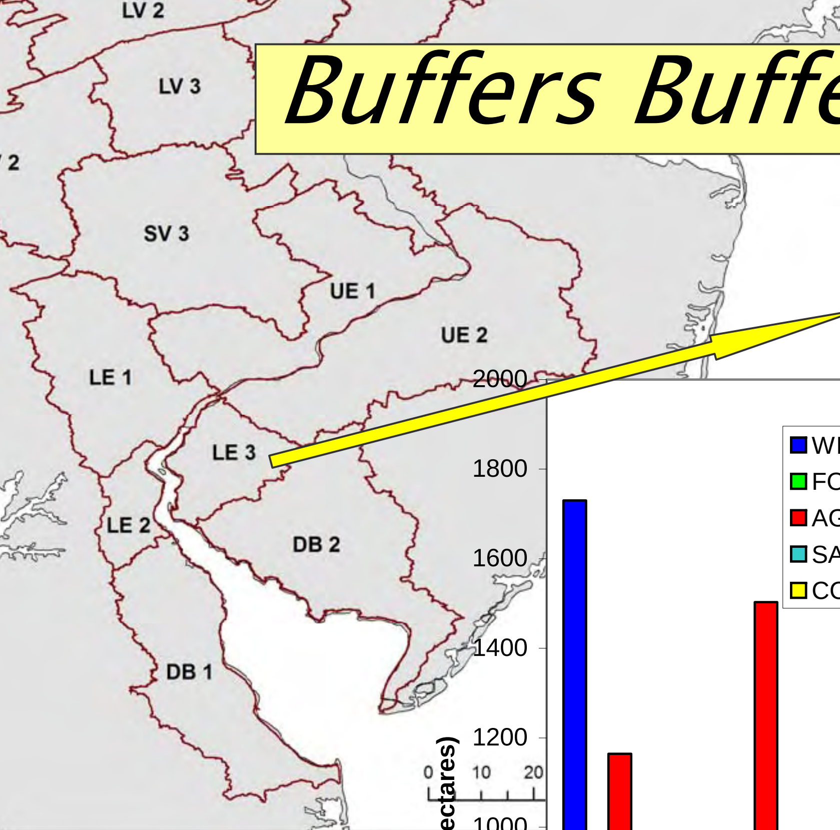
Irregular terrain impedes orderly shoreline transgression.

Tidal marsh is squeezed between rising waters and impassable barriers, and are progressively lost.

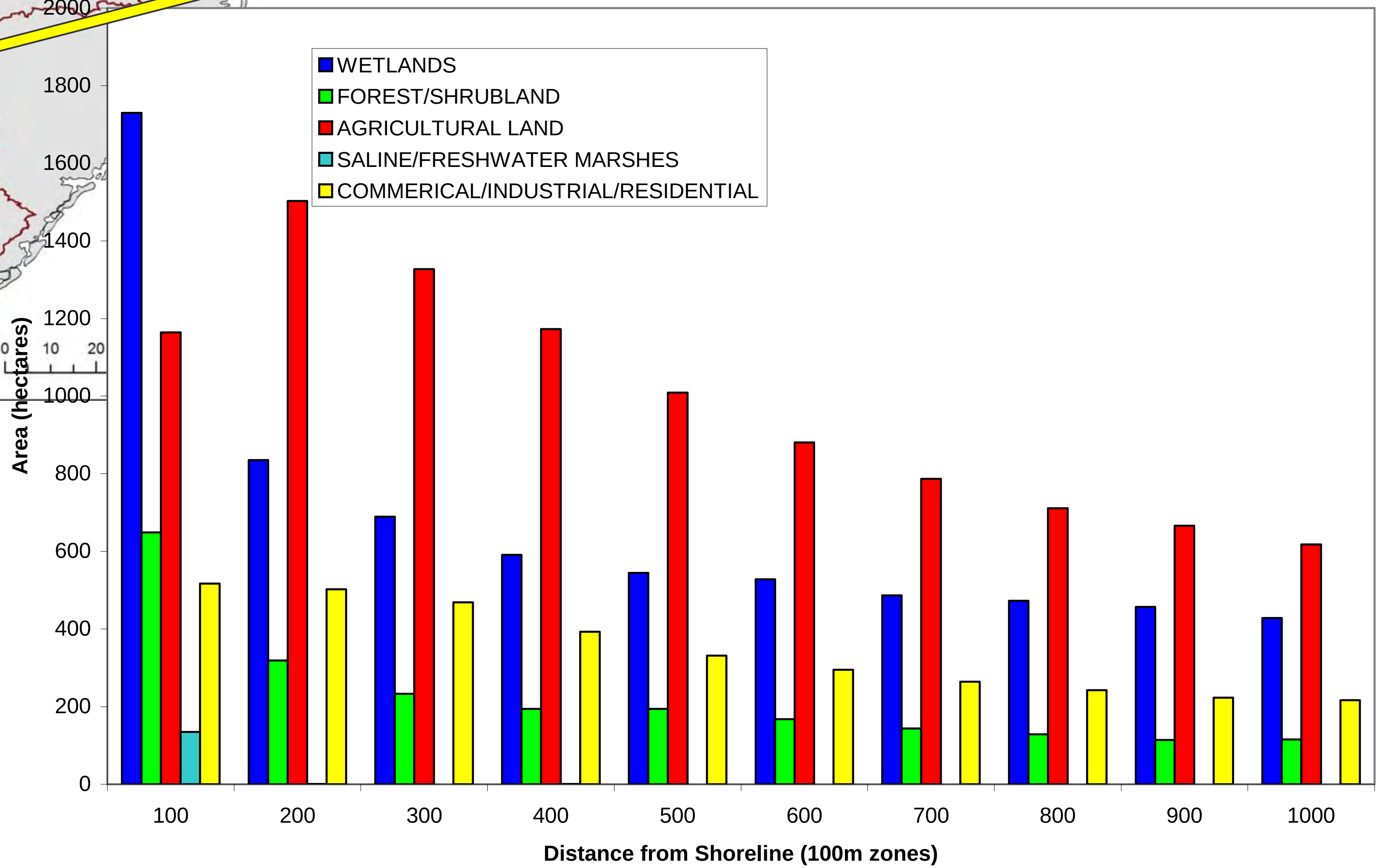


Slide from M. Craghon, Rutgers

Buffers Buffers Buffers = Resiliency



Land Use in Tidal Marsh Buffer Zone in the Lower Estuary of NJ (LE3)



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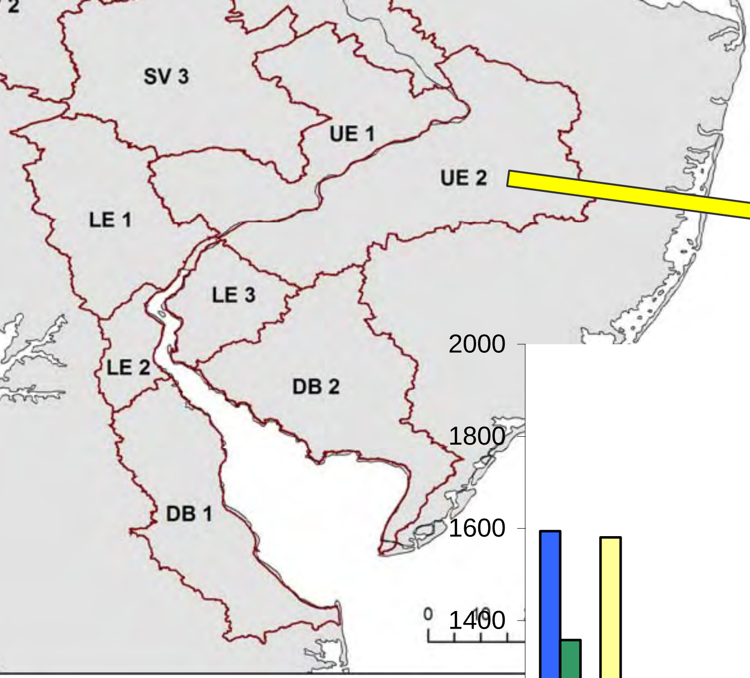
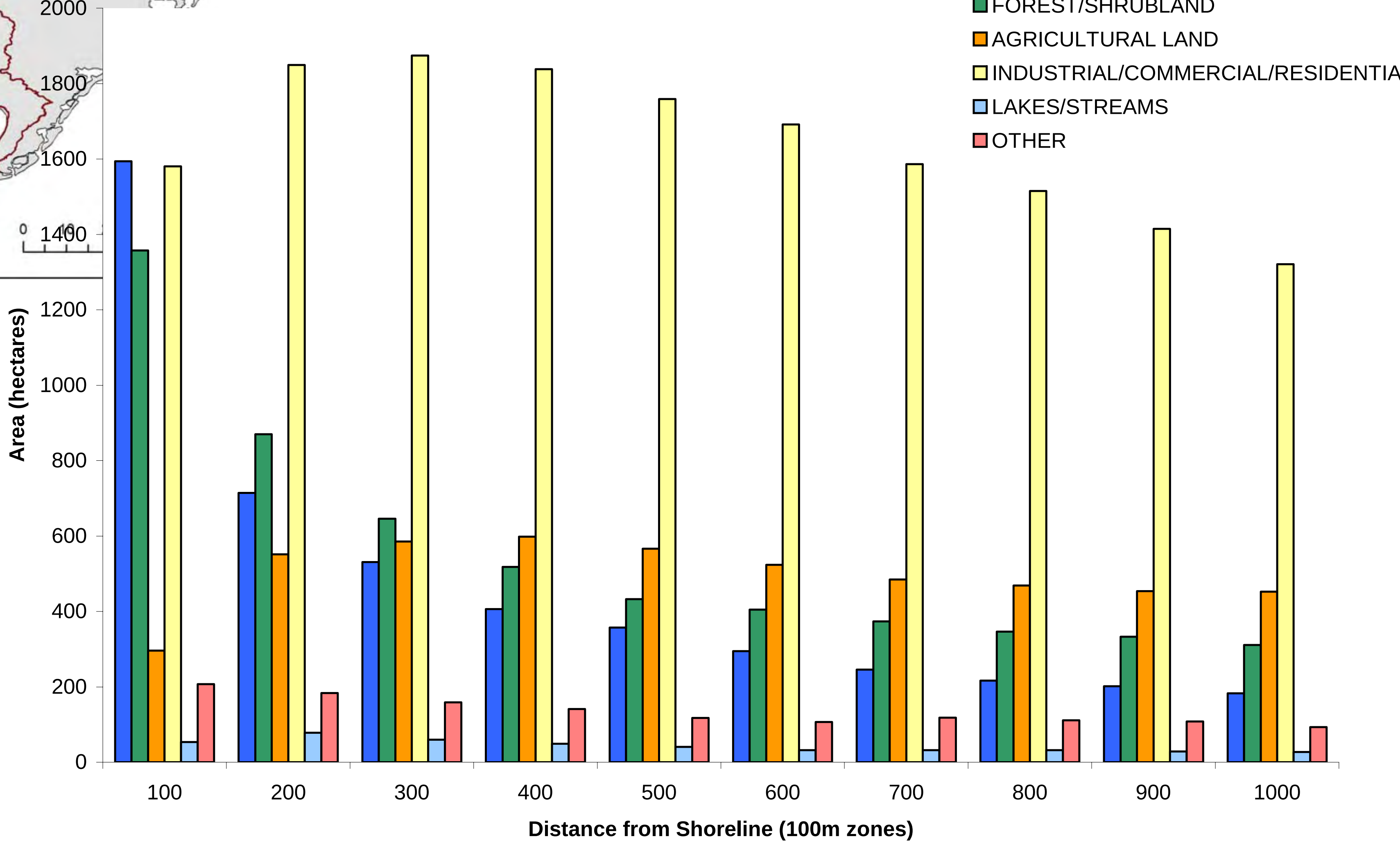
Land Use in Tidal Marsh Buffer Zone in the Upper Estuary of NJ (UE2)





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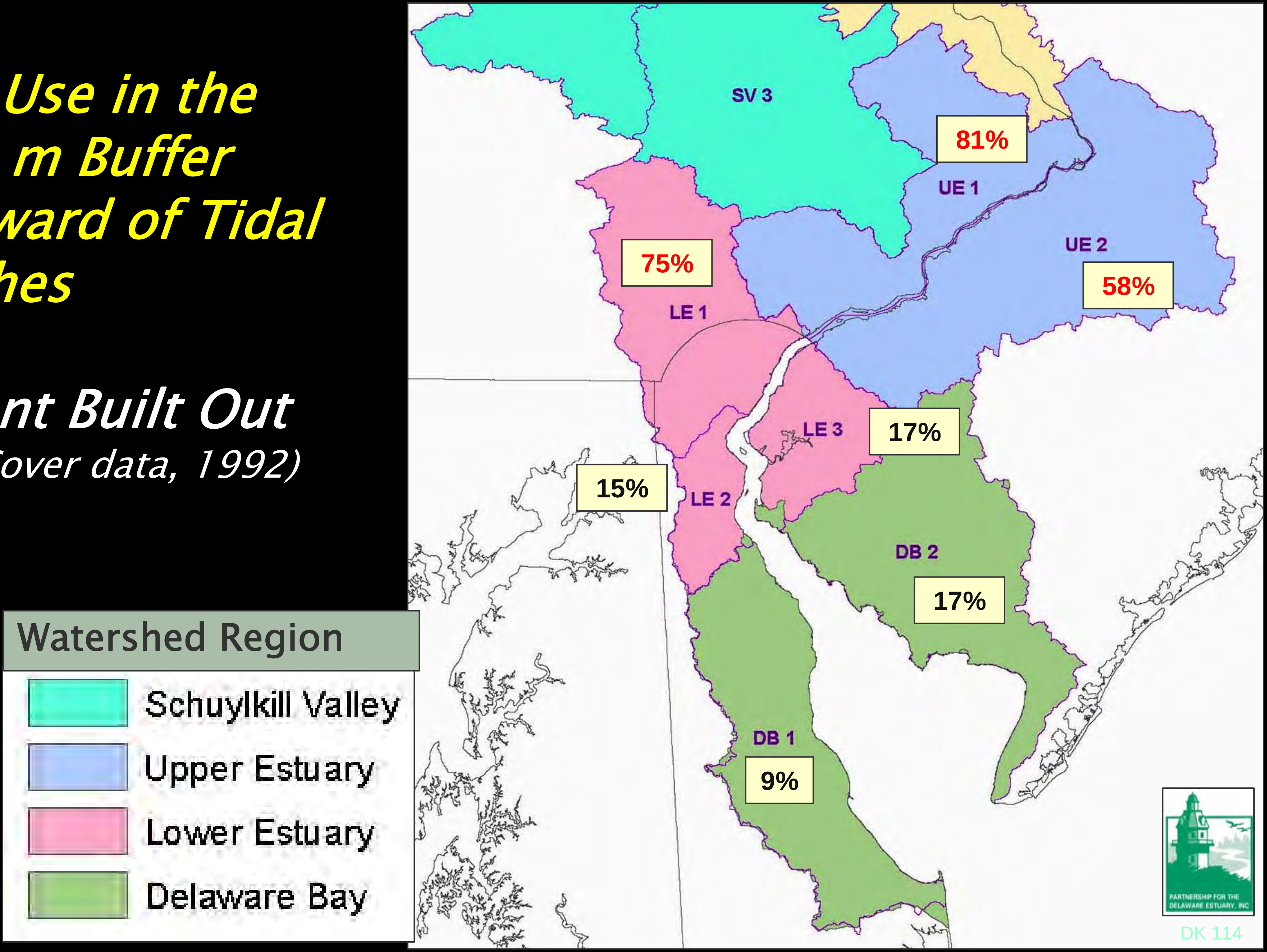
Land Use in the 1000 m Buffer Landward of Tidal Marshes

Percent Built Out

(Land Cover data, 1992)



Climate Adaptation Planning

Status

Tidal Wetland Sub-group
Velinsky & Kreeger

ID Vulnerabilities
- **Subgroup Formed**
- **Initiating Vulnerability Assessment**
- **Draft for Summer CAWG Meeting**

Ecological Valuation

Adaptation Options — **Late Fall**

Recommendations and Reporting — **Winter**

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Summary – What Can We Do?

1. Work to slow climate change

2. Develop an understanding of likely consequences
   disruption, disconnects, thresholds

3. Consider climate and other changes together
   synergisms

4. Accept that change is occurring (change happens)
   and restoration for past conditions may be unwise

5. Work together to devise the most opportune and
   effective strategies to ensure best possible
   natural resource health for tomorrow

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You Can Help!

DK

What natural resource vulnerabilities are you concerned about in the Delaware Estuary

What options or actions can you suggest for adaptation to climate change in the Delaware Estuary and its watershed?

dkreeger@DelawareEstuary.org

– End –

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