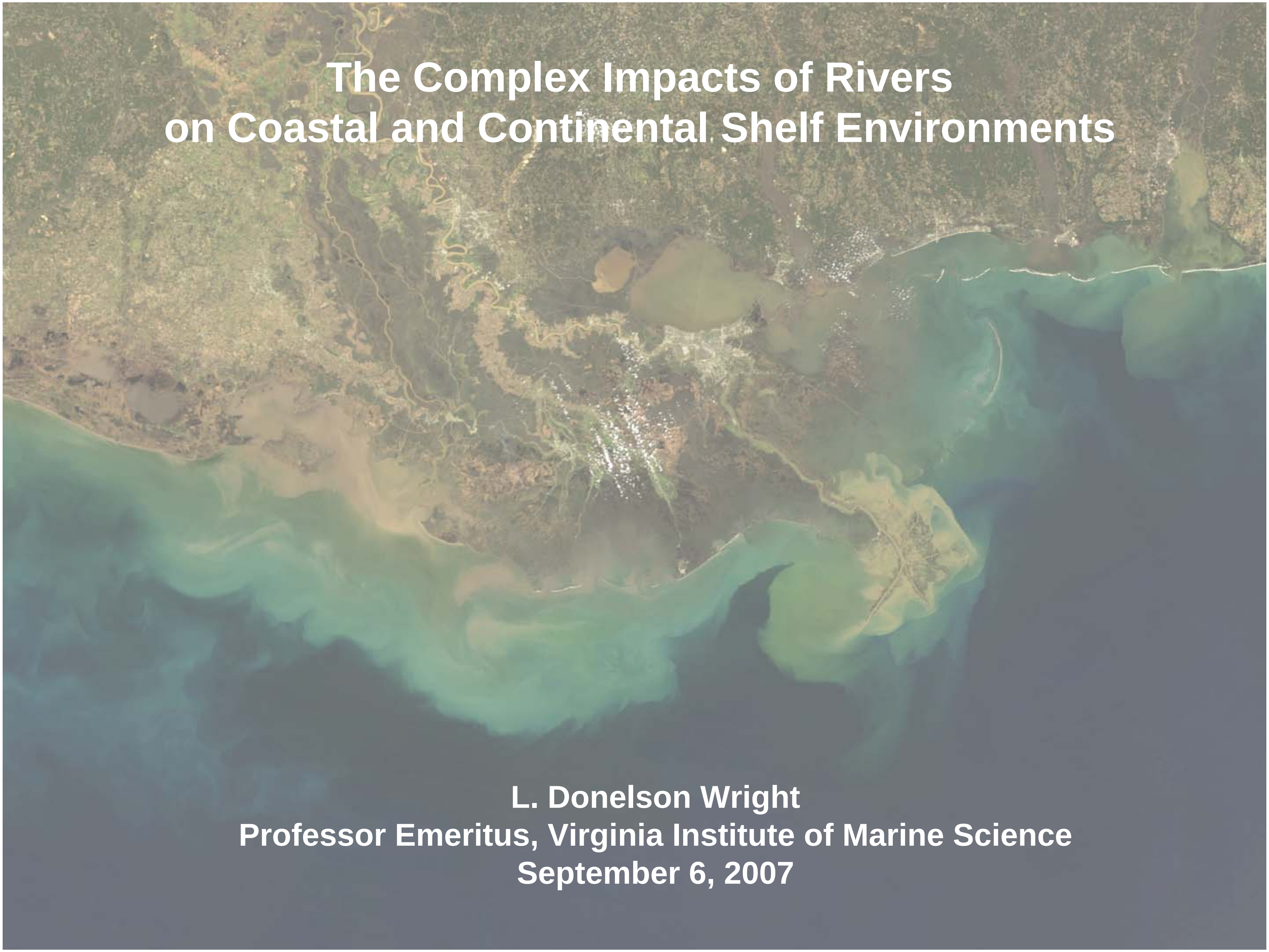
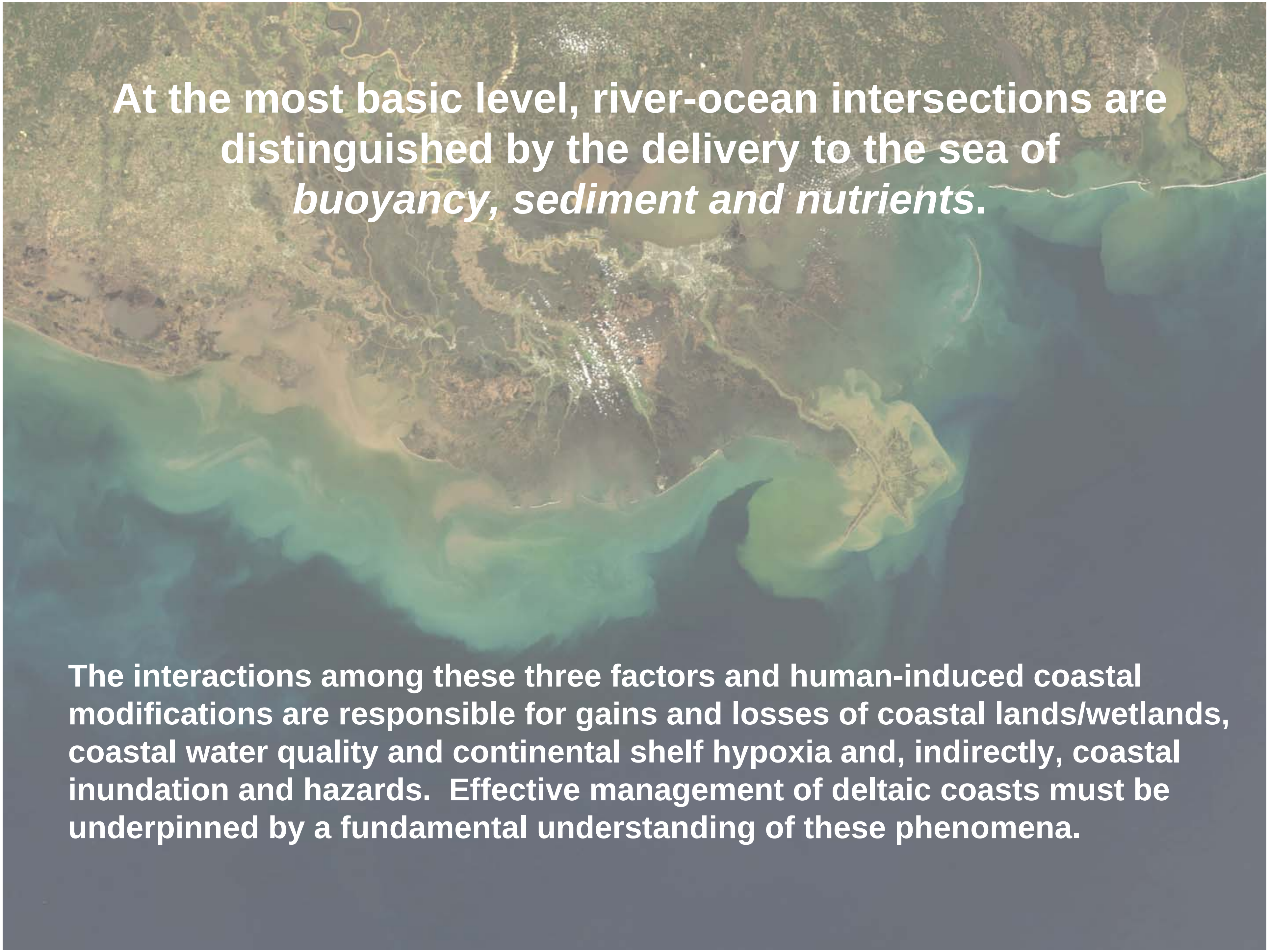


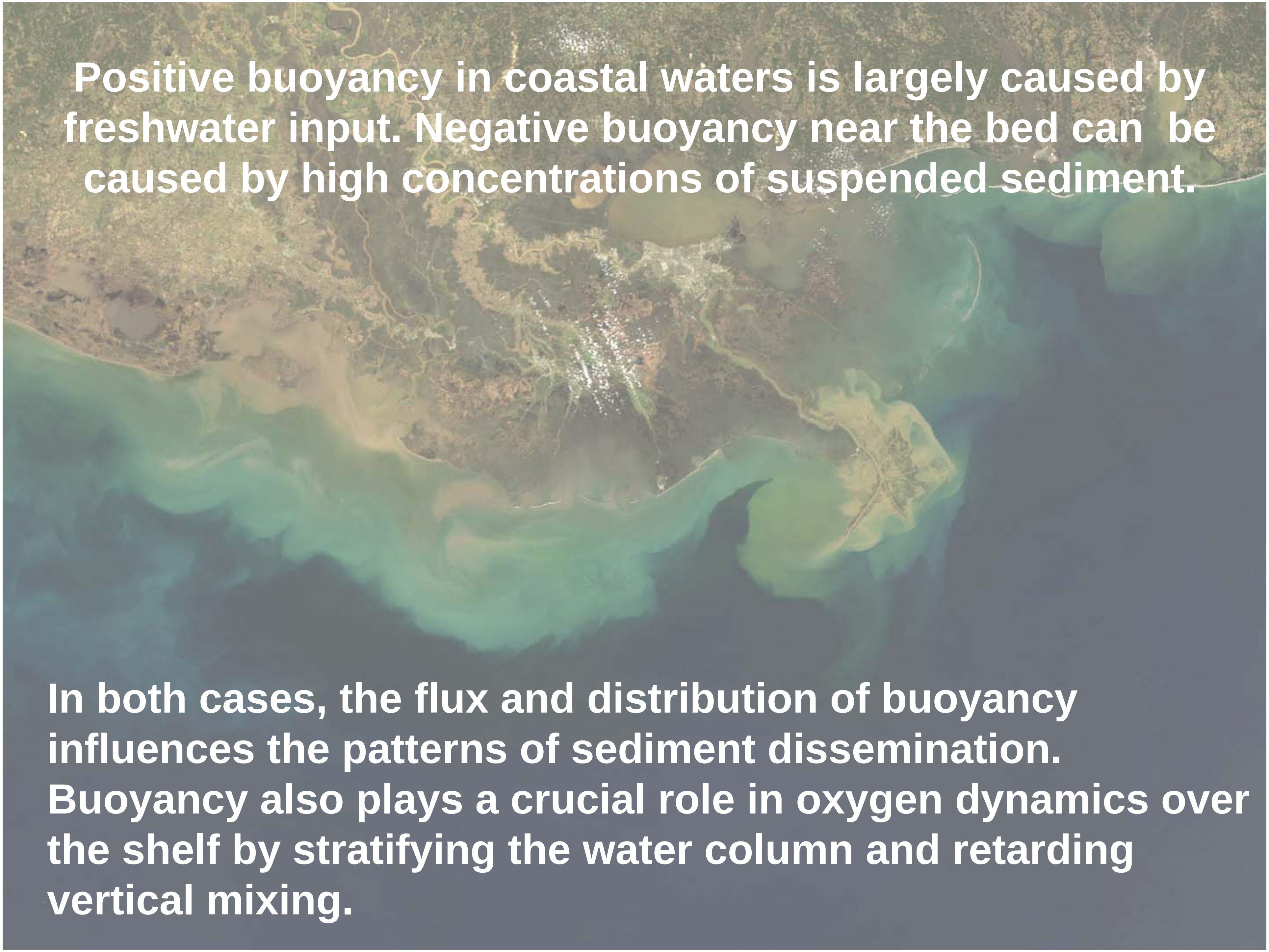
The Complex Impacts of Rivers on Coastal and Continental Shelf Environments

L. Donelson Wright
Professor Emeritus, Virginia Institute of Marine Science
September 6, 2007



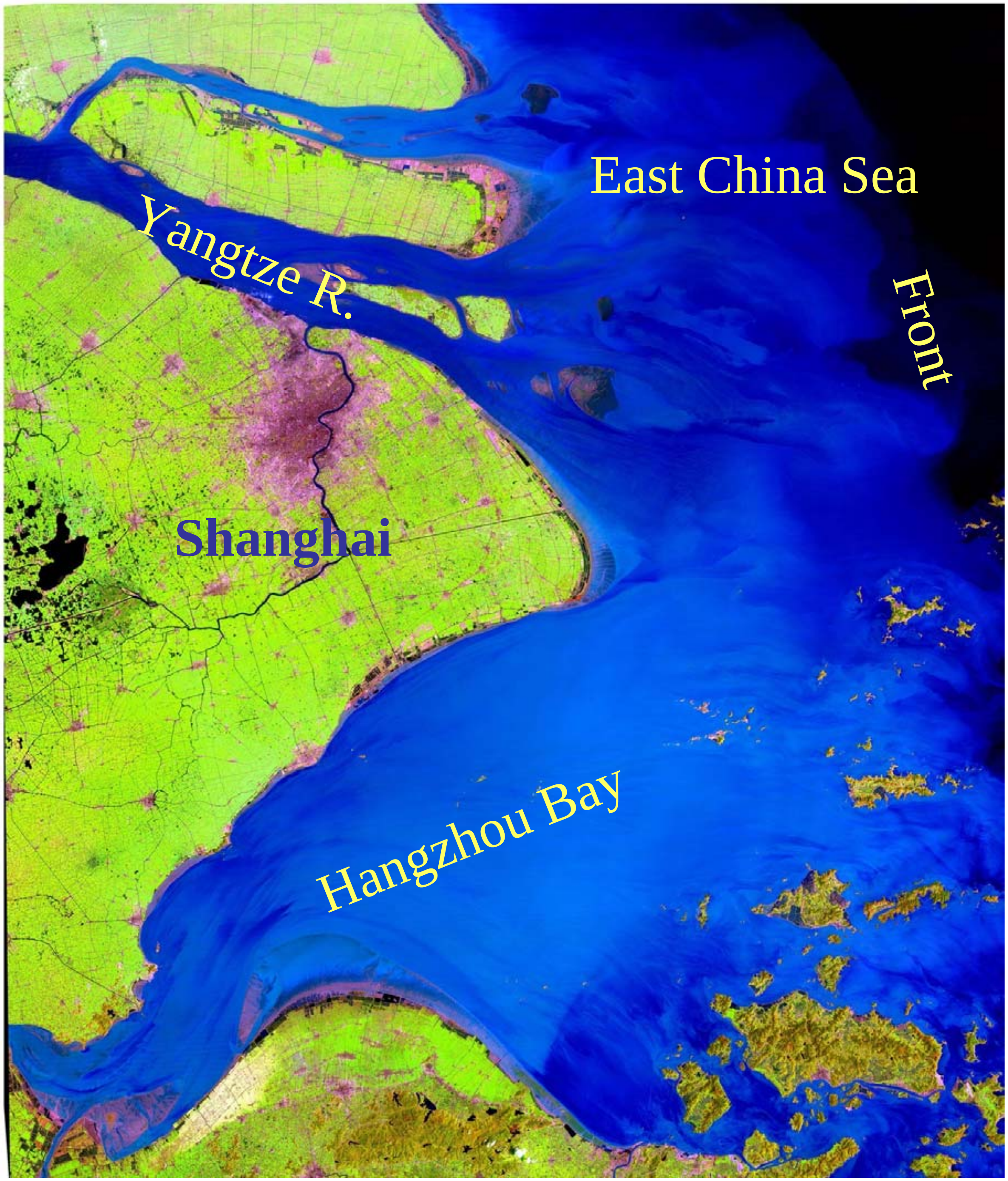
At the most basic level, river-ocean intersections are distinguished by the delivery to the sea of *buoyancy, sediment and nutrients*.

The interactions among these three factors and human-induced coastal modifications are responsible for gains and losses of coastal lands/wetlands, coastal water quality and continental shelf hypoxia and, indirectly, coastal inundation and hazards. Effective management of deltaic coasts must be underpinned by a fundamental understanding of these phenomena.



Positive buoyancy in coastal waters is largely caused by freshwater input. Negative buoyancy near the bed can be caused by high concentrations of suspended sediment.

In both cases, the flux and distribution of buoyancy influences the patterns of sediment dissemination. Buoyancy also plays a crucial role in oxygen dynamics over the shelf by stratifying the water column and retarding vertical mixing.



Buoyancy, b, per unit volume of a parcel of water is

$$b = -g\frac{(\rho - \rho_o)}{\rho_o}$$

Reduced gravity

g´= -b

ρ = density of parcel

ρ_o = ambient density

$$g' = g\frac{(\rho - \rho_o)}{\rho_o}$$

Gradient Richardson number, Ri

$$\text{Ri} = \frac{\text{stability from buoyancy}}{\text{instability from shear}}$$

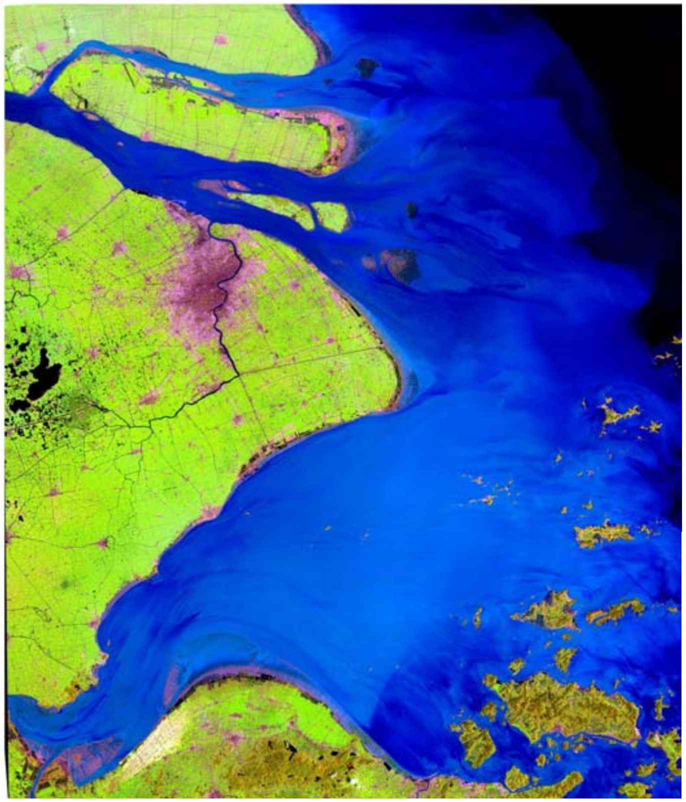
Or, scaled

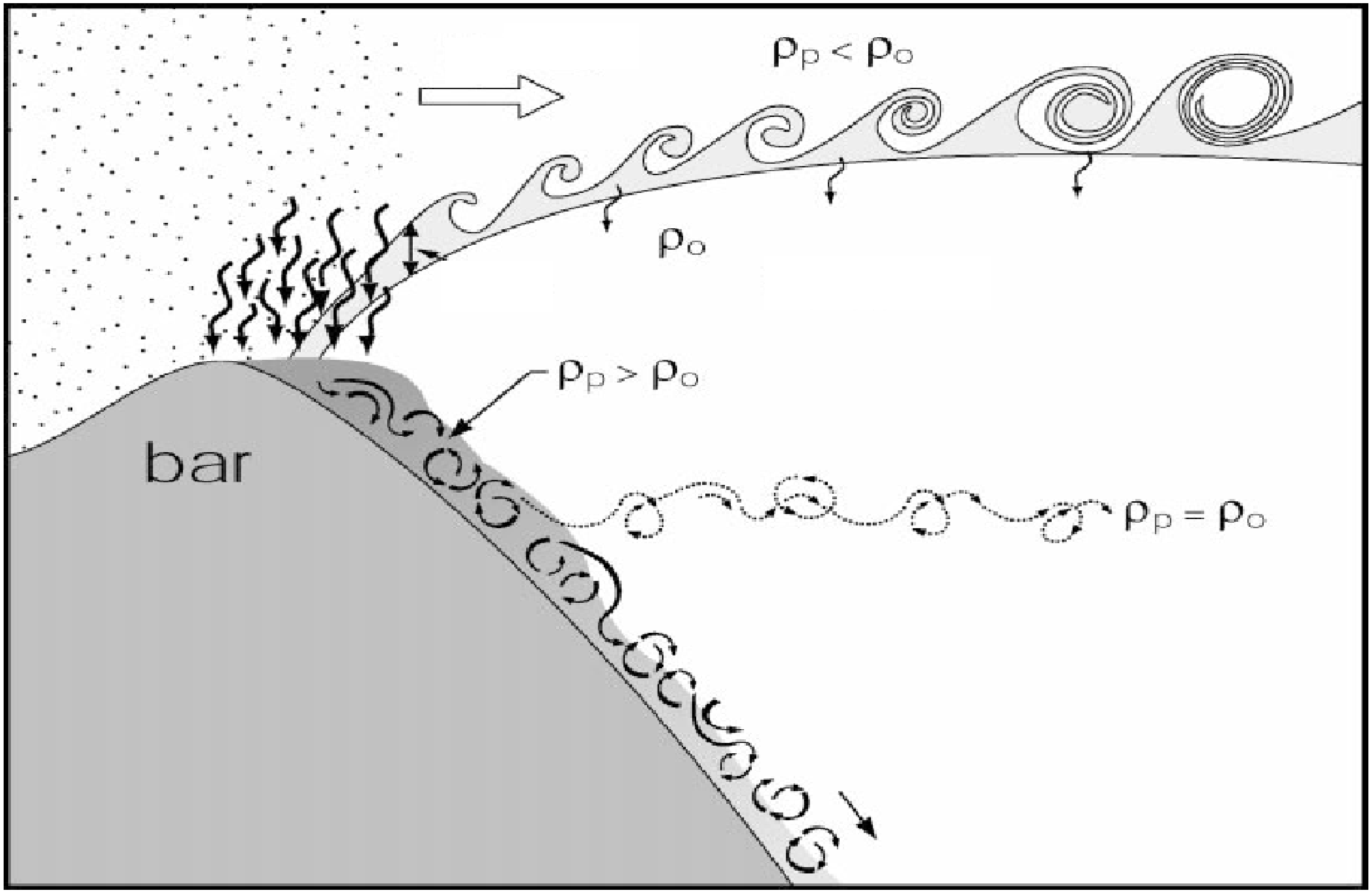
$$\text{Ri} = \frac{-\frac{g}{\rho}\frac{d\rho}{dz}}{\left({}^{du}\!/\!{}_{dz}\right)^2} \qquad \text{Ri} \approx \frac{-\frac{g}{\rho}\frac{\Delta\rho}{H}}{\left({}^{U}\!/\!{}_{H}\right)^2} = \frac{\Delta\rho}{\rho}\frac{gH}{U^2}$$

ρ= water density, H= water depth

Buoyancy and Sediment Dispersal

Muddy rivers deliver extensive amounts of land-building sediment and light-attenuating turbidity to the coastal ocean. The dispersal of this material is influenced by buoyancy and its interaction with coastal circulation.

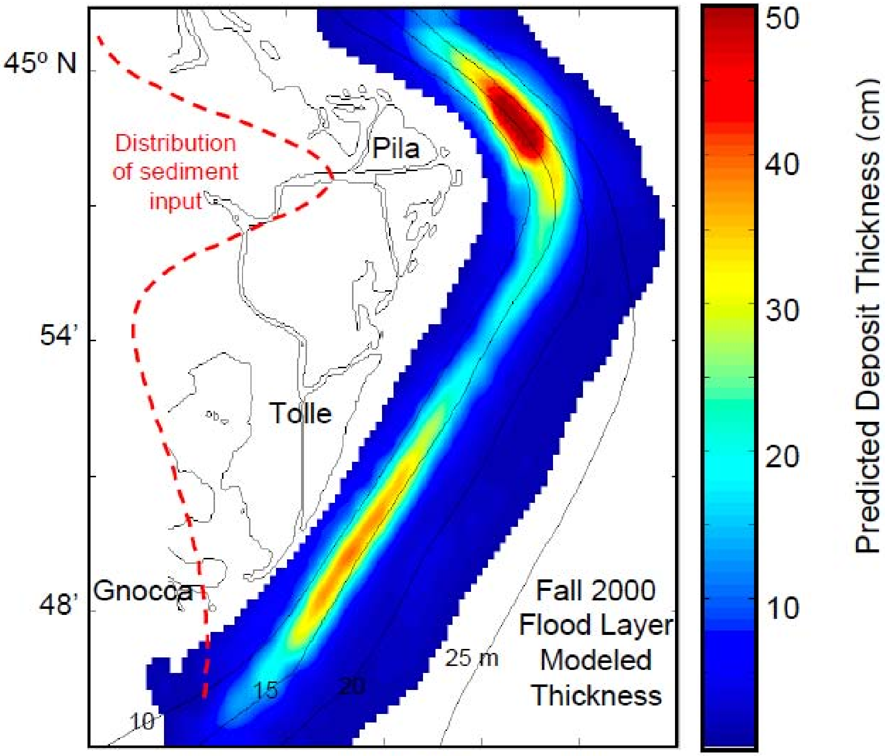




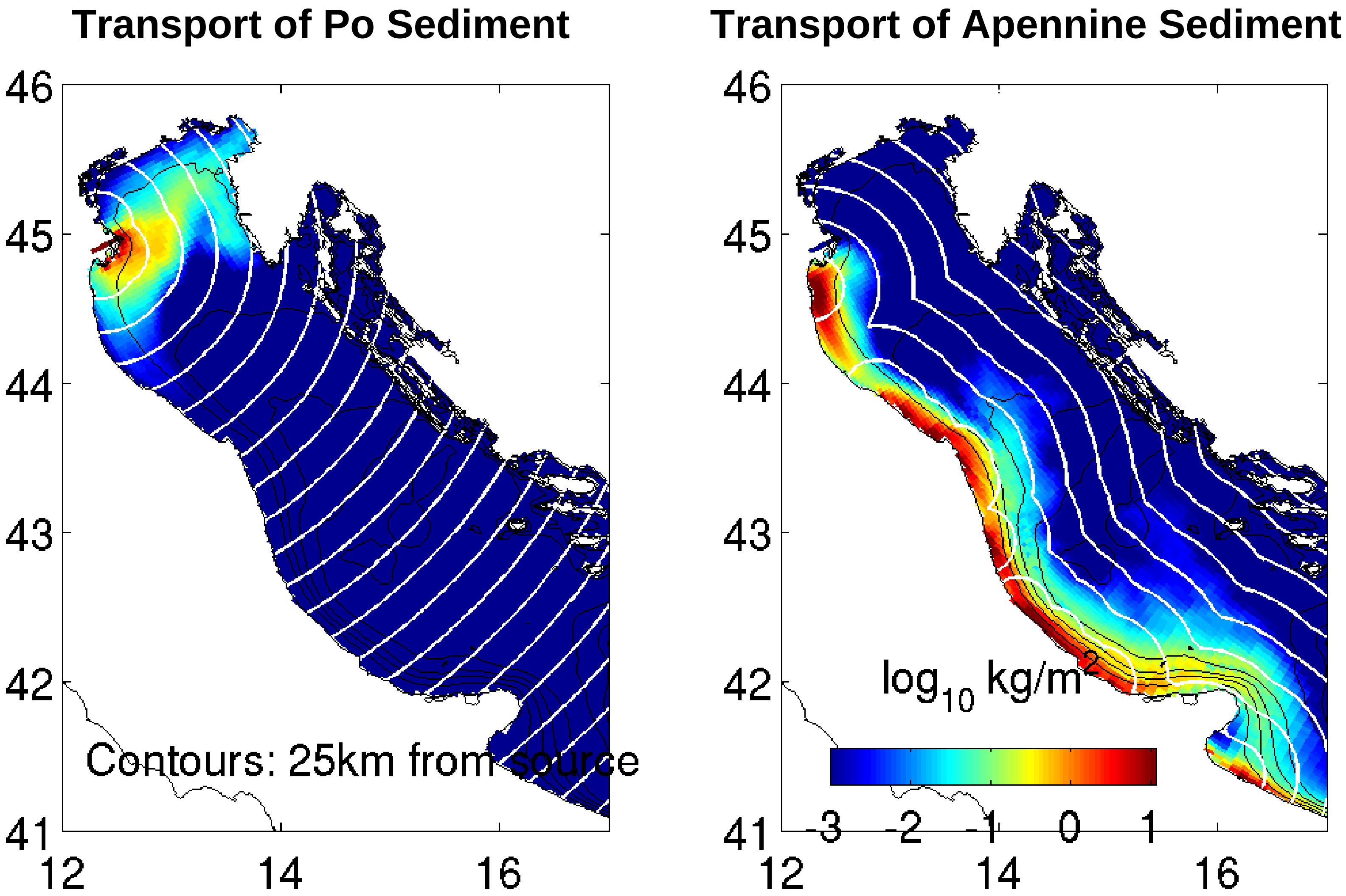
Schematic representation of plumes split into hypopycnal ($\rho_r < \rho_o$) and hyperpycnal ($\rho_r > \rho_o$) at the head of the Sepik River canyon. From Kineke et al. (2000).

Po River Delta

Sediments distributed along shelf within buoyant plumes



(Friedrichs & Scully. in press)

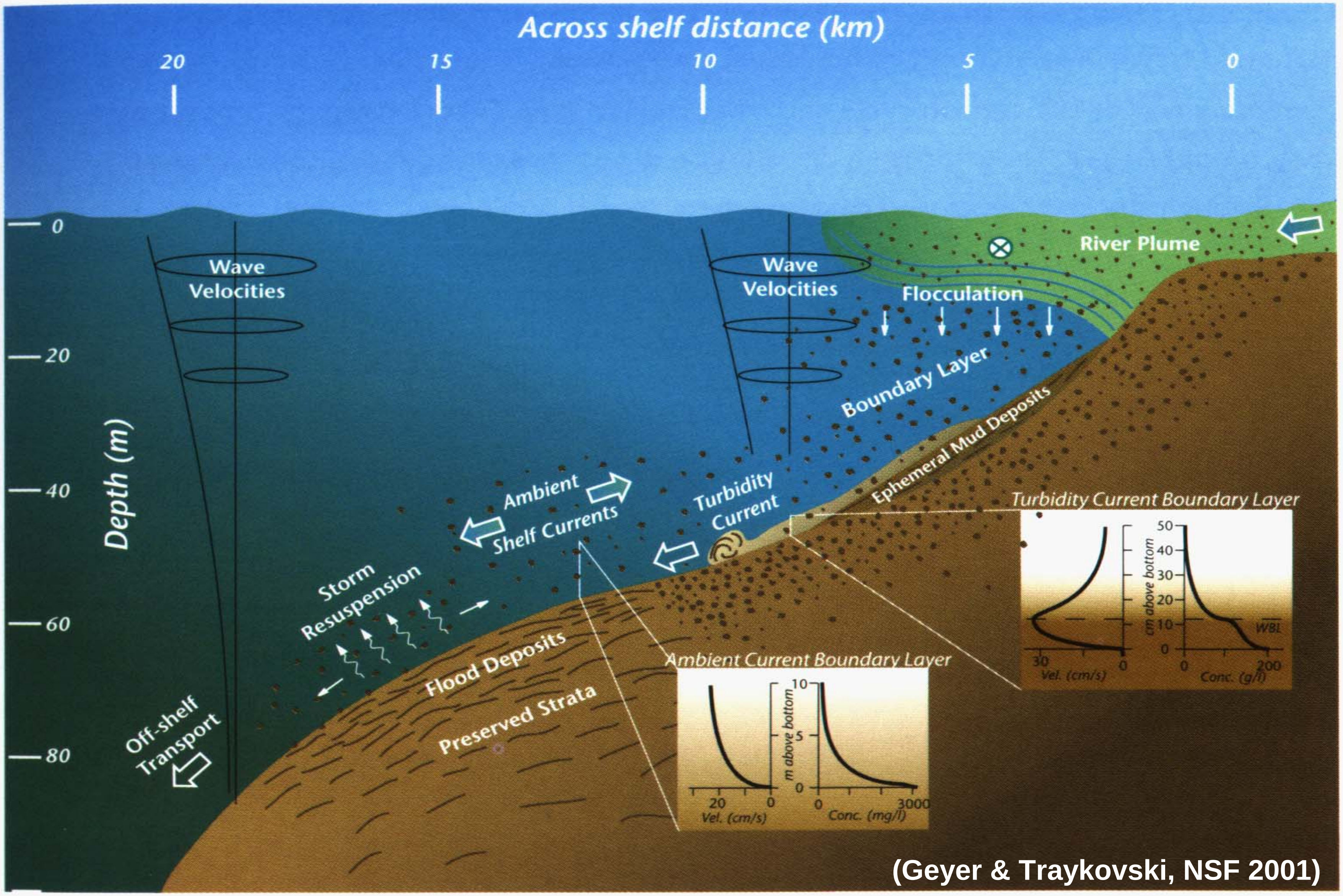


Harris, Sherwood, Signell, Bever, and Warner, submitted to *Jour. Geophys. Res.*, August 2006

Gravity-driven Across-shelf Sediment Flux

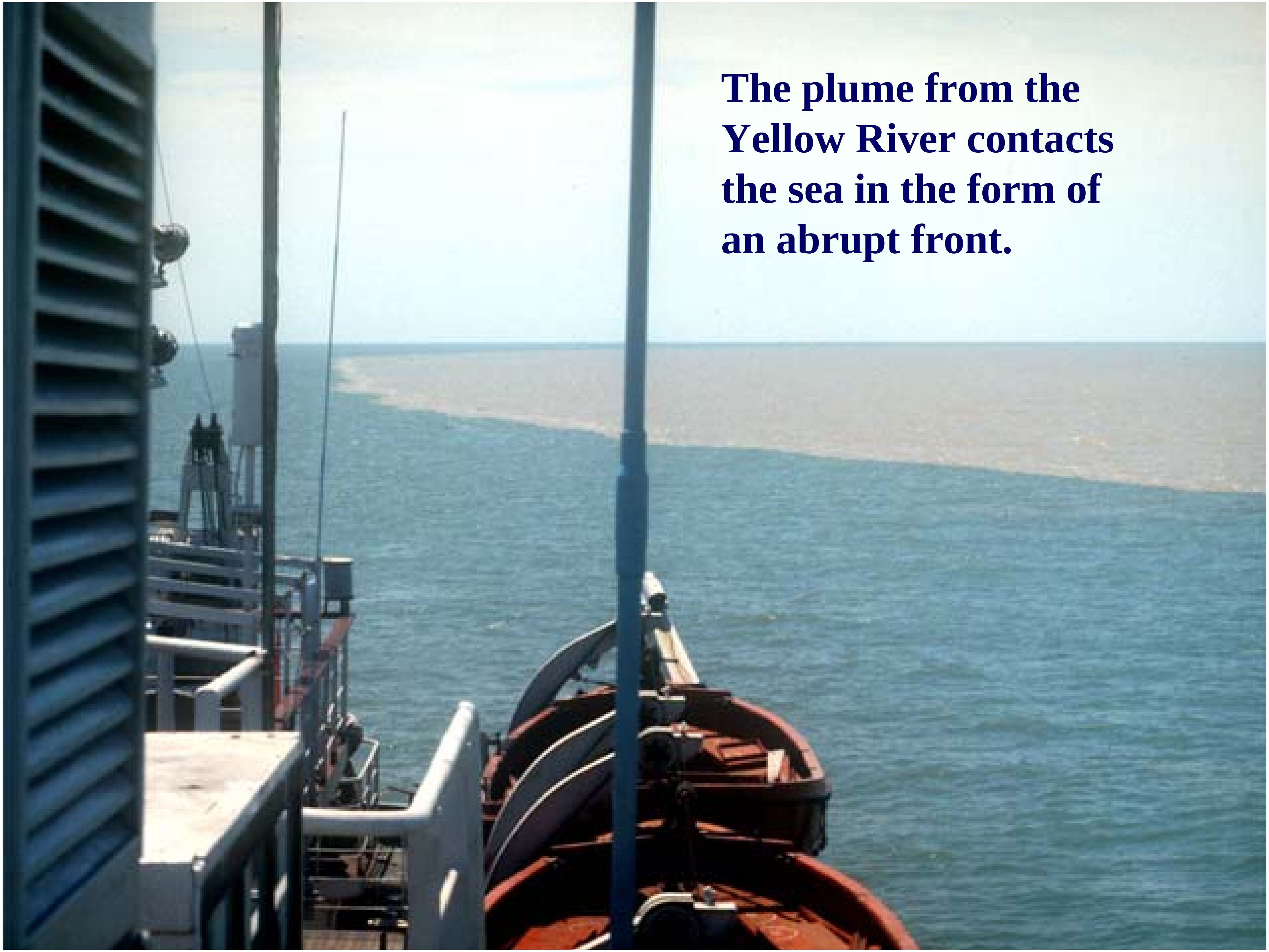
Recent field observations from several shelf environments show that gravity-driven transport within wave and current supported hyperpycnal layers is an important mode of fine sediment transport across continental shelves.

Some references:
Ogsten *et al. 2000 Cont. Shelf Res*., 20:2141-2162;
Scully *et al. 2003 Jour.Geophys. Res., 108(C4), 3120;*
Traykovski *et al. 2000 Cont. Shelf Res., 20:2113-2140;*
Wright *et al. 2001, Marine Geology* 175: 25-45;
Wright et al., 2002 *Cont. Shelf Res*., 175: 25-45
Wright and Friedrichs, 2006 *Cont. Shelf Res.*

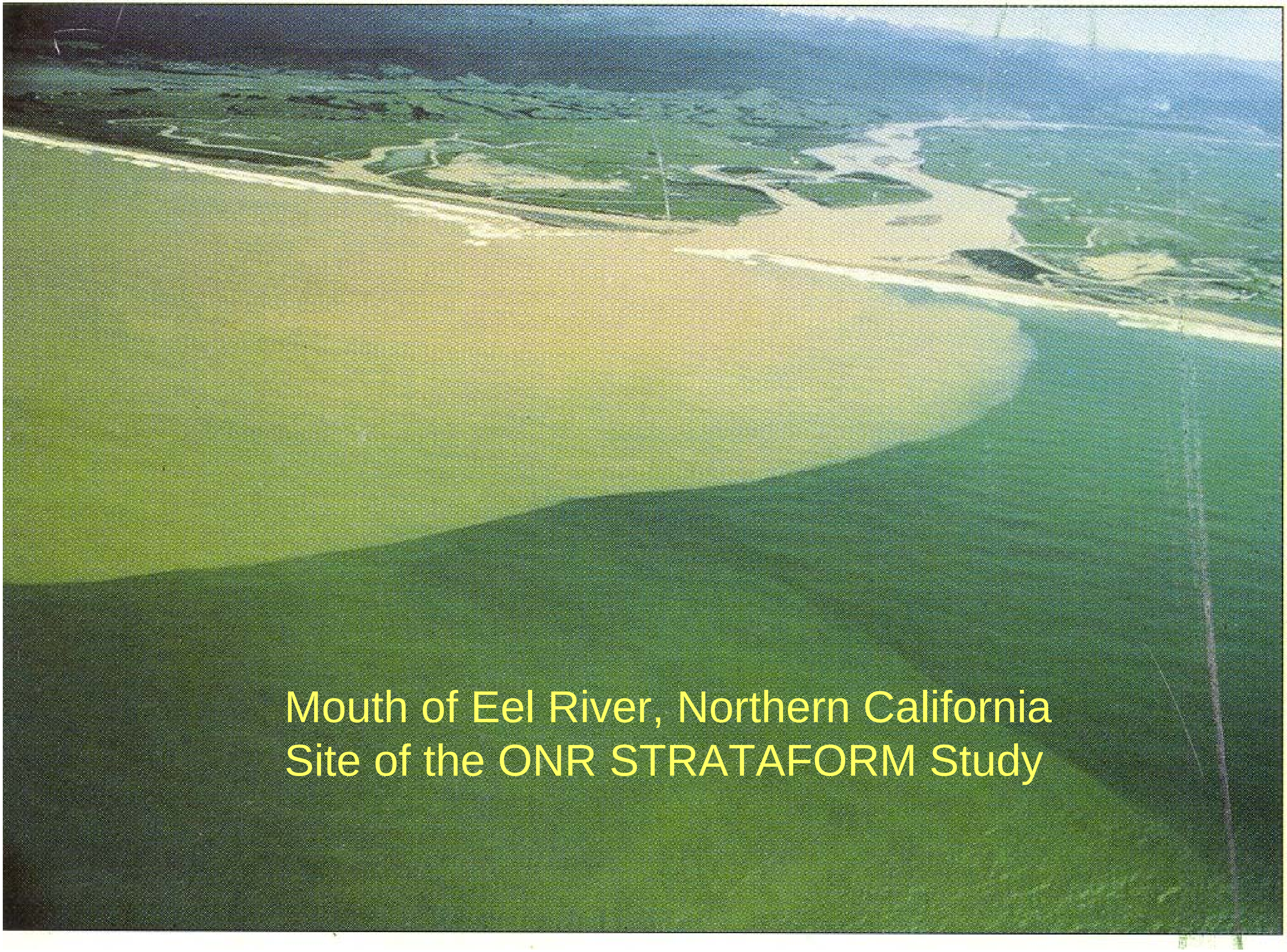


(Geyer & Traykovski, NSF 2001)

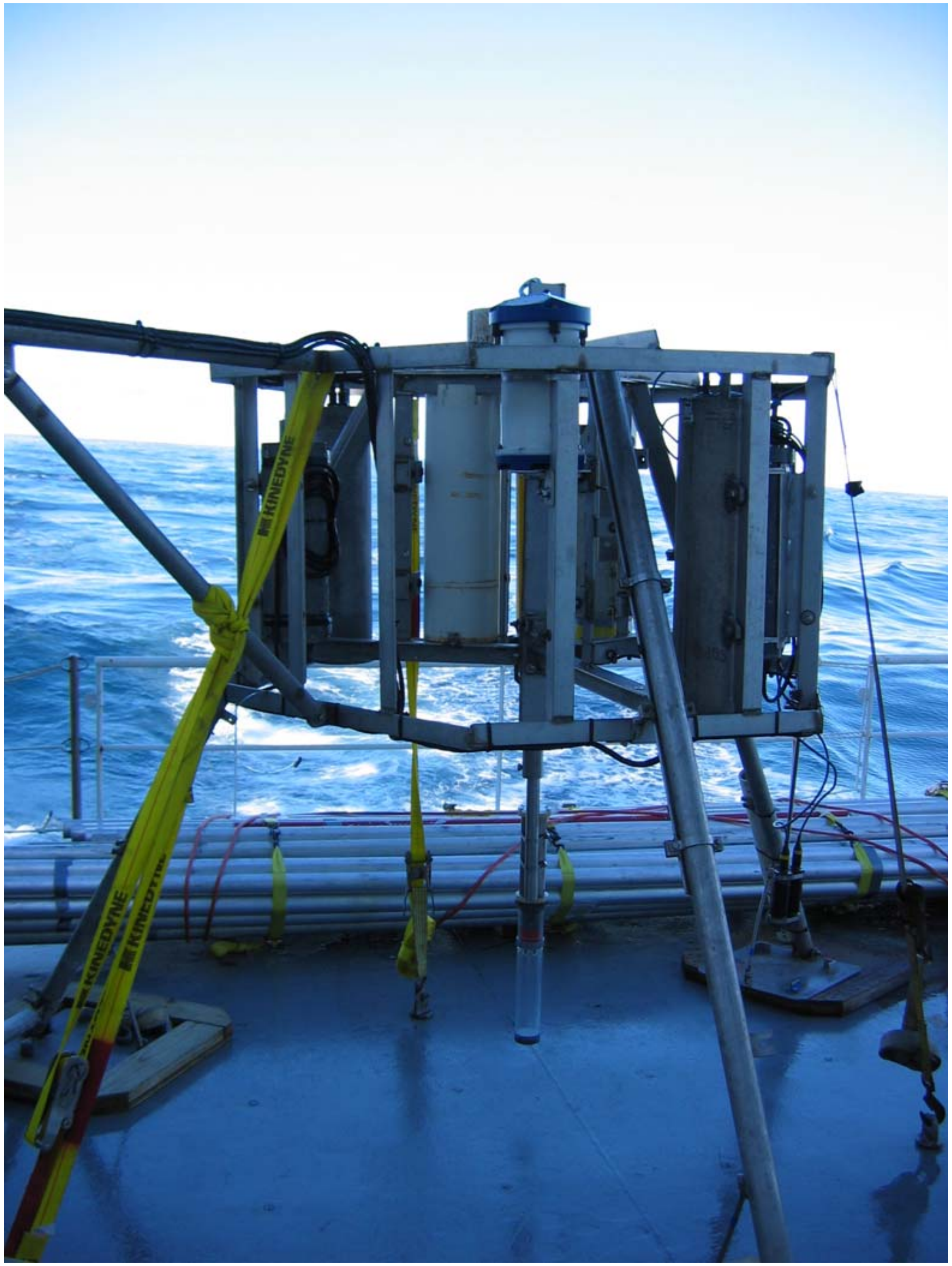
Huanghe Delta
Gulf of Bohai



The plume from the Yellow River contacts the sea in the form of an abrupt front.



Mouth of Eel River, Northern California
Site of the ONR STRATAFORM Study

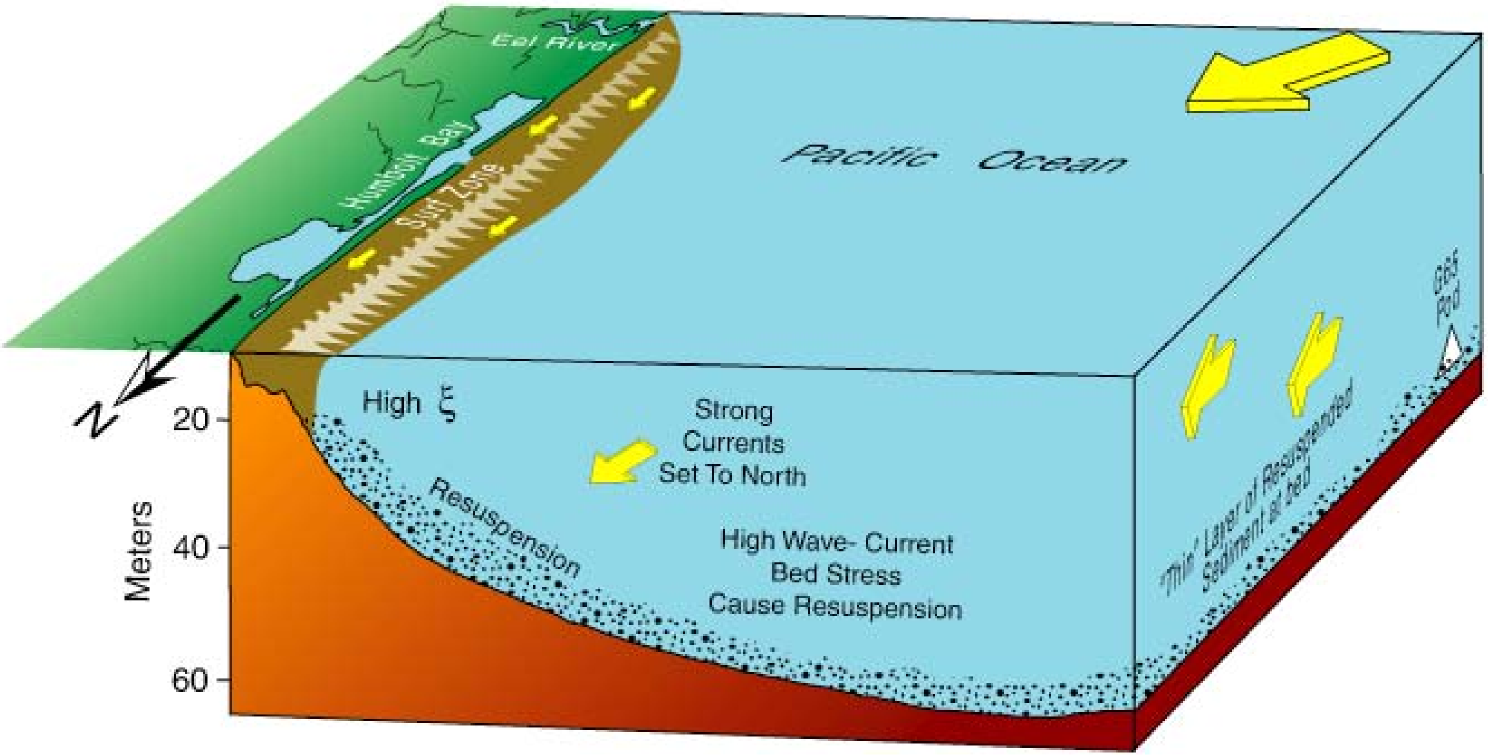


Acoustic Doppler velocimeters

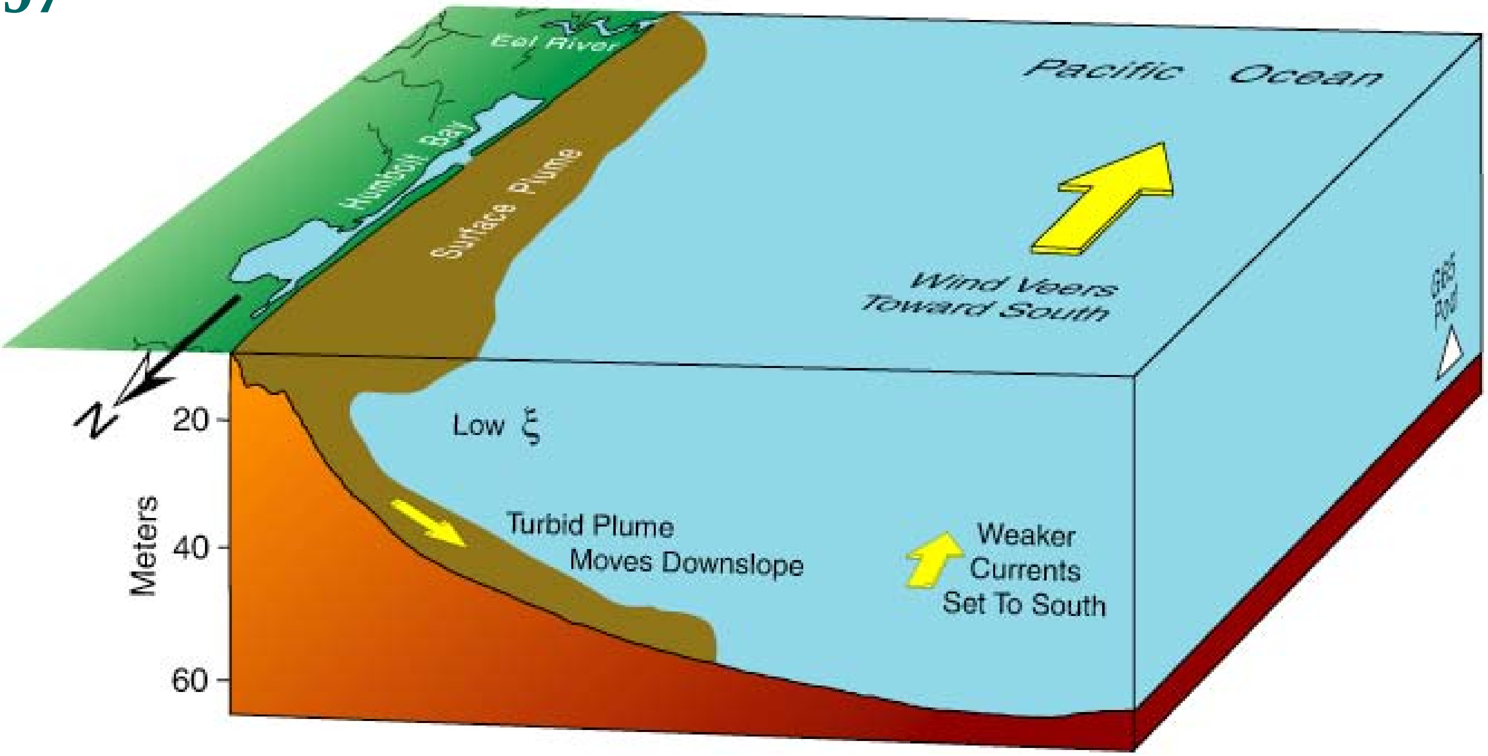
Eel River Shelf, Jan. 1997

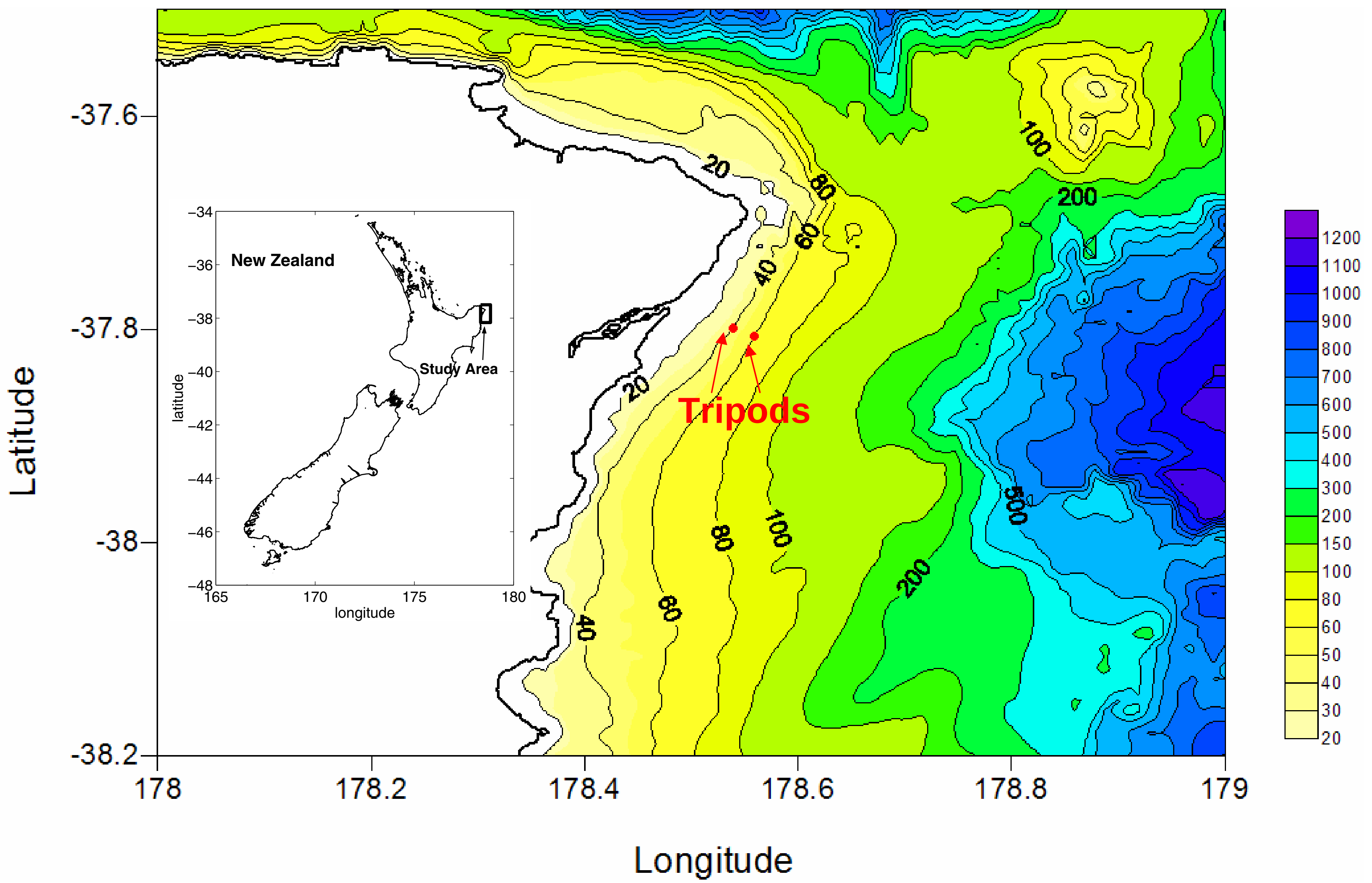
Stage I

Plume trapped against coast



Eel River Shelf, Jan. 1997





Latitude
-37.6
-37.8
-38
-38.2
178
178.2
178.4
178.6
178.8
179
Longitude
20
40
60
80
100
200
500
Tripods
New Zealand
Study Area
latitude
longitude
−34
−36
−38
−40
−42
−44
−46
−48
165
170
175
180
1200
1100
1000
900
800
700
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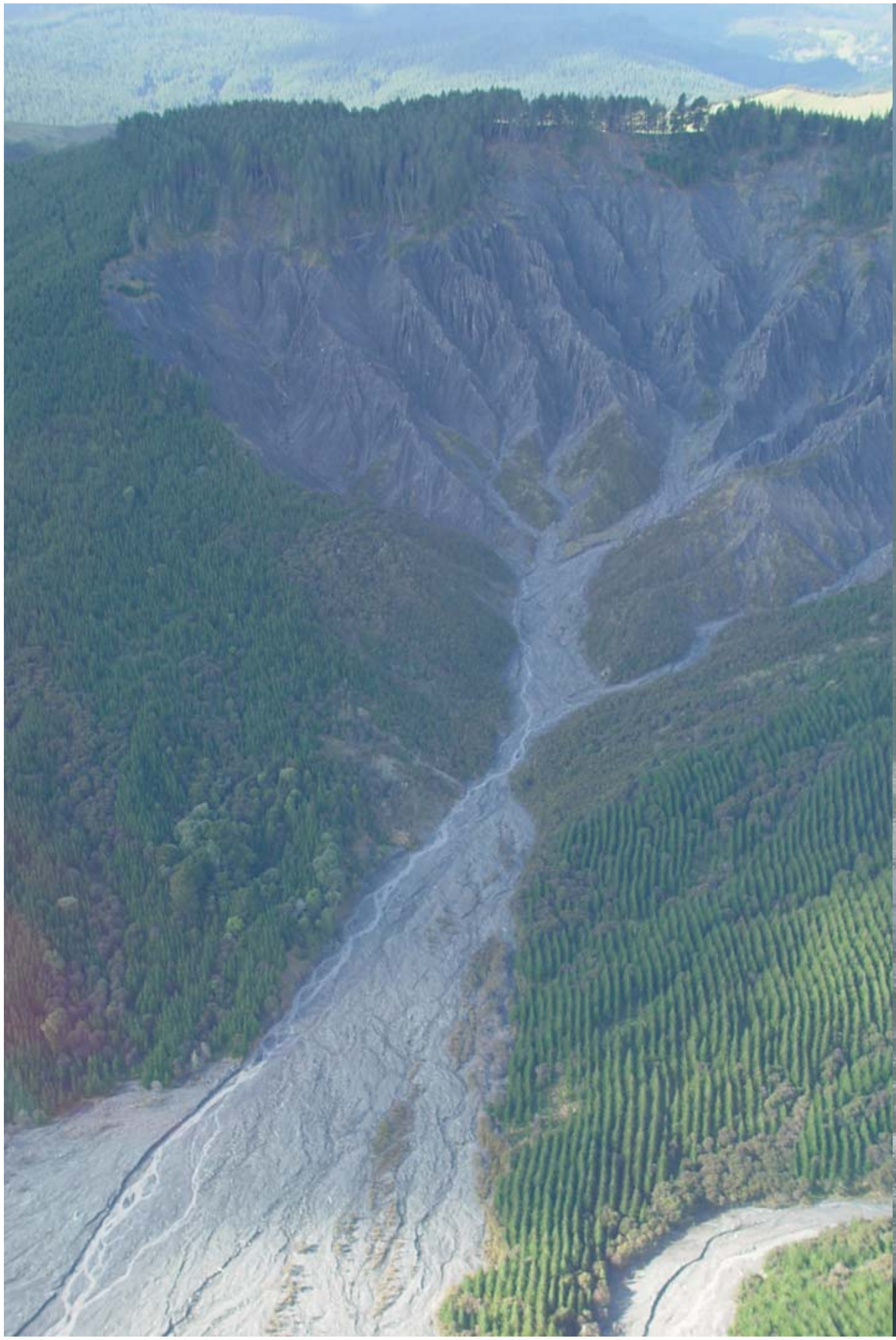
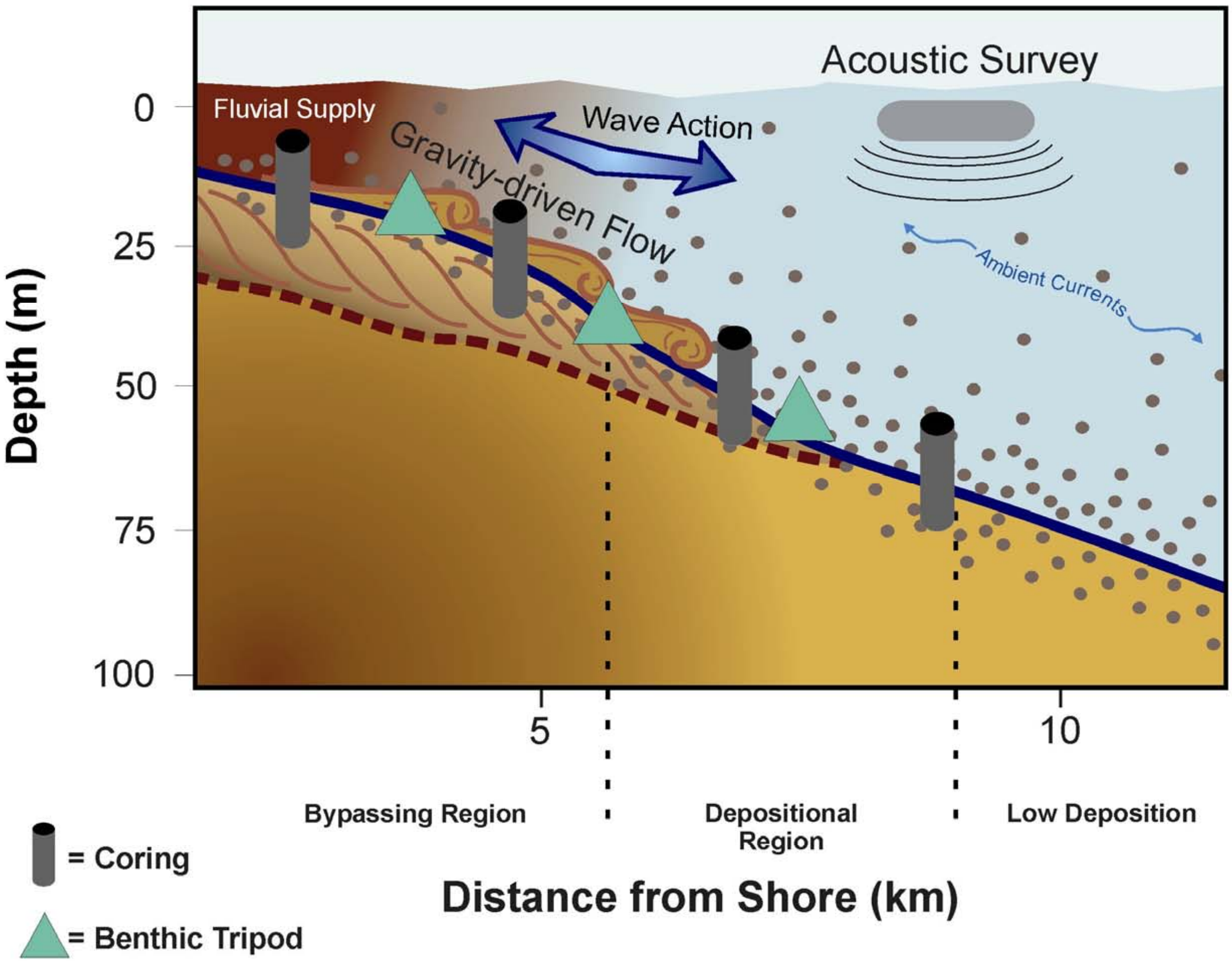
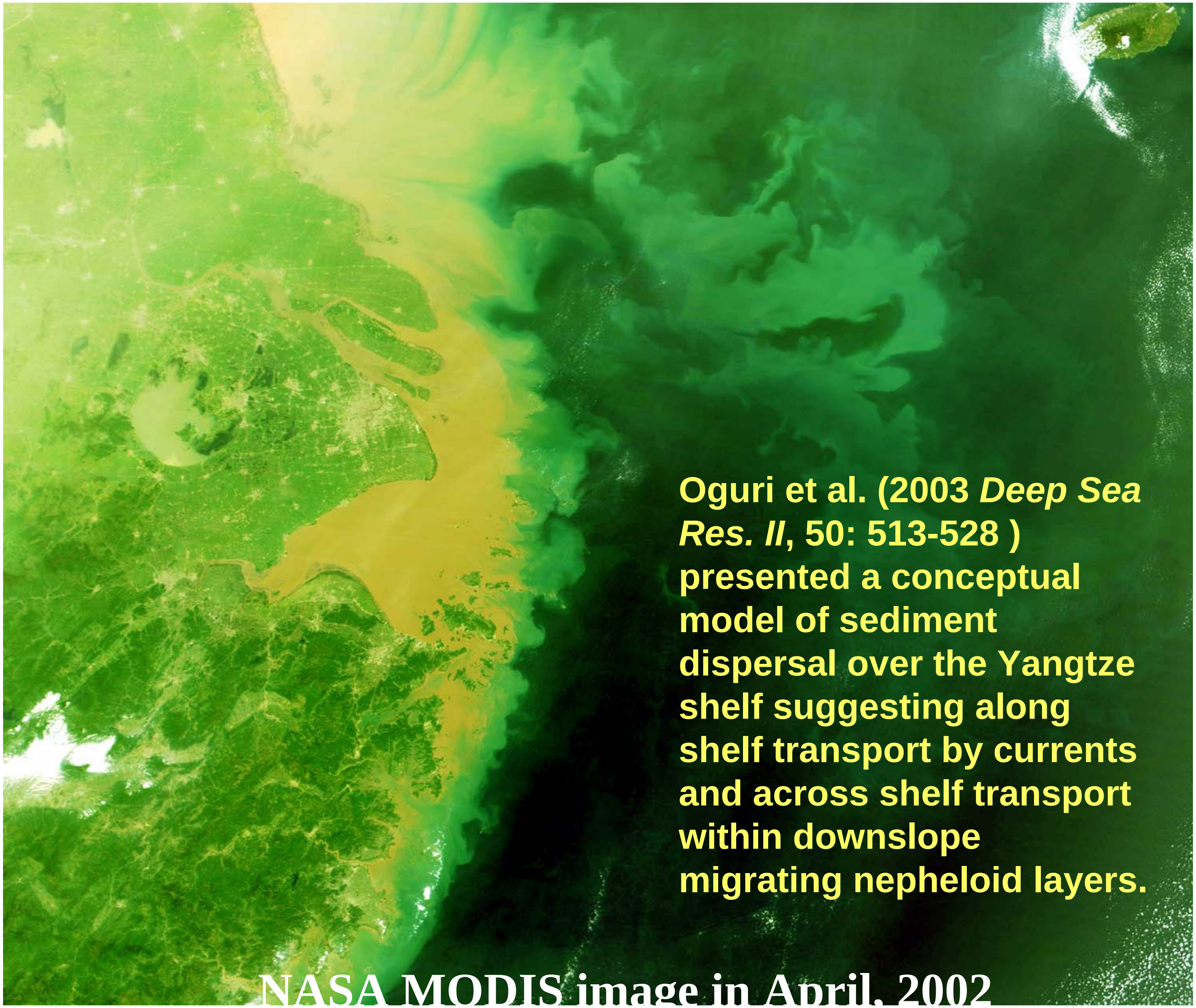
100
80
60
50
40
30
20



Shelf off the mouth of the Waiapu River of New Zealand’s North Island

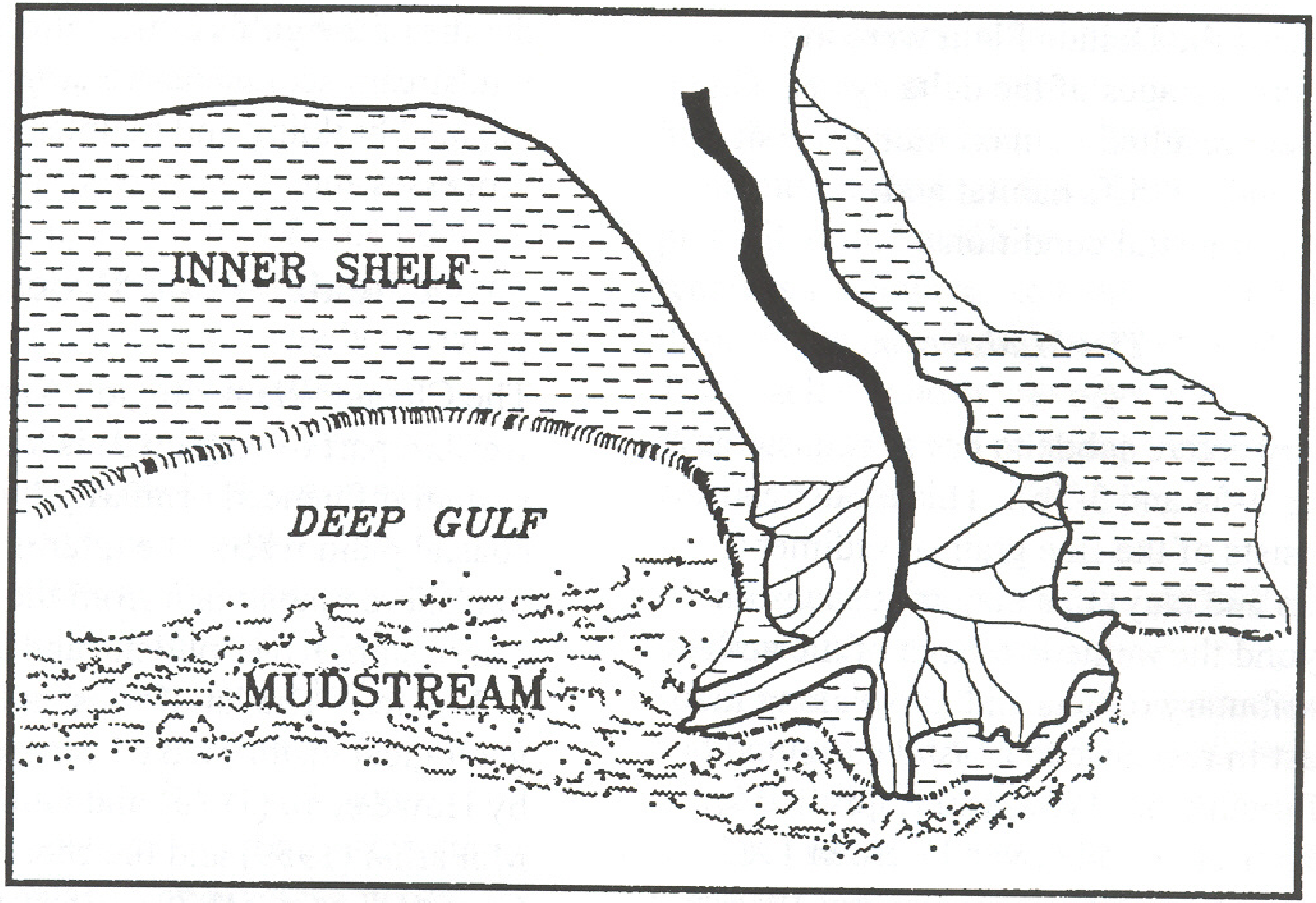
The sediment-charged river effluent of the Waiapu River, New Zealand is often deflected along shore and trapped within the surf zone by obliquely-incident waves and wind-driven currents.


Acoustic Survey
Fluvial Supply
Wave Action
Gravity-driven Flow
Ambient Currents
Depth (m)
0
25
50
75
100
5
10
Bypassing Region
Depositional Region
Low Deposition
Distance from Shore (km)
= Coring
= Benthic Tripod



Oguri et al. (2003 *Deep Sea Res. II*, 50: 513-528) presented a conceptual model of sediment dispersal over the Yangtze shelf suggesting along shelf transport by currents and across shelf transport within downslope migrating nepheloid layers.

NASA MODIS image in April, 2002


INNER SHELF
DEEP GULF
MUDSTREAM

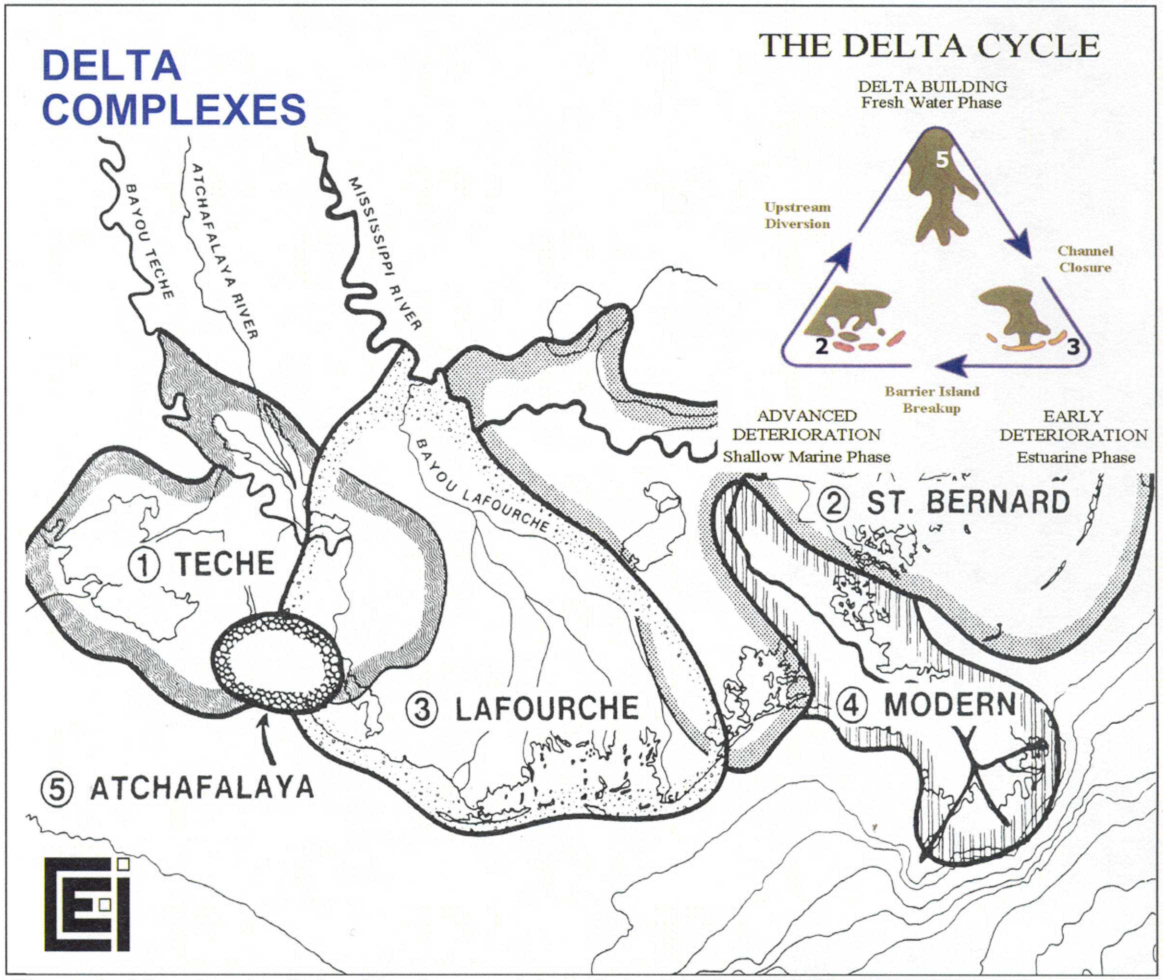


Figure 4. Map showing Delta Complexes or lobes. Delta lobes evolve through a systematic sequence of change called the delta cycle. The number on each lobe corresponds to stages of the cycles as shown in the inserted diagram.

BUOYANCY + NUTRIENTS+ MIXING: OXYGEN DYNAMICS

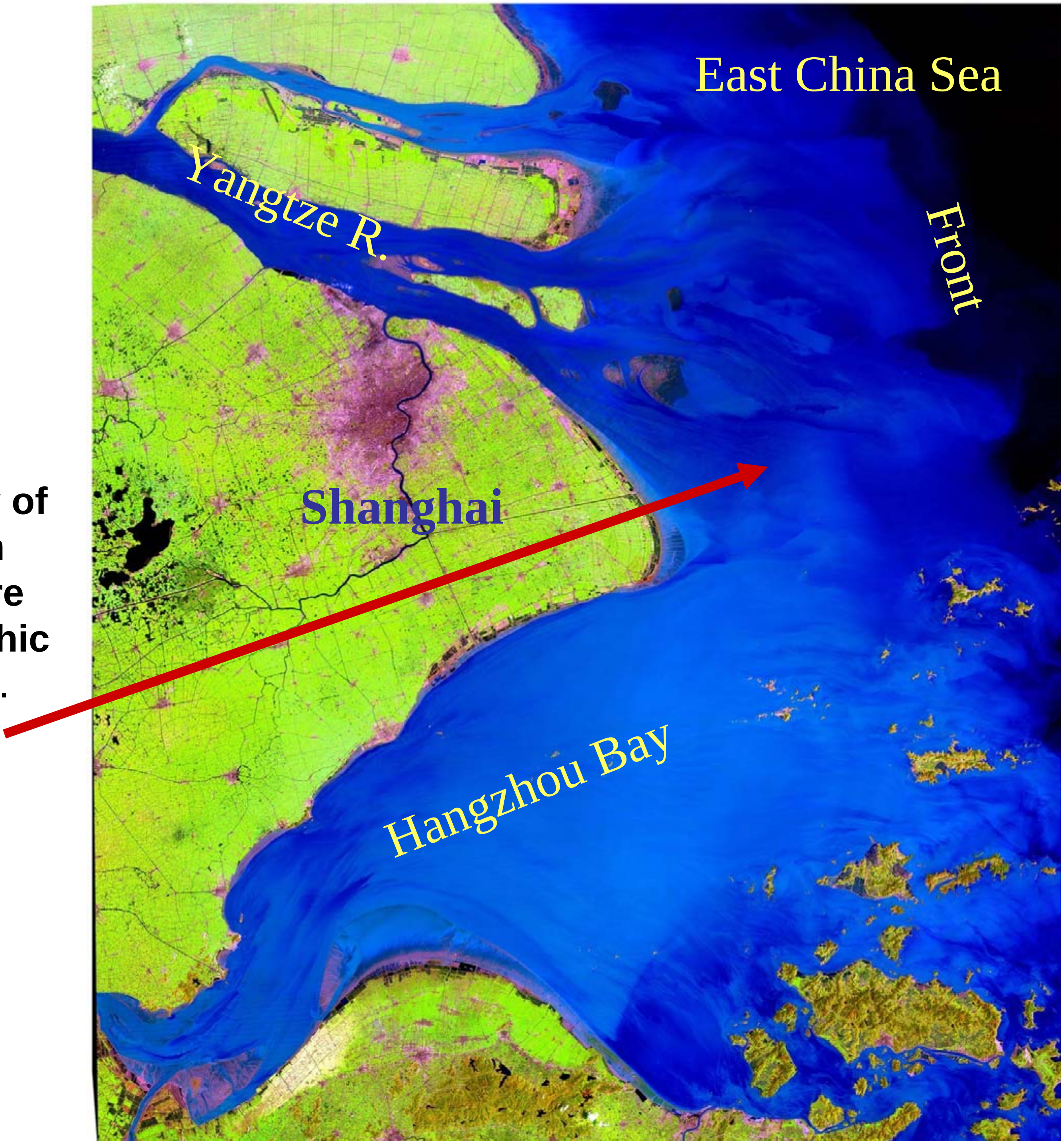
Positive buoyancy in coastal waters is largely caused by freshwater input. Negative buoyancy near the bed can be caused by high concentrations of suspended sediment. In both cases, resulting density stratification retards vertical mixing while velocity shear causes it.

The Changjiang (Yangtze) Estuary East China Sea

Rhoads and colleagues developed a conceptual model of biological processes on the continental shelf of the East China Sea related to the effluent and sediment delivery of a large river system.

The Changjiang (Yangtze) Estuary East China Sea

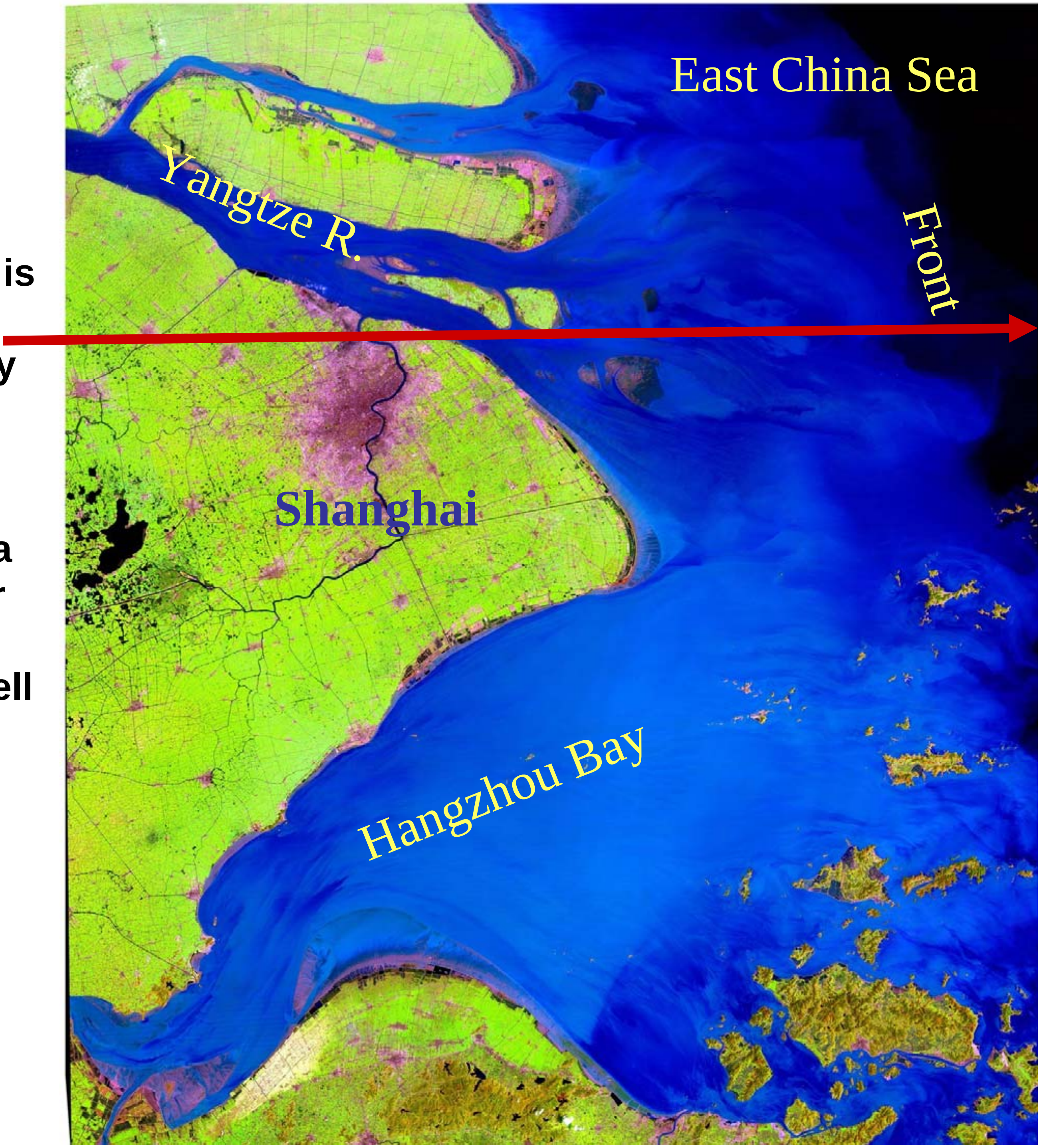
Inshore regions are characterized by high inputs of suspended sediments and nutrients. Primary production is limited by the availability of light. High sedimentation (erosion and transport are likely as well) limits benthic community development.

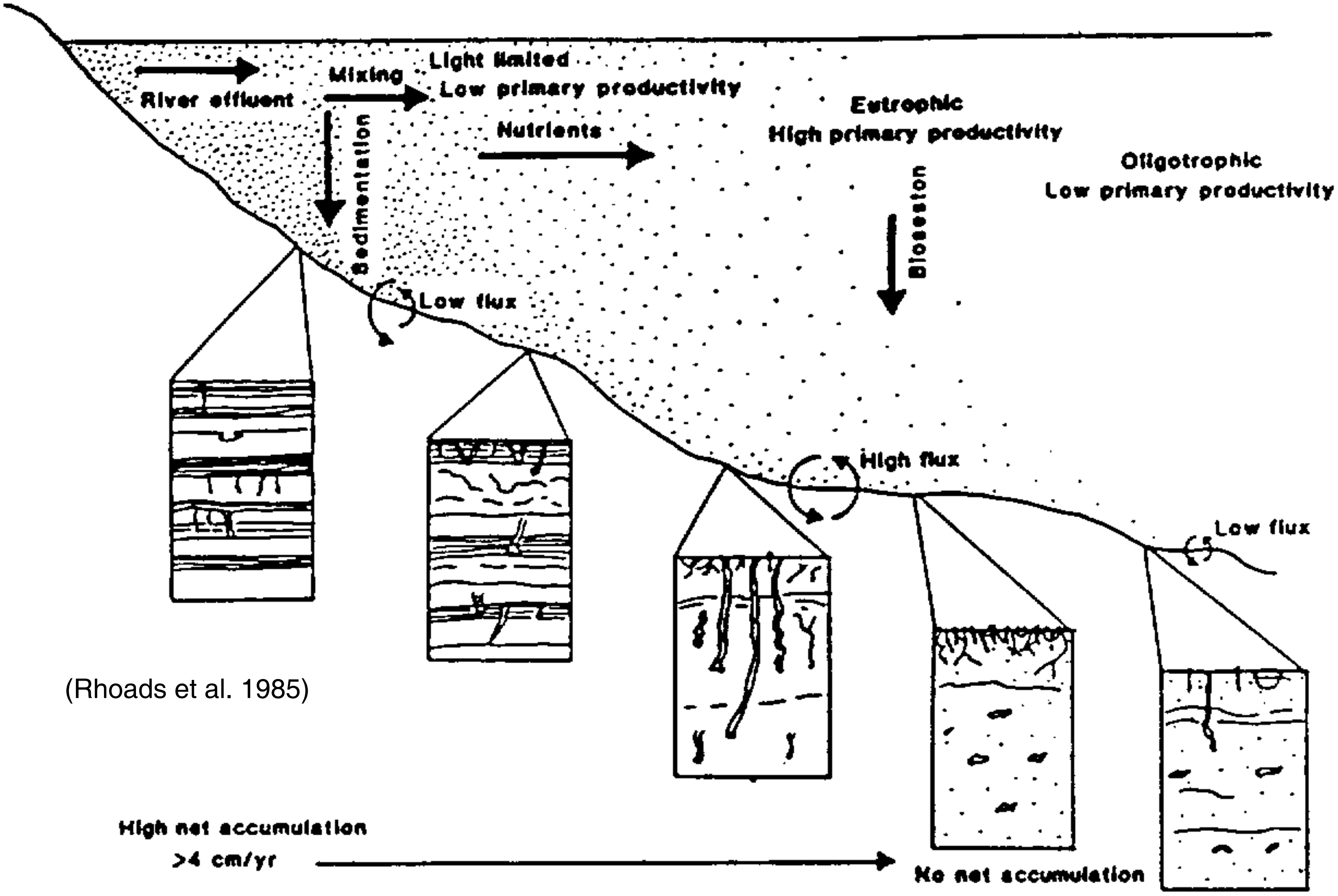


The Changjiang (Yangtze) Estuary East China Sea

Further offshore, turbidity is less due to the settling of particulate matter. Primary productivity is high due to high nutrient availability. Benthic secondary production is high due to a high rate of organic matter deposition from the water column. Sediments are well bioturbated.

Eventually nutrients become the limiting factor for primary producers. Benthic productivity is limited by low food availability.





(Rhoads et al. 1985)

Turbidity influences location of spring bloom and macrobenthos (ex. East China Sea)

Oxygen Balance Equation

$$\frac{\partial O_2}{\partial t} = -u\frac{\partial O_2}{\partial x} - v\frac{\partial O_2}{\partial y} - w\frac{\partial O_2}{\partial z} + K_z\frac{\partial^2 O_2}{\partial z^2} + \vec{F}_{as} - \mathrm{Resp.} + \mathrm{photosynthesis}$$

Change (1) (2) (3) (4) (5) (6) (7)

1.- Across shelf flux; 2.- Along shelf flux; 3.- Vertical flux
4.- Turbulent vertical mixing; 5.- Flux across air-sea interface
6.- Consumption by respiration; 7.- Production via photosynthesis

Hypoxia occurs through the interaction of physical conditions and nutrient loadings that lead to excess phytoplankton production. That fuels respiration in the isolated bottom waters and allows oxygen consumption to exceed import of oxygen.

Oxygen Balance Equation

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Change (1) (2) (3) (4) (5) (6) (7)

1.- Across shelf flux; 2.- Along shelf flux; 3.- Vertical flux
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Gradient Richardson Number

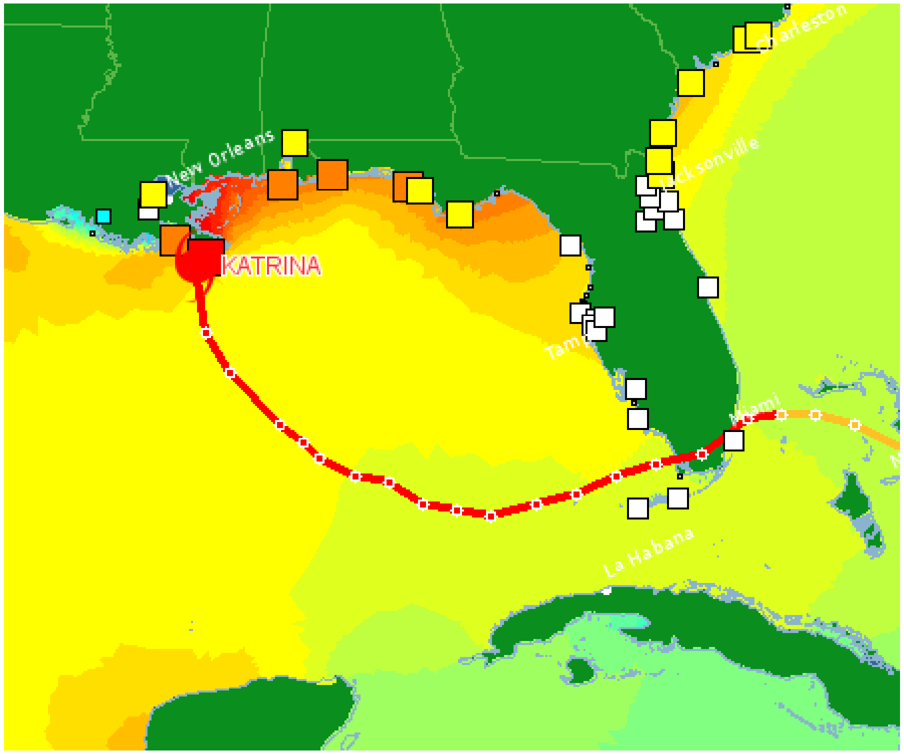
$$Ri = \frac{\left(\frac{-g}{\rho}\frac{\partial \rho}{\partial z}\right)}{\left(\frac{\partial V}{\partial z}\right)^2} = \frac{\text{resistance to vertical exchange due to stratification}}{\text{increased likelihood of vertical exchange due to shear}}$$

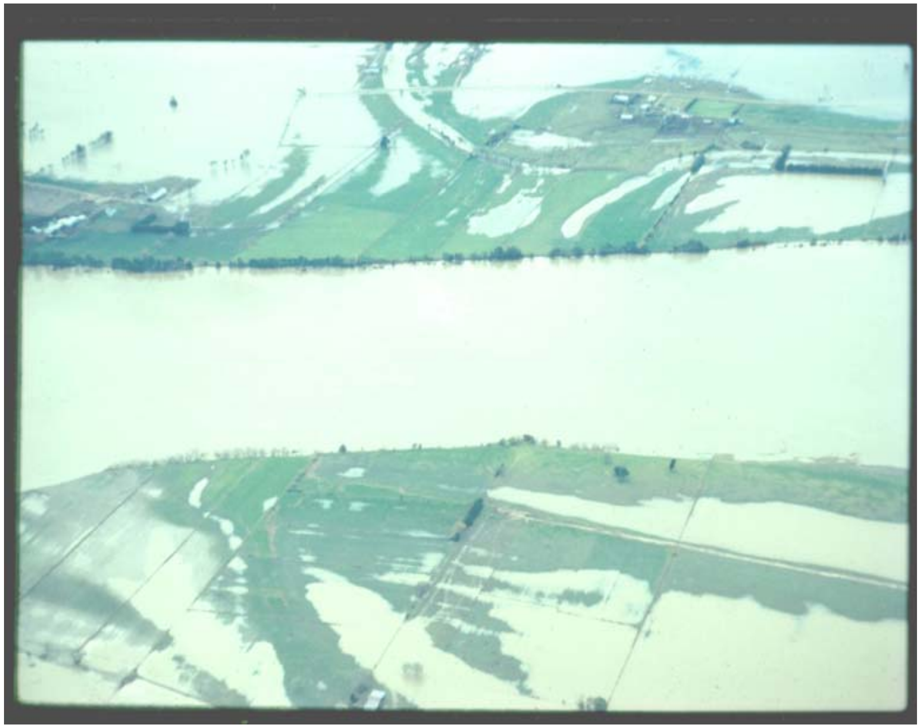
Ri > ~ 1/4 , mixing suppressed; Ri < ~ 1/4 , mixing enabled

Managing Threatened Deltaic Systems: Louisiana Case

In coastal Louisiana, socioeconomic urgency is attached to three strongly intersecting coastal issues:

(1) coastal inundation,
(2) coastal land loss, and
(3) continental shelf hypoxia.





Managing Threatened Deltaic Systems: Louisiana Case

“Ecosystem-based management requires integration of multiple system components and uses, identifying and striving for sustainable outcomes, precaution in avoiding deleterious actions, and adaptation based on experience to achieve effective solutions.” D.F Boesch, 2006

Managing Threatened Deltaic Systems: Louisiana Case

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"The ideal future condition of the Mississippi River Delta would be one that achieves --- a sustainable coastal ecosystem that supports and protects the environment, economy and culture of southern Louisiana" (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998).

Managing Threatened Deltaic Systems: Louisiana Case

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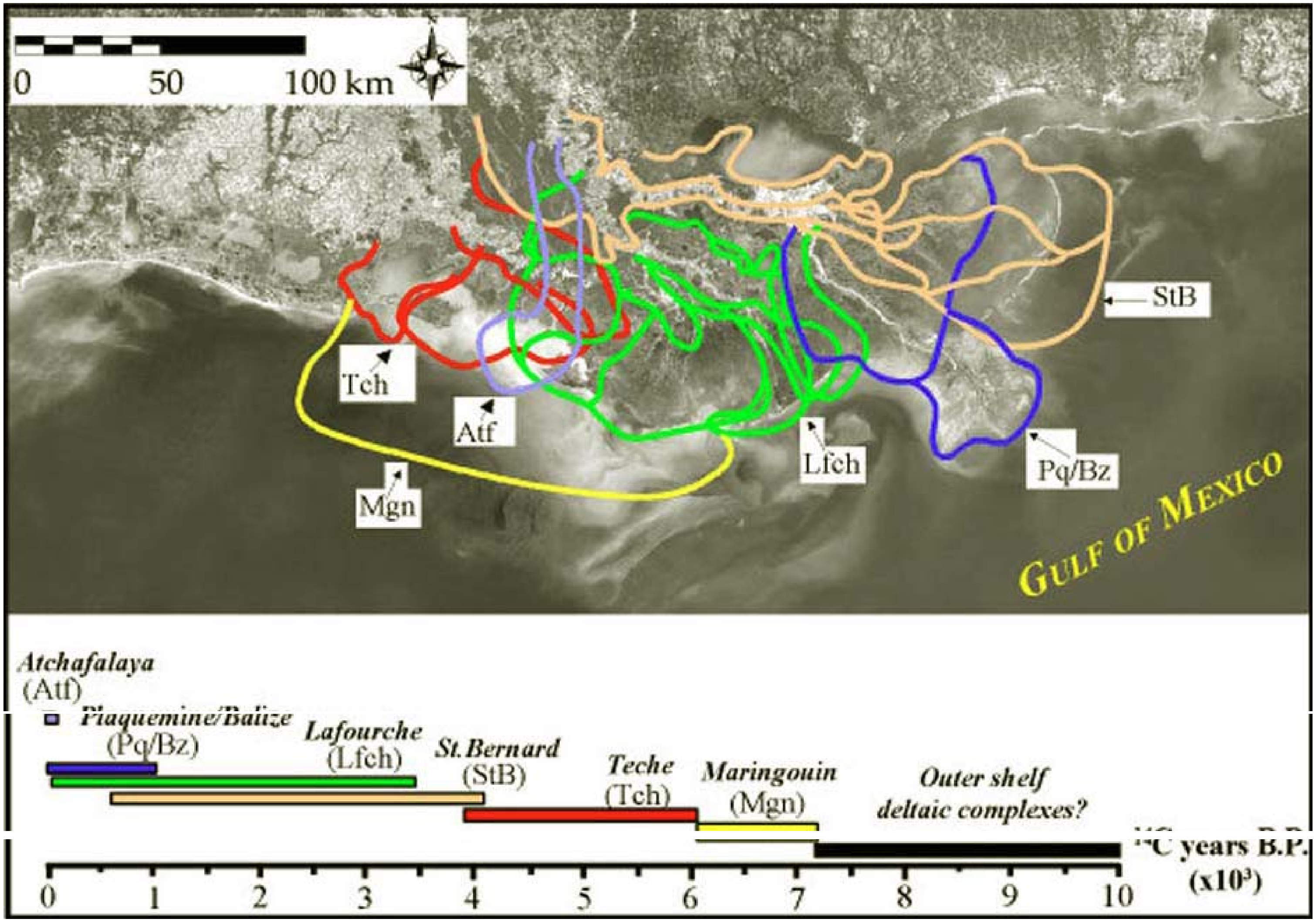
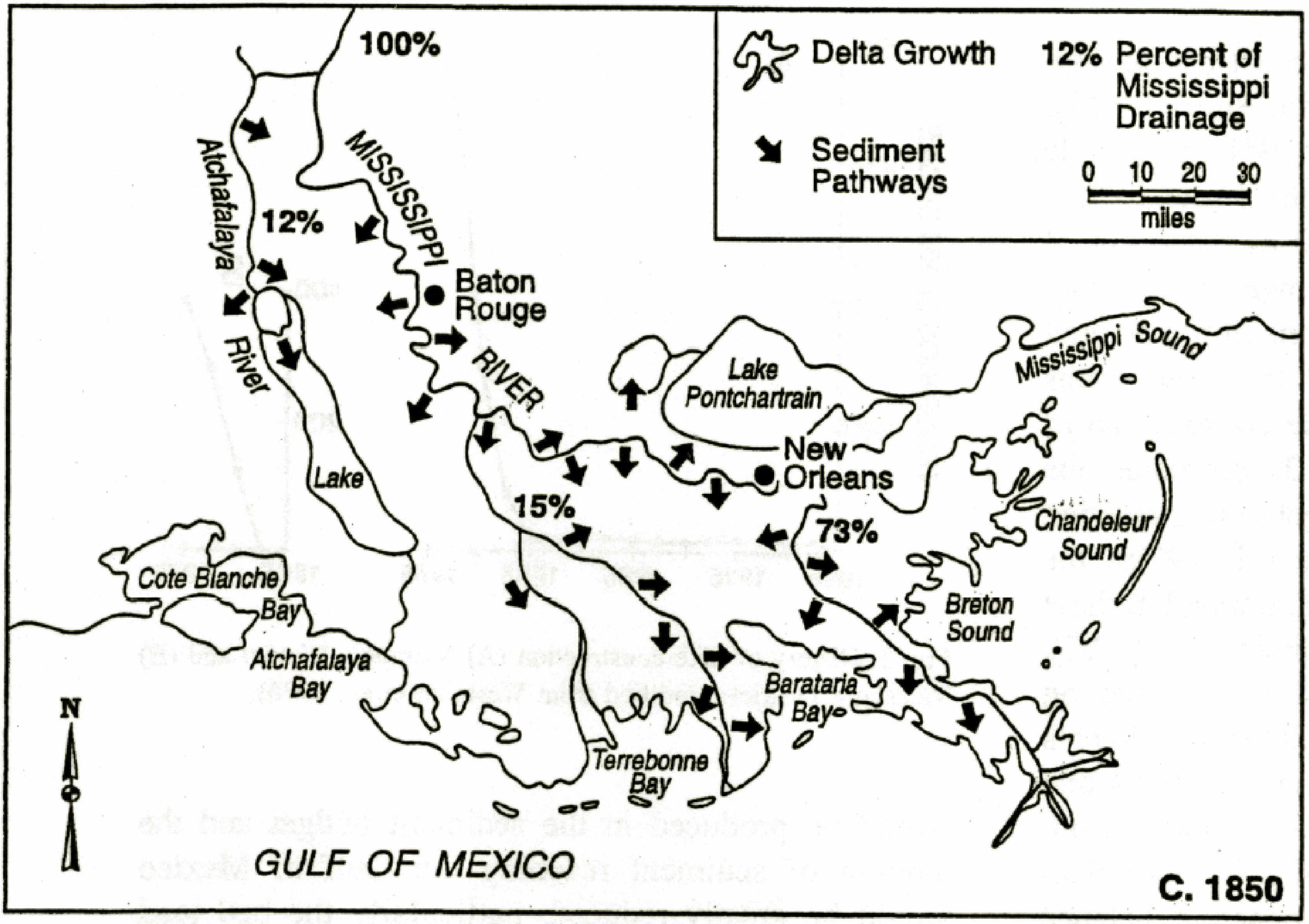
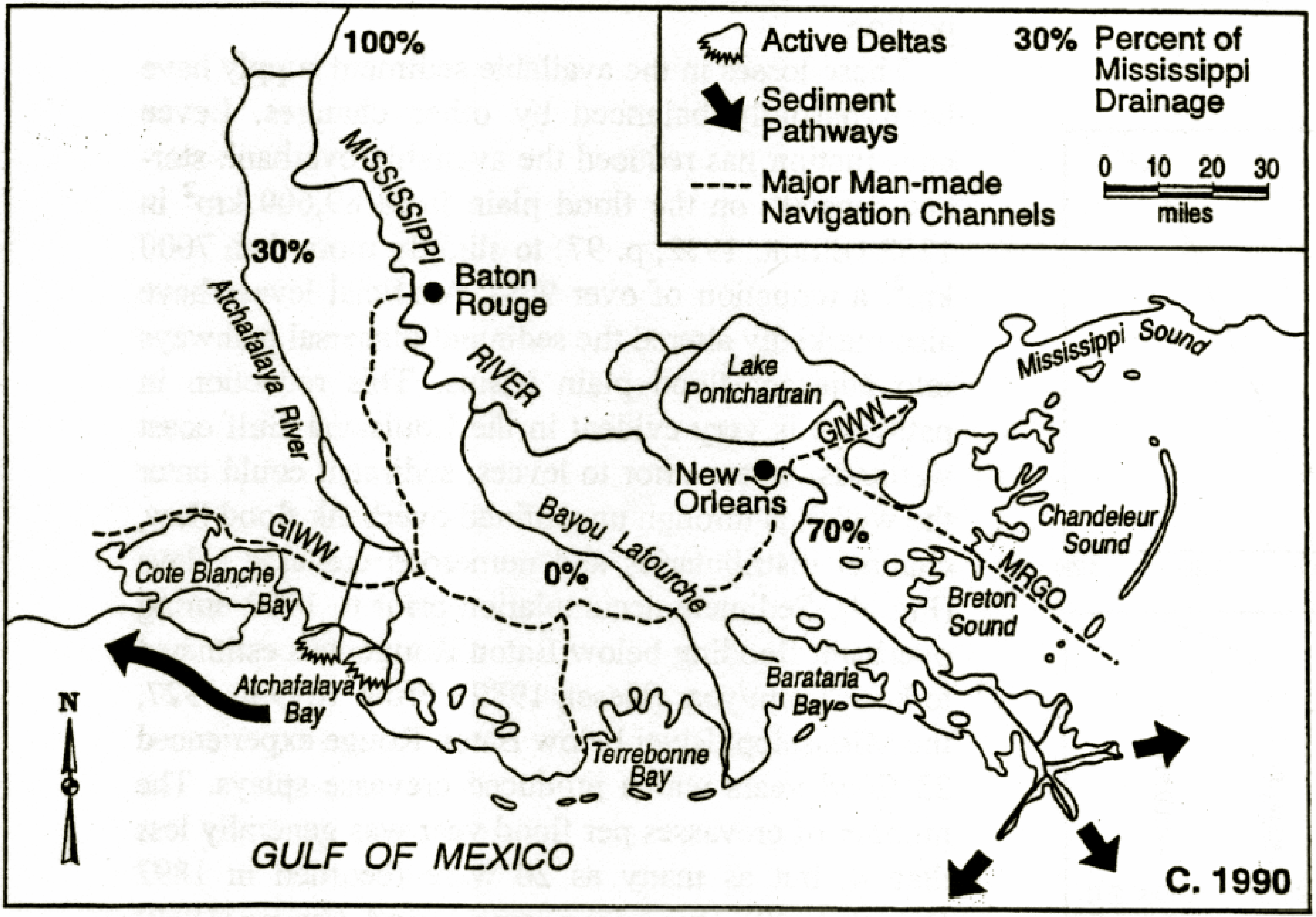
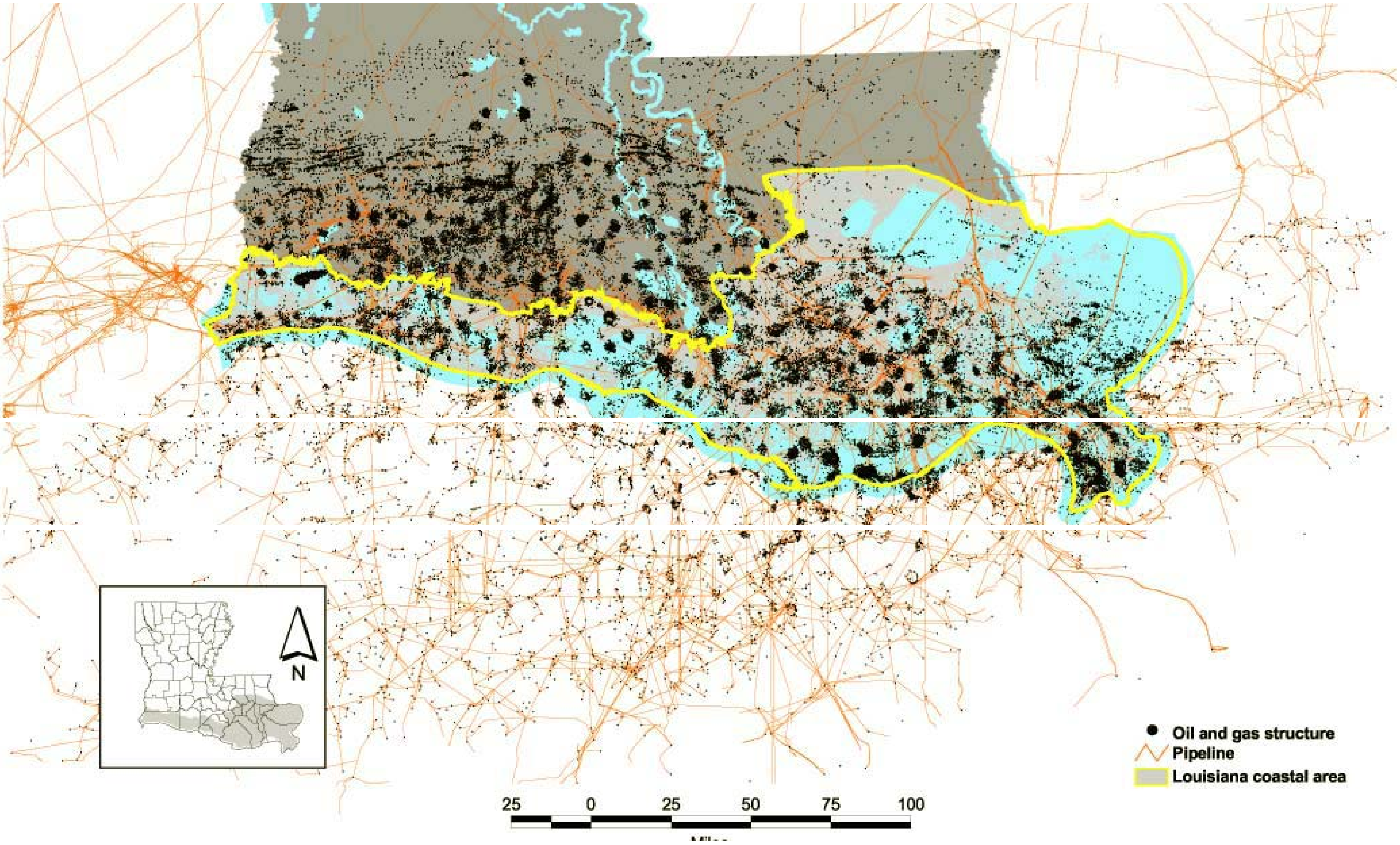
***“Saving Louisiana’s coastal region is a very complex and—in planning parlance—a “wicked” problem. The actions that must be taken to restore the coastal area will have to be bold, massive, costly, and continuing. The inherent nature of the solutions being proposed will come into conflict with the ways things are being done now.”* (National Research Council, 2006)**


0
50
100 km
StB
Tch
Atf
Mgn
Lfch
Pq/Bz
GULF OF MEXICO
Atchafalaya
(Atf)
Plaquemine/Balize
(Pq/Bz)
Lafourche
(Lfch)
St.Bernard
(StB)
Teche
(Tch)
Maringouin
(Mgn)
Outer shelf
deltaic complexes?
^{14}C years B.P.
(x10^3)
0
1
2
3
4
5
6
7
8
9
10


Delta Growth
12% Percent of Mississippi Drainage
Sediment Pathways
0 10 20 30
miles
100%
12%
15%
73%
Atchafalaya River
MISSISSIPPI RIVER
Baton Rouge
New Orleans
Lake Pontchartrain
Mississippi Sound
Chandeleur Sound
Breton Sound
Barataria Bay
Terrebonne Bay
Atchafalaya Bay
Cote Blanche Bay
Lake
GULF OF MEXICO
N
C. 1850



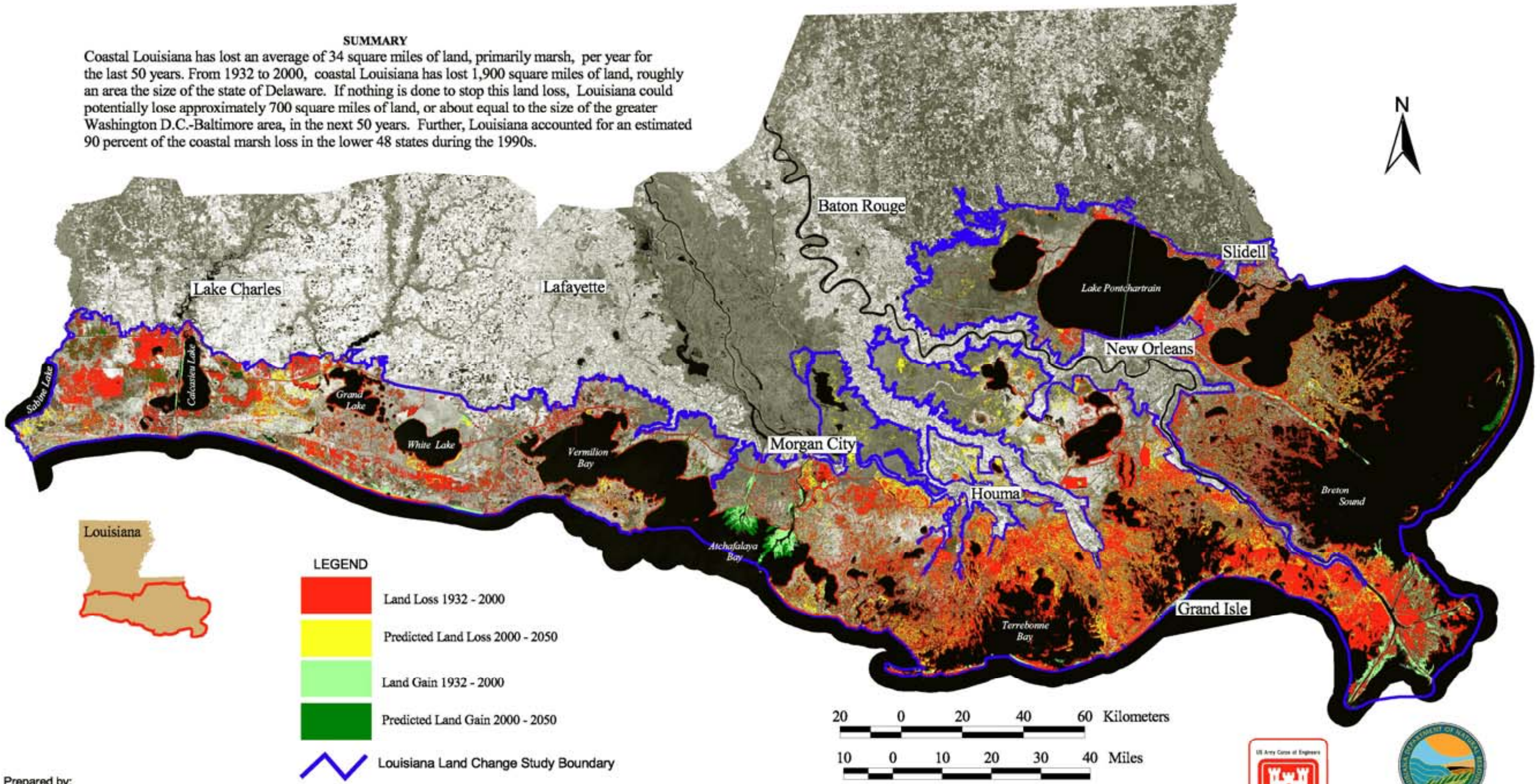
Active Deltas
Sediment Pathways
Major Man-made Navigation Channels
30% Percent of Mississippi Drainage
0 10 20 30
miles
100%
30%
MISSISSIPPI
RIVER
Baton Rouge
Atchafalaya River
Lake Pontchartrain
Mississippi Sound
GIWW
New Orleans
70%
Chandeleur Sound
MRGO
Breton Sound
Bayou Lafourche
0%
GIWW
Cote Blanche Bay
Atchafalaya Bay
Barataria Bay
Terrebonne Bay
N
GULF OF MEXICO
C. 1990


N
● Oil and gas structure
Pipeline
Louisiana coastal area
25
0
25
50
75
100
Miles

100+ Years of Land Change for Coastal Louisiana

SUMMARY

Coastal Louisiana has lost an average of 34 square miles of land, primarily marsh, per year for the last 50 years. From 1932 to 2000, coastal Louisiana has lost 1,900 square miles of land, roughly an area the size of the state of Delaware. If nothing is done to stop this land loss, Louisiana could potentially lose approximately 700 square miles of land, or about equal to the size of the greater Washington D.C.-Baltimore area, in the next 50 years. Further, Louisiana accounted for an estimated 90 percent of the coastal marsh loss in the lower 48 states during the 1990s.



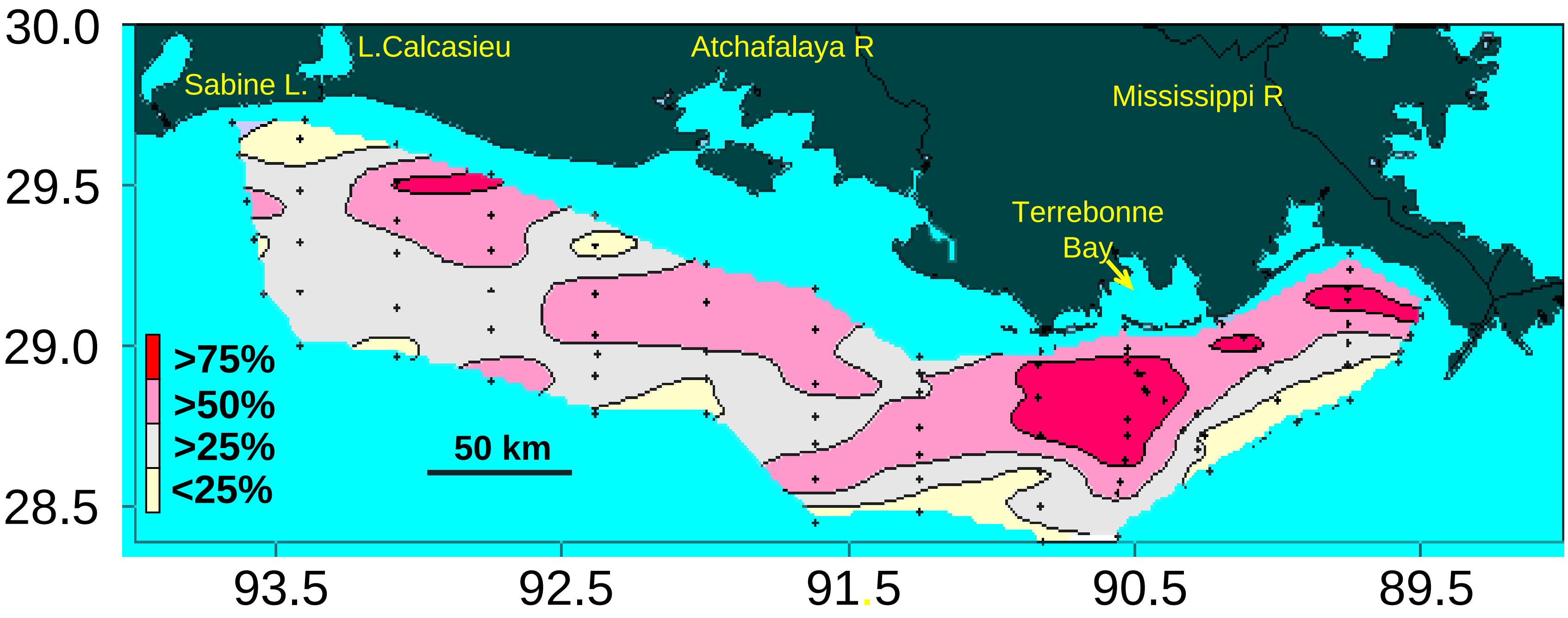
Background is 2000 Thematic Mapper panchromatic band.

Prepared by:
U.S. Geological Survey
National Wetlands Research Center
Lafayette, LA

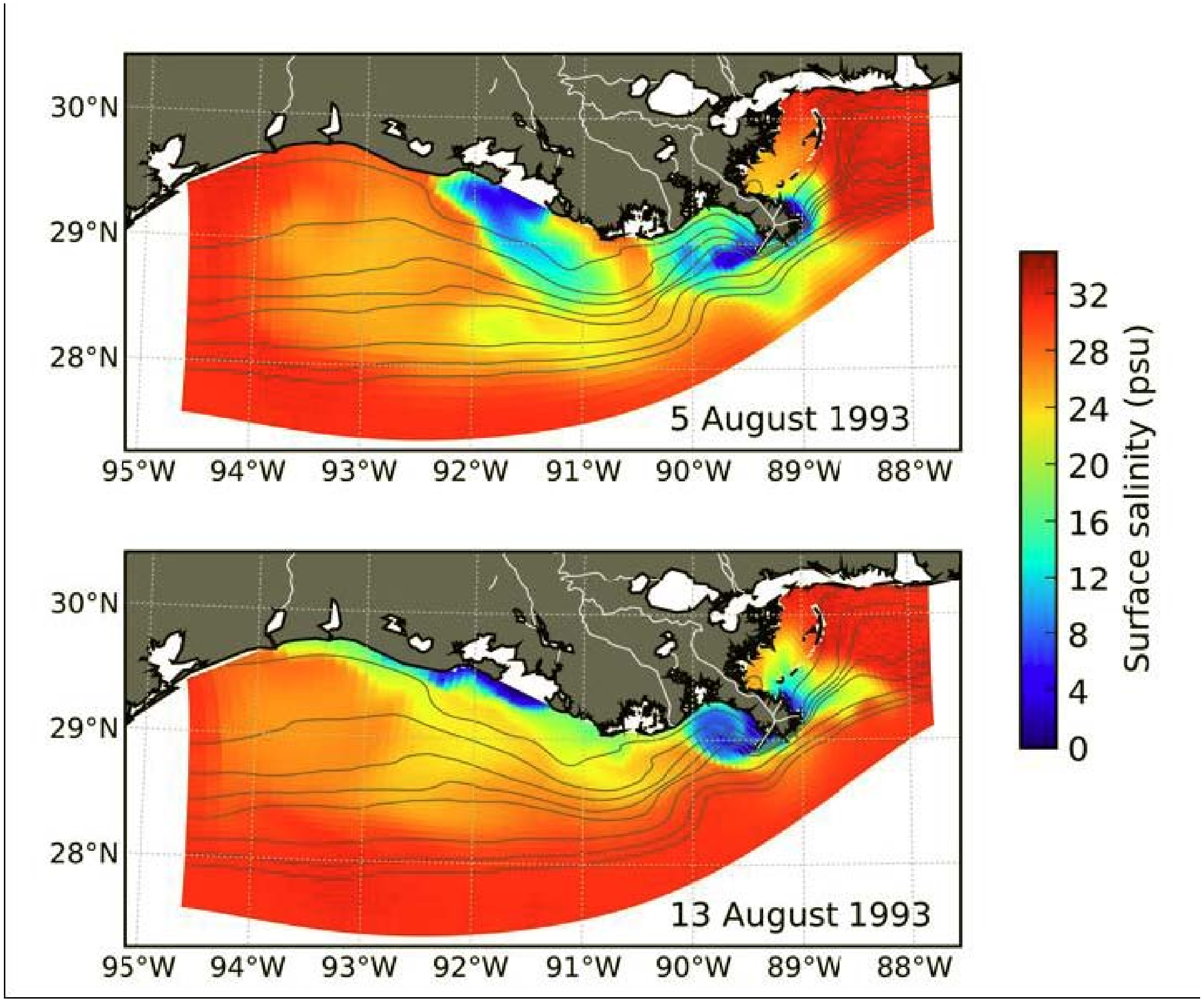
Map ID: USGS-NWRC 2003-03-085

The Mississippi Watershed supplies nutrients to the Gulf of Mexico

Hypoxia occurs through the interaction of physical conditions and nutrient loadings that lead to excess phytoplankton production. That fuels respiration in the isolated bottom waters and allows oxygen consumption to exceed import of oxygen. Both nutrient loads and freshwater inputs to the Northern Gulf co-vary from year to year.

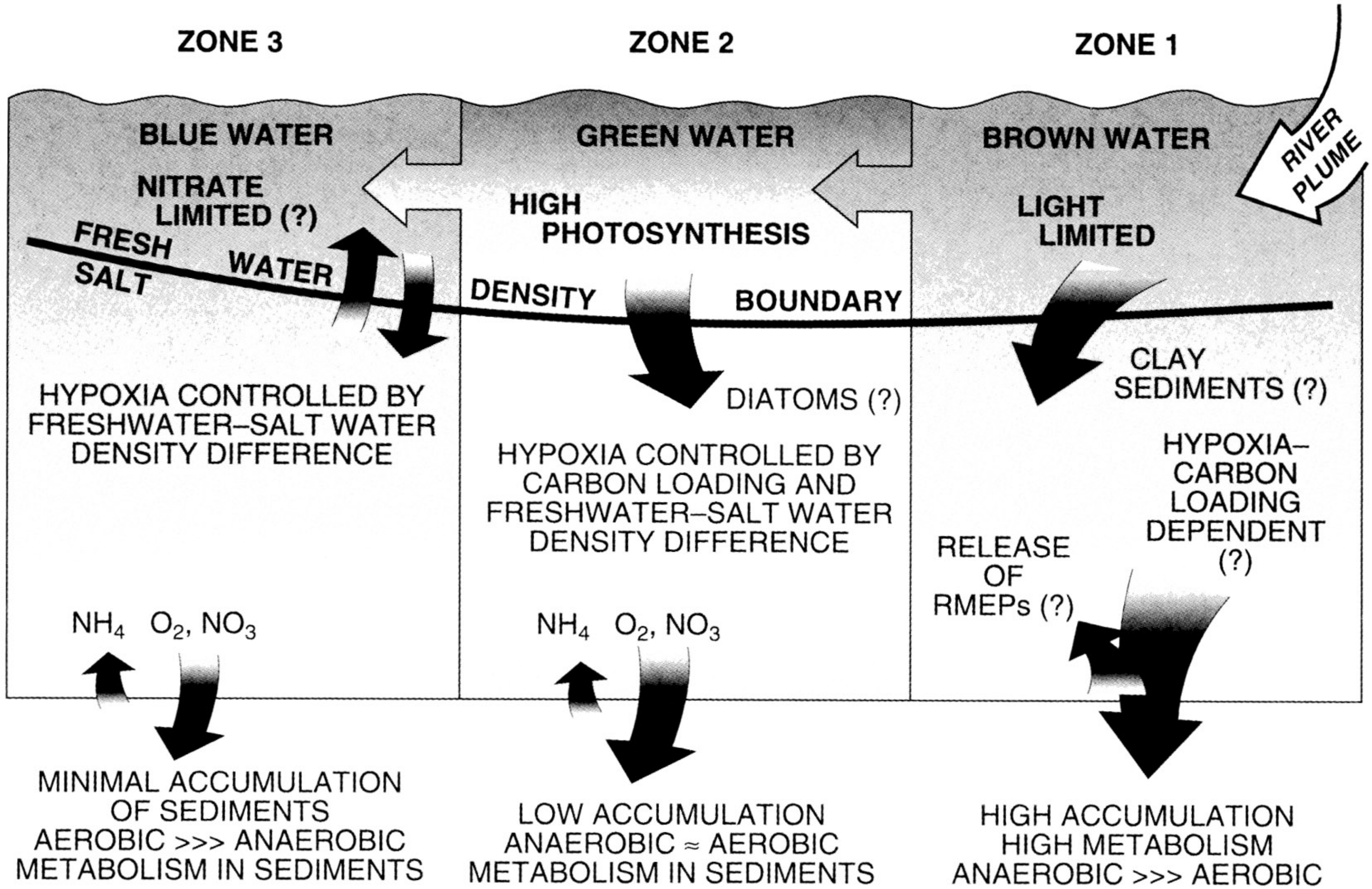


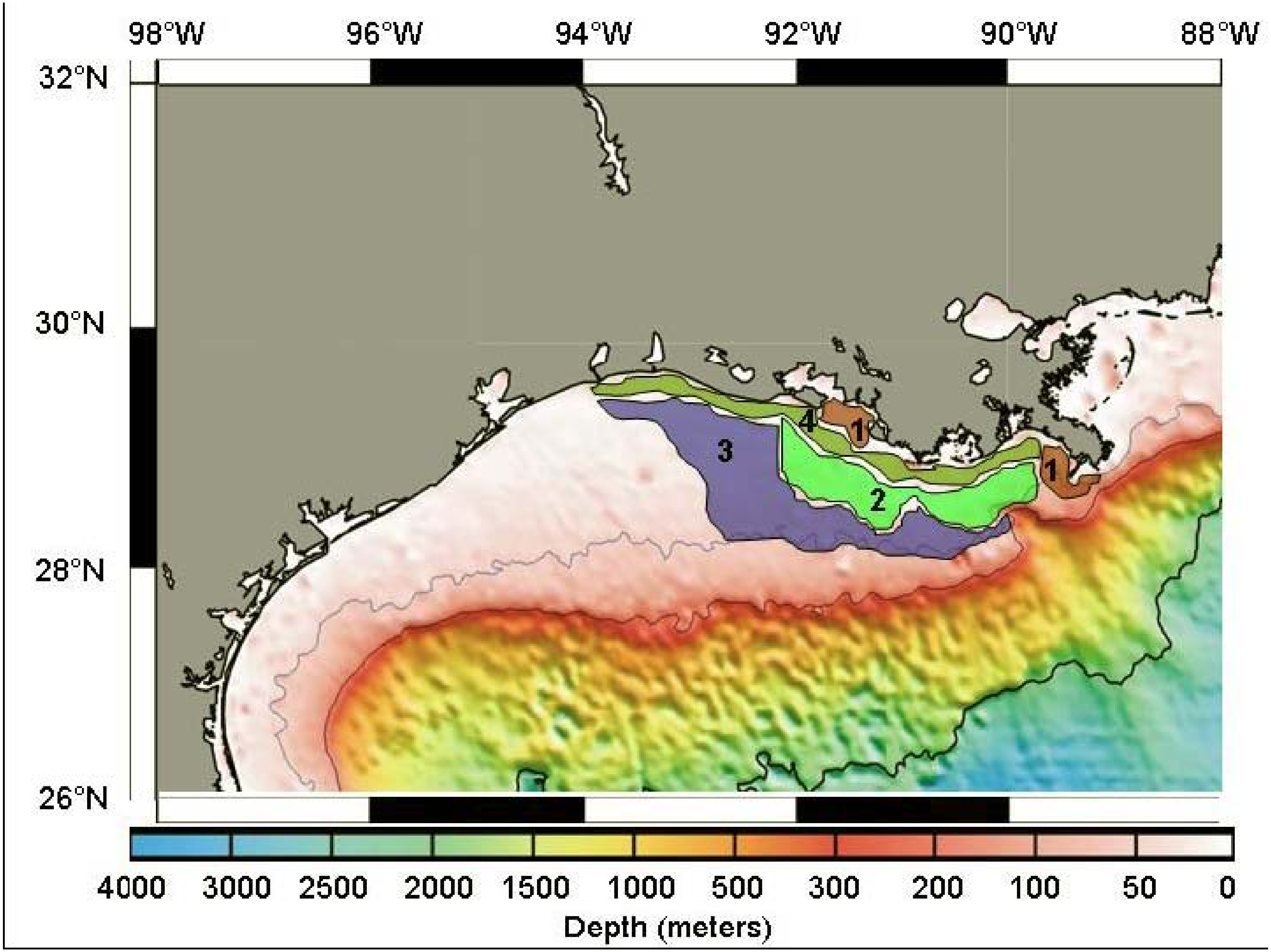
Distribution of frequency of occurrence of mid-summer hypoxia — based on data from Rabalais, Turner and Wiseman from the 60 to 80 station grid repeatedly sampled from 1985-1999.



Modeled surface salinity showing the freshwater plumes from the Atchafalaya and Mississippi Rivers during upwelling favorable winds (top panel) and during downwelling favorable winds 8 days later From Hetland and DiMarco (2007).

Rowe and Chapman 2002




98°W
96°W
94°W
92°W
90°W
88°W
32°N
30°N
28°N
26°N
3
4
1
1
2
4000
3000
2500
2000
1500
1000
500
300
200
100
50
0
Depth (meters)

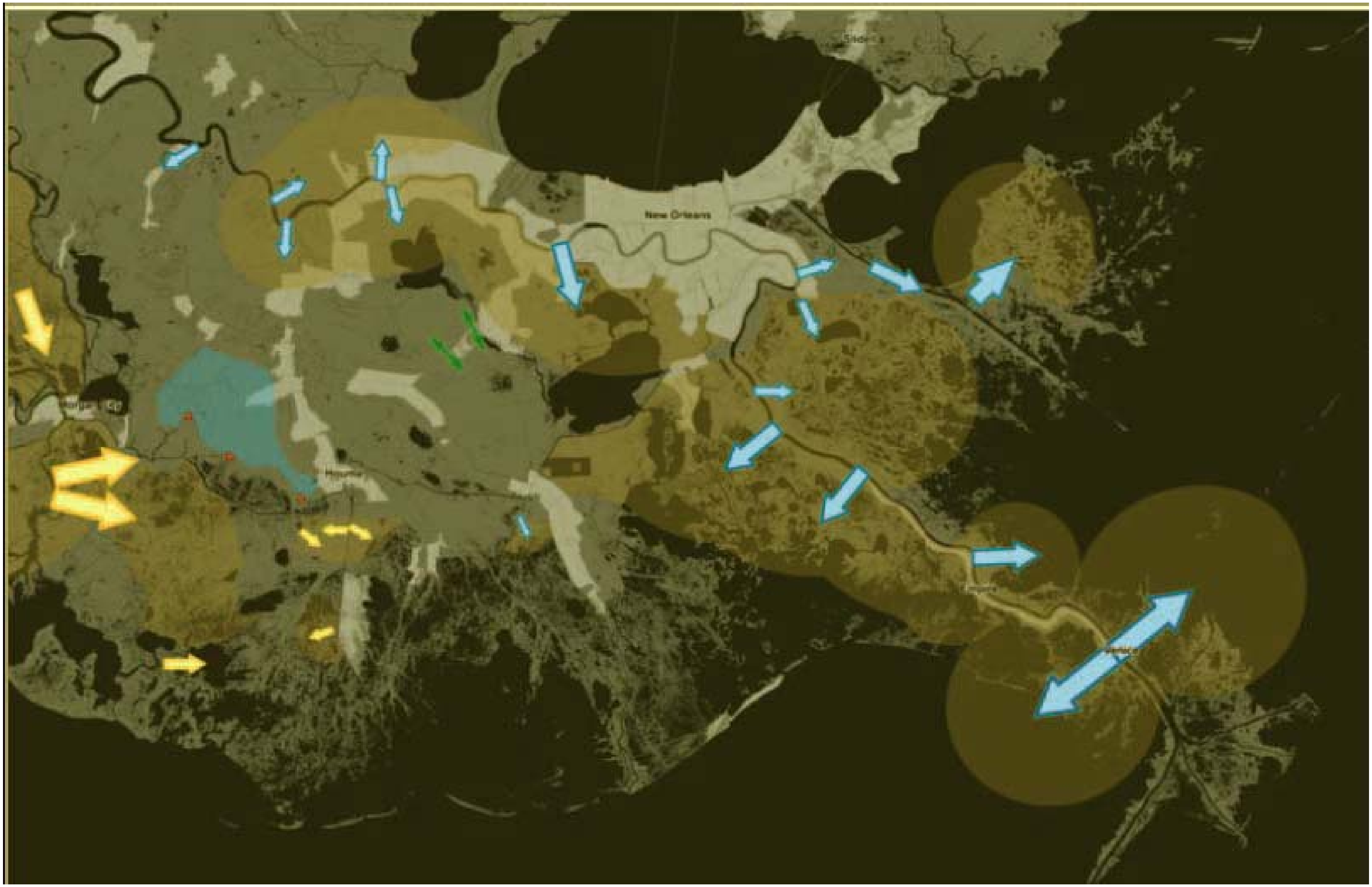
Managing Threatened Deltaic Systems: Louisiana Case

> ***“Saving Louisiana’s coastal region is a very complex and—in planning parlance—a “wicked” problem. The actions that must be taken to restore the coastal area will have to be bold, massive, costly, and continuing. The inherent nature of the solutions being proposed will come into conflict with the ways things are being done now.”*** **(National Research Council, 2006)**

STAKEHOLDERS WITH CONFLICTING INTERESTS

a. Navigation Versus Restoration
b. Oil and Gas
c. Commercial and Recreational Fishing
d. Recreation and Tourism
e. Agriculture and Rural Economy
f. Urbanization
g. Politicians and the political will to decide

There are plans for significant diversions of the water, nutrients and sediment outflow from the Mississippi River into the Gulf to reduce land loss.




Empire
Venice

Gradient Richardson number, Ri

$$\text{Ri} = \frac{\text{stability from buoyancy}}{\text{instability from shear}}$$

Or, scaled

$$\text{Ri} = \frac{-\frac{g}{\rho}\frac{d\rho}{dz}}{\left({}^{du}\!/\!{}_{dz}\right)^2} \qquad \text{Ri} \approx \frac{-\frac{g}{\rho}\frac{\Delta\rho}{H}}{\left({}^{U}\!/\!{}_{H}\right)^2} = \frac{\Delta\rho}{\rho}\frac{gH}{U^2}$$

ρ= water density, H= water depth

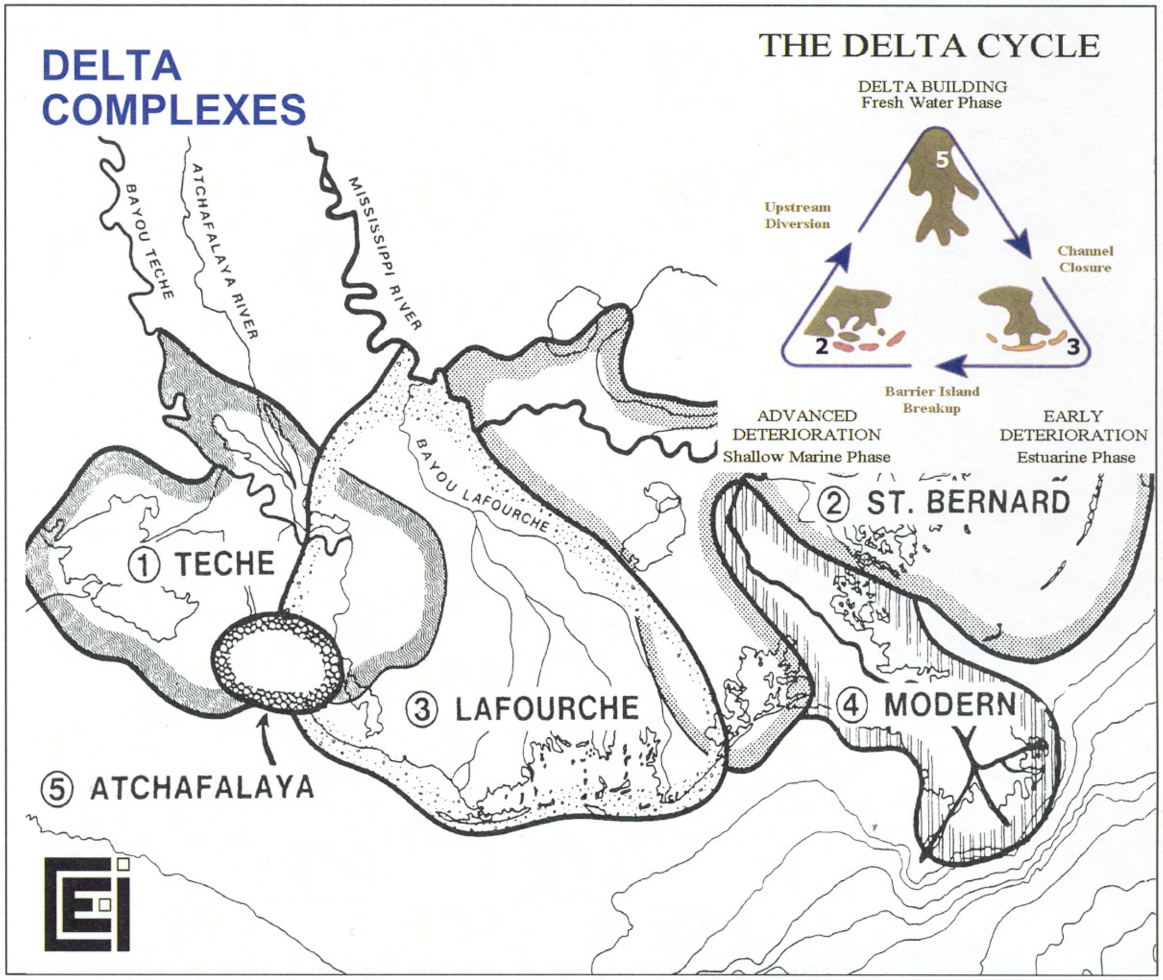
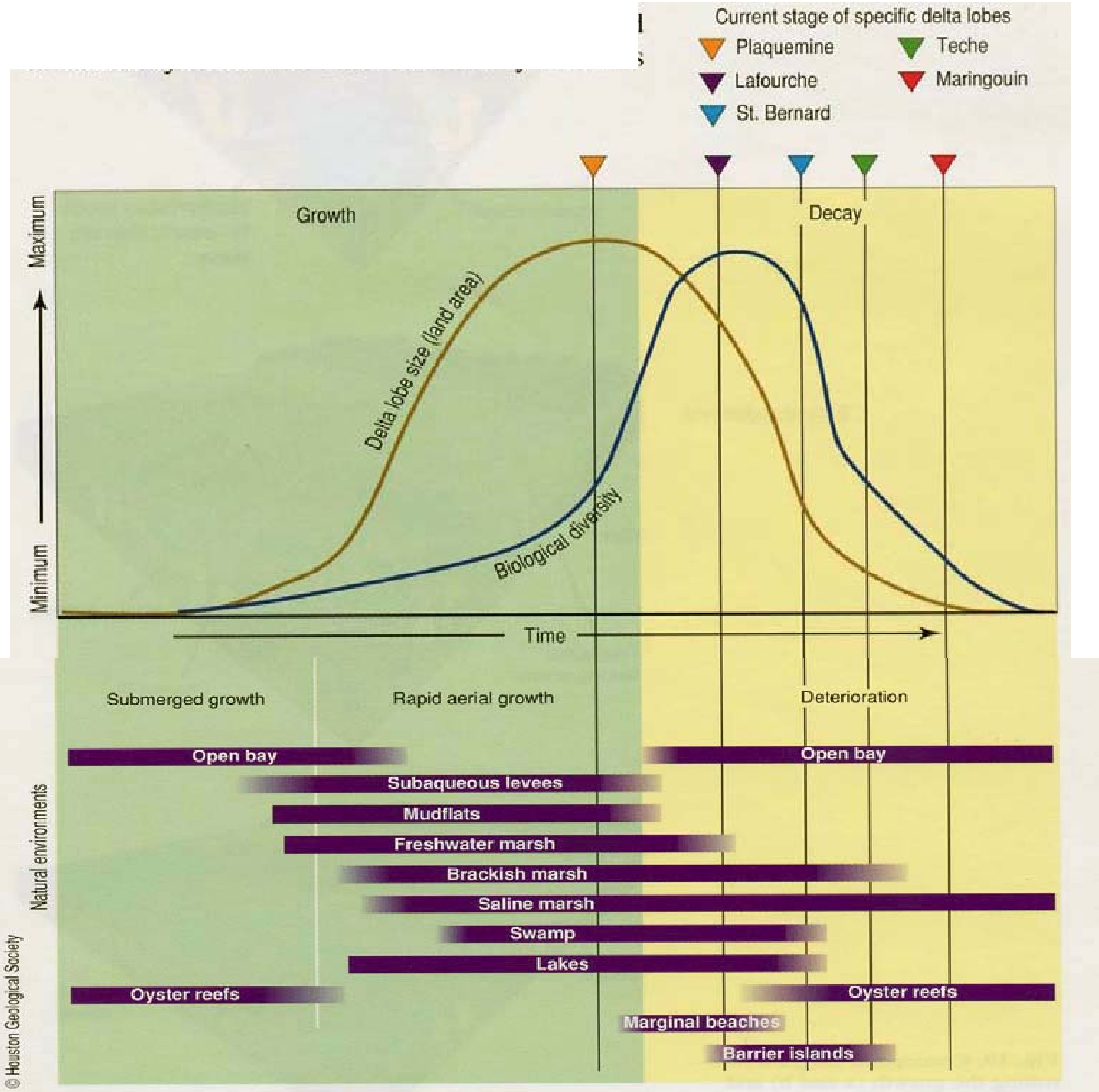
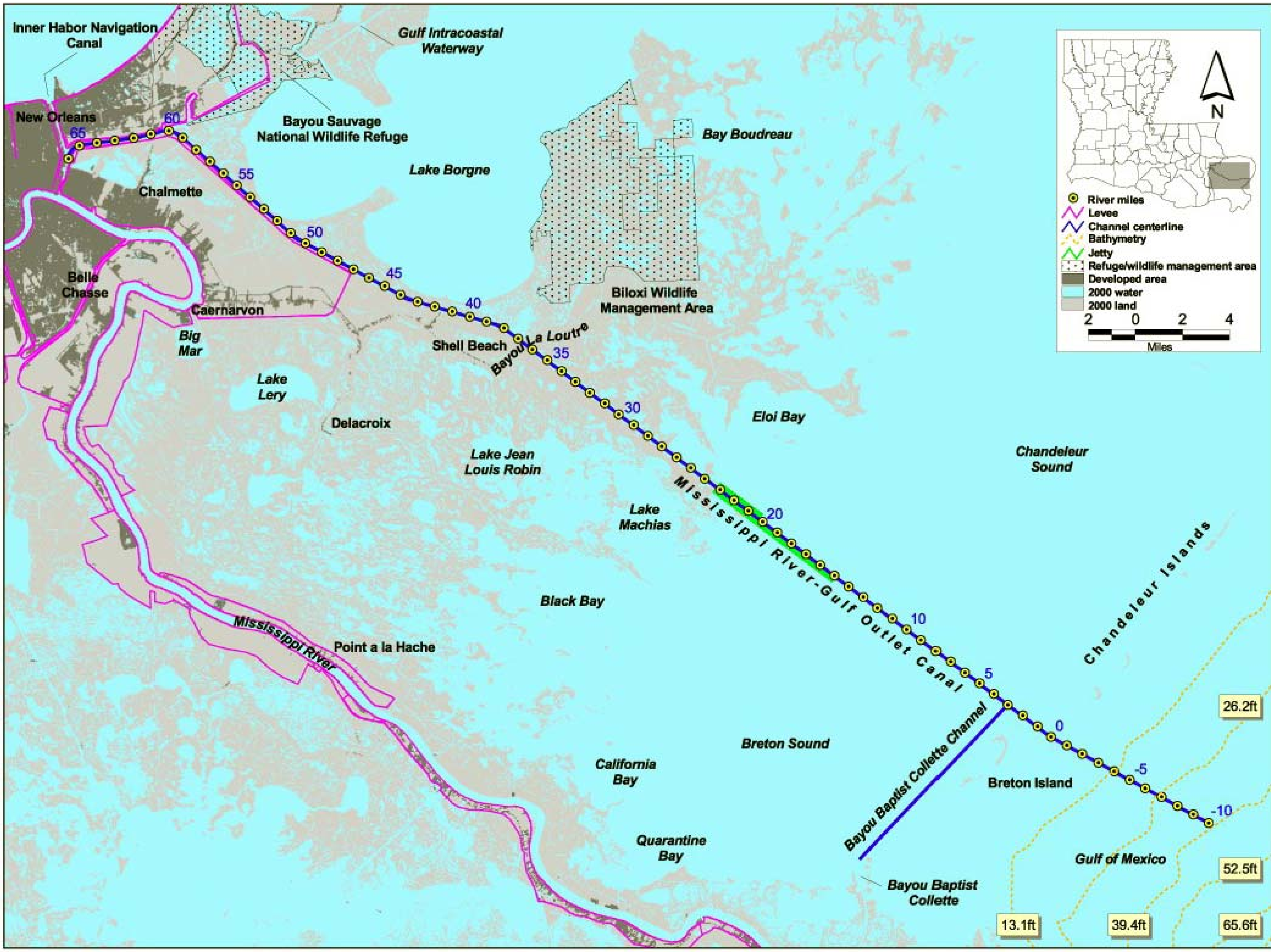


Figure 4. Map showing Delta Complexes or lobes. Delta lobes evolve through a systematic sequence of change called the delta cycle. The number on each lobe corresponds to stages of the cycles as shown in the inserted diagram.

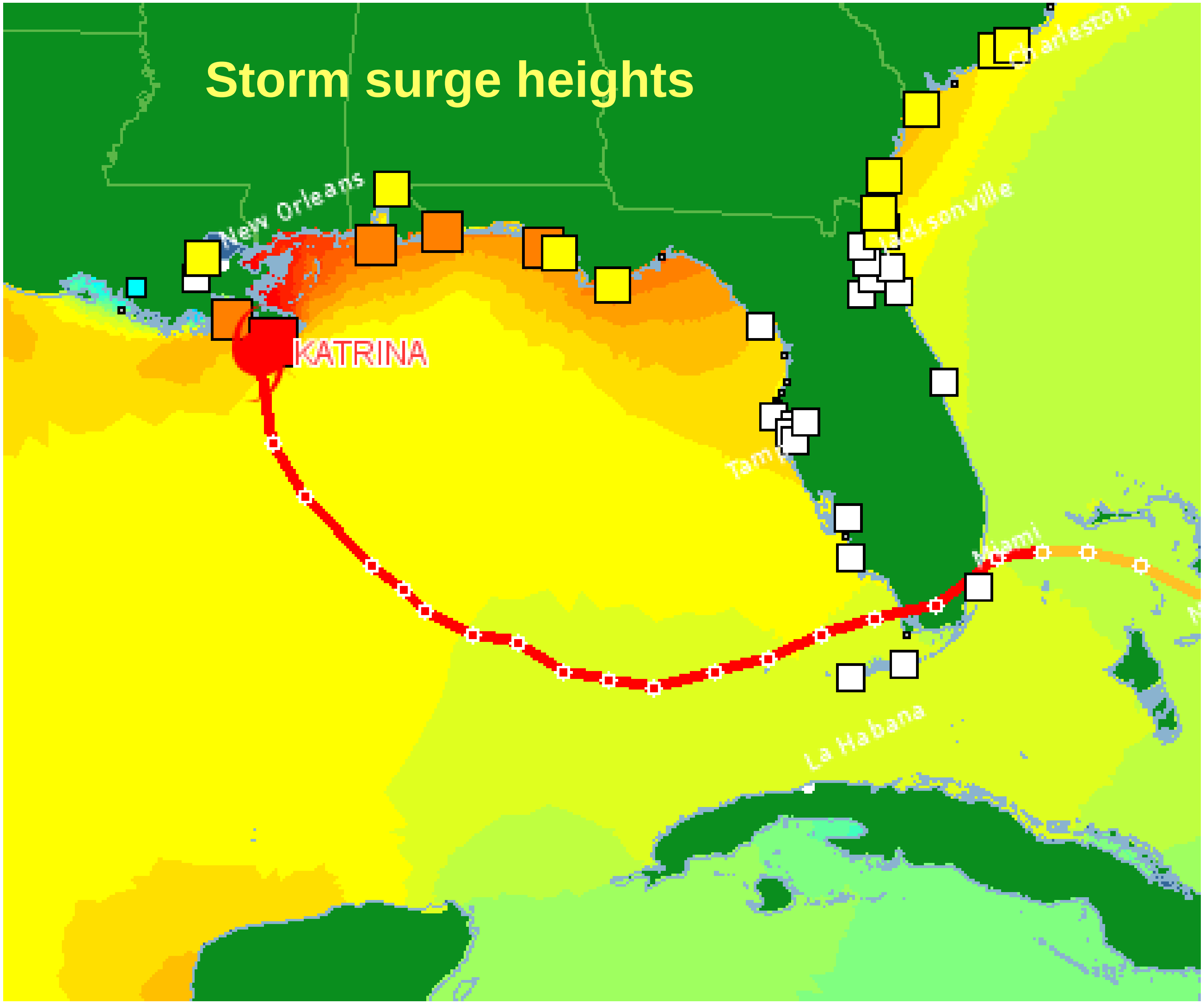


© Houston Geological Society

Fig. 18. Graphical depiction of the growth and decay of a delta lobe (adapted from Gagliano and Van Beek 1975; Neill and Deegan 1986). Habitat and biological diversity peak in the early to middle stage of the decay phase.


Inner Habor Navigation Canal
Gulf Intracoastal Waterway
New Orleans
65
60
Bayou Sauvage National Wildlife Refuge
Bay Boudreau
55
Lake Borgne
Chalmette
50
45
40
Belle Chasse
Caernarvon
Biloxi Wildlife Management Area
Big Mar
Shell Beach
Bayou La Loutre
35
Lake Lery
Delacroix
30
Eloi Bay
Chandeleur Sound
Lake Jean Louis Robin
Lake Machias
20
Mississippi River-Gulf Outlet Canal
Chandeleur Islands
Black Bay
10
Mississippi River
Point a la Hache
5
0
Bayou Baptist Collette Channel
Breton Sound
California Bay
Breton Island
-5
-10
Quarantine Bay
Gulf of Mexico
Bayou Baptist Collette
26.2ft
52.5ft
13.1ft
39.4ft
65.6ft
N
River miles
Levee
Channel centerline
Bathymetry
Jetty
Refuge/wildlife management area
Developed area
2000 water
2000 land
2
0
2
4
Miles

Storm surge heights



Managing Threatened Deltaic Systems: Louisiana Case

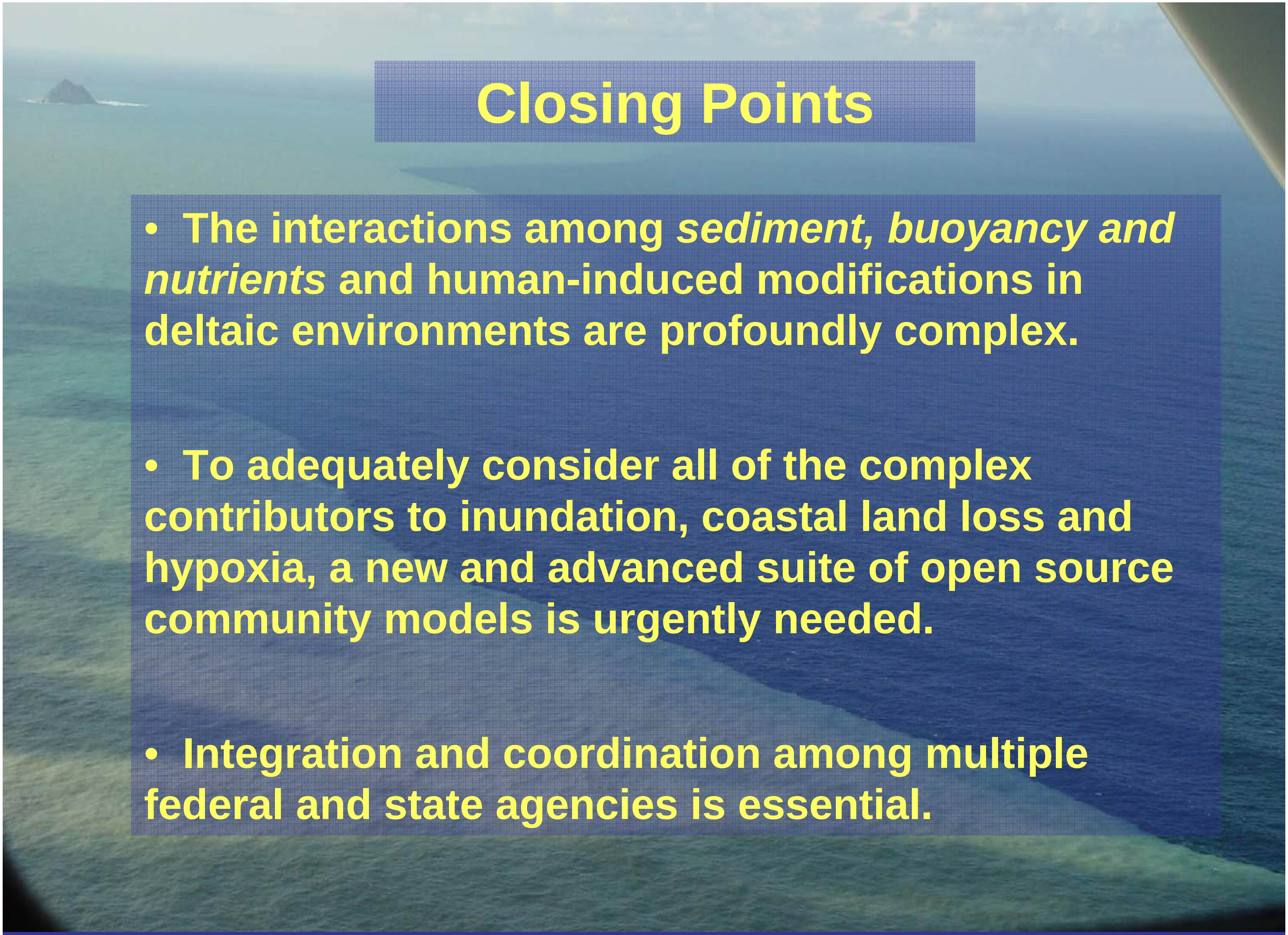
***"The actions that must be taken to restore the coastal area will have to be bold, massive, costly, and continuing. The inherent nature of the solutions being proposed will come into conflict with the ways things are being done now."* (National Research Council, 2006)**

Some Relevant References

(1) Coastal Protection and Restoration Authority of Louisiana, 2007. *Integrated Ecosystem Restoration and Hurricane Protection: Louisiana's Comprehensive Master Plan for a Sustainable Coast.* CPRA, Office of the Governor 117 pp; www.louisianacoastal planning.org

(2) National Research Council, Committee on the Restoration and Protection of Coastal Louisiana 2006 *Drawing Louisiana's New Map: Addressing Land Loss in Coastal Louisiana* Washington DC, The National Academies Press 206 pp.

(3) EPA SAB, 2007. Science Advisory Board (SAB) Hypoxia Panel Draft Advisory Report , 323 pp. For pdf: (http://www.epa.gov/fedrgstr/EPA-SAB/2007/August/Day-30/sab17197.htm. This draft does not represent EPA policy.



Closing Points

- The interactions among *sediment, buoyancy and nutrients* and human-induced modifications in deltaic environments are profoundly complex.

- To adequately consider all of the complex contributors to inundation, coastal land loss and hypoxia, a new and advanced suite of open source community models is urgently needed.

- Integration and coordination among multiple federal and state agencies is essential.