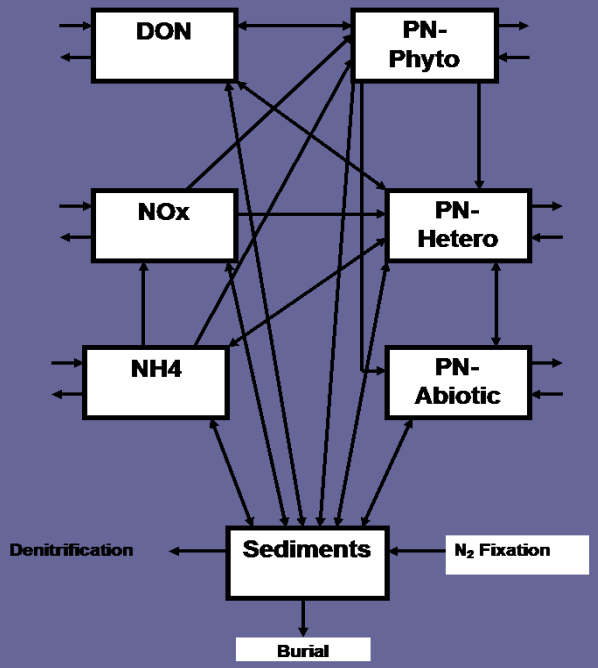
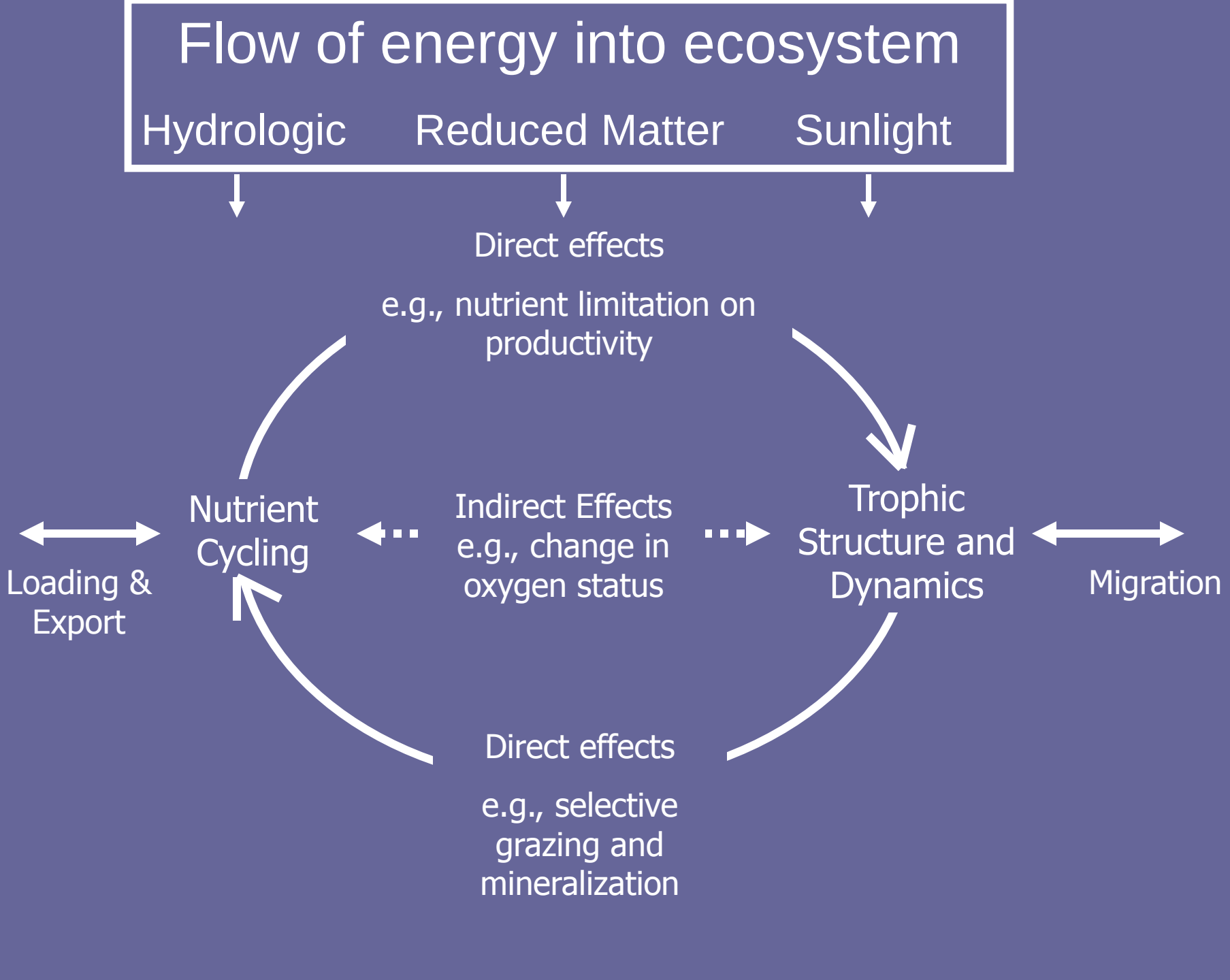
Nitrogen Cycling Networks of the Neuse River Estuary and Eutrophication Response



Robert R. Christian
East Carolina University

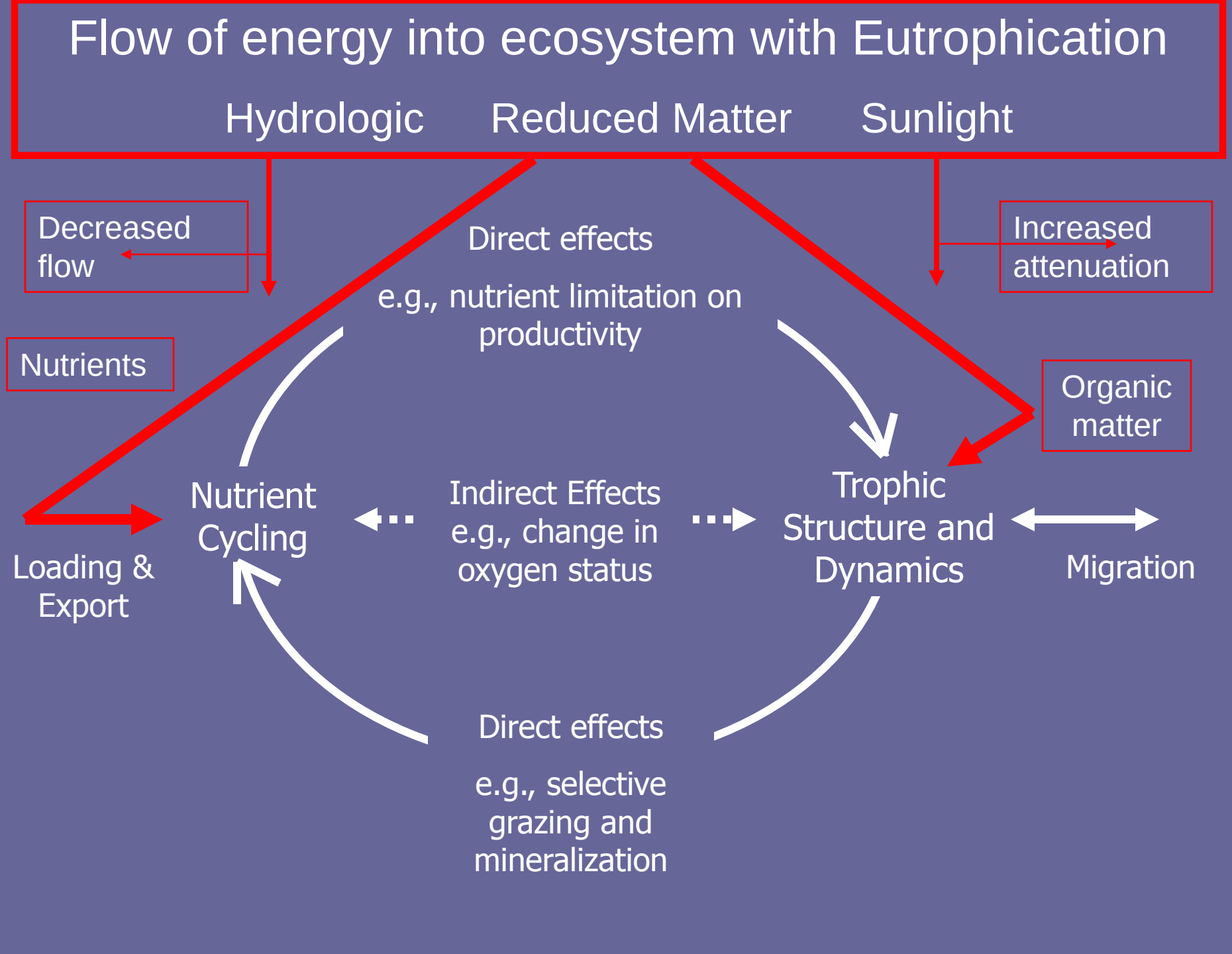
Bo Dame, Jeff Johnson, Joe Luczkovich & Cassondra Thomas, East Carolina University
Galen Johnson & Pete Peterson, IMS-UNC Chapel Hill
Dan Baird, Univ. of Port Elizabeth
Bob Ulanowicz & Ursula Scharler, Univ. of Maryland


Flow of energy into ecosystem
Hydrologic
Reduced Matter
Sunlight
Direct effects
e.g., nutrient limitation on productivity
Nutrient Cycling
Indirect Effects e.g., change in oxygen status
Trophic Structure and Dynamics
Loading & Export
Migration
Direct effects
e.g., selective grazing and mineralization

Defining Eutrophication

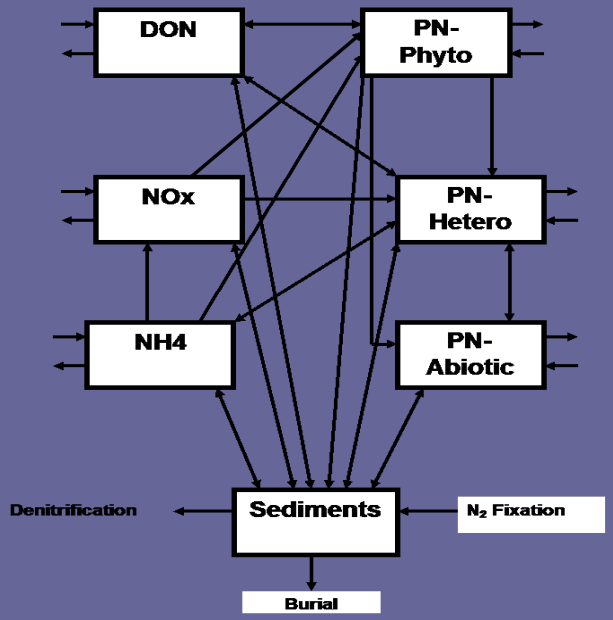
Eutrophication (noun) – an increase in the rate of supply of organic matter to an ecosystem.

Nixon, S. W. (1995) Ophelia 41: 199


Flow of energy into ecosystem with Eutrophication
Hydrologic
Reduced Matter
Sunlight
Decreased flow
Increased attenuation
Direct effects
e.g., nutrient limitation on productivity
Nutrients
Organic matter
Nutrient Cycling
Indirect Effects
e.g., change in oxygen status
Trophic Structure and Dynamics
Loading & Export
Migration
Direct effects
e.g., selective grazing and mineralization

Network Ecology

- An approach to ecology based on the perception of nature as networks of interactions



- These networks of nodes (compartments, standing stocks) are connected by arcs (flows)
- A variety of properties of networks can be characterized through ***network analysis***
- Properties of nature can be inferred from network properties

Objectives

- To introduce capabilities of network analysis as a tool for ecosystem assessment of eutrophication effects on
  - Nitrogen cycling
  - Food webs (only briefly)
- To discuss efforts to link nutrient cycling to trophic dynamics
  - Nitrogen cycling and primary producers
  - Eutrophication's indirect effects of hypoxia on trophic structure and dynamics (only briefly)

Key Points about Network Analysis

- **“Network analysis” is plural!** This is a group of analyses (algorithms) that are particularly good at:
  - **(1)** Categorizing system parts relative to others
  - **(2)** Evaluating indirect interactions and relationships,
  - **(3)** Indexing system-level conditions

- **Network analysis is MODEL ANALYSIS not CONSTRUCTION or DYNAMIC SIMULATION**

Eastern North Carolina

Little exchange with Ocean, small astronomical tides

Freshwater Flushing Times

NRE: 50 days

PS: 11 months

Eutrophication of Neuse River estuary

- Symptoms
  - Harmful algal blooms
  - Hypoxia/Anoxia
  - Fish Kills
- State Response
  - Lower N loading by 30%
  - ModMon
- Needs met by ModMon
  - Understanding and prediction of nitrogen cycling, hydrology, biological response to loading

Christian, R. R., and C. R. Thomas. 2003. Network analysis of nitrogen inputs and cycling in the Neuse River Estuary, North Carolina, USA. Estuaries 26:815-828.

Historical Information on the Neuse River and Estuary from Studies by ECU

(Boyer, Daniel, Heath, Lackey, Rizzo, Stanley)

Time Period

- **Initial studies:** 1981-1984
- **Intensive sampling:** Mar. 1985-Feb. 1989.
- **ModMon Modeling:** 1997- .
- **Pamlico Sound response to hurricanes:** 1999-2002.

Locations and intensity during intensive sampling

- **Planktonic metabolism:** biweekly-triweekly at 7 stations from head to mouth.
- **Loading:** weekly at 4 sites.
- **Benthic metabolism:** from head to mouth.

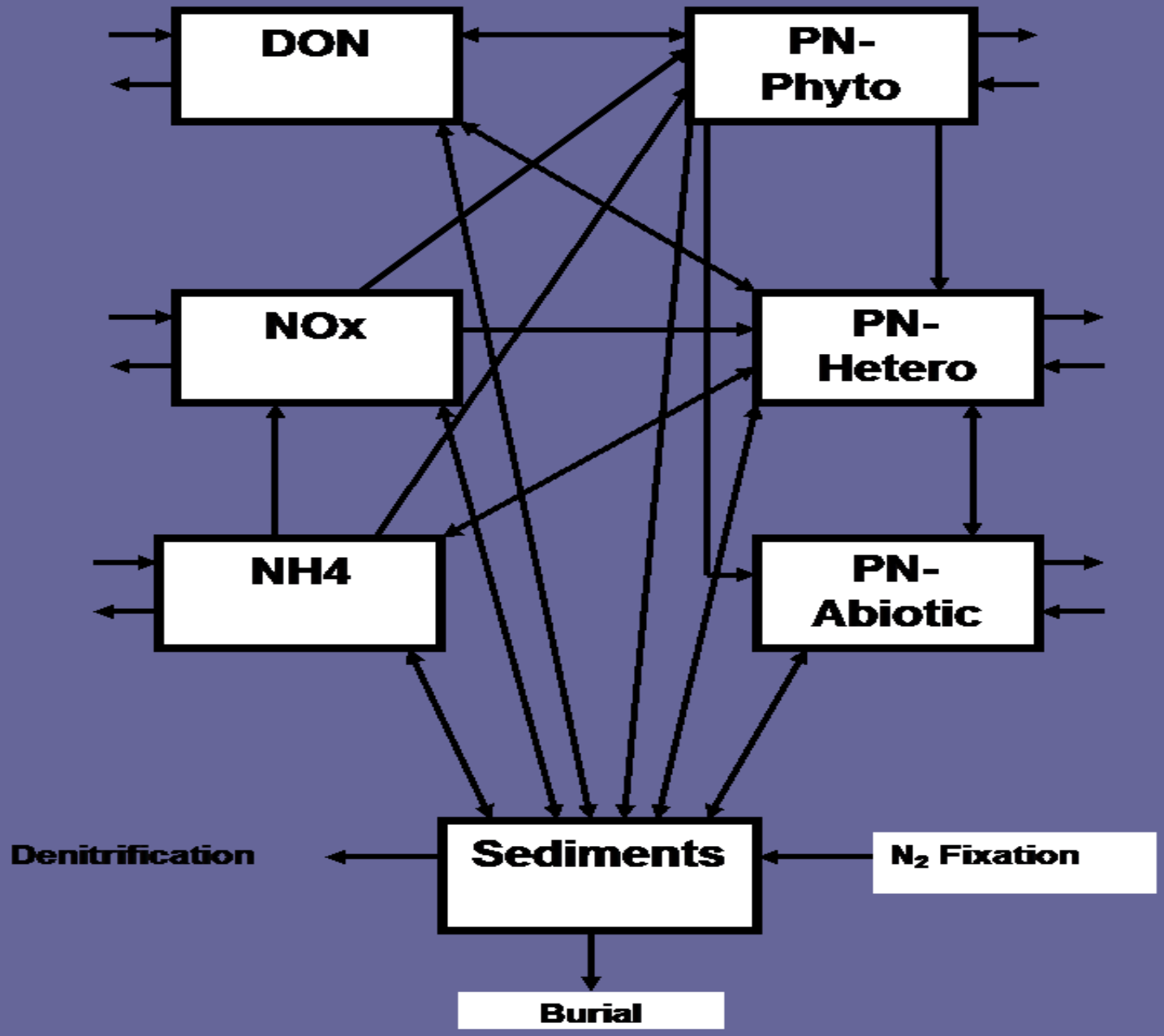
Historical Information on the Neuse River and Estuary from Studies by ECU

Measurements

- **General:** hydrology & WQ standing stocks
- **Planktonic metabolism:** primary productivity; DIN uptake; & ammonification. Metabolism vs. light.
- **Benthic metabolism:** exchange of DO, ammonium, nitrate, & phosphate. Exchange vs. light.

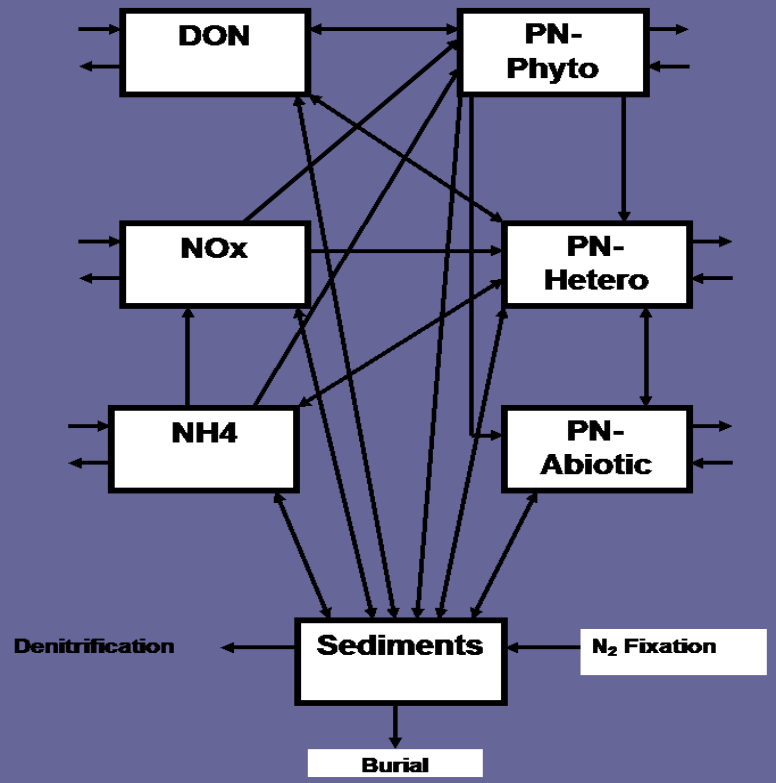
Information

- Standing stock & loading estimates and distributions.
- Temporally and spatially integrated process rates.
- Selected hydrology from head to mouth.
- Parameter and equation estimates for process rate mechanisms.


DON
PN-
Phyto
NOx
PN-
Hetero
NH4
PN-
Abiotic
Denitrification
Sediments
N_2 Fixation
Burial

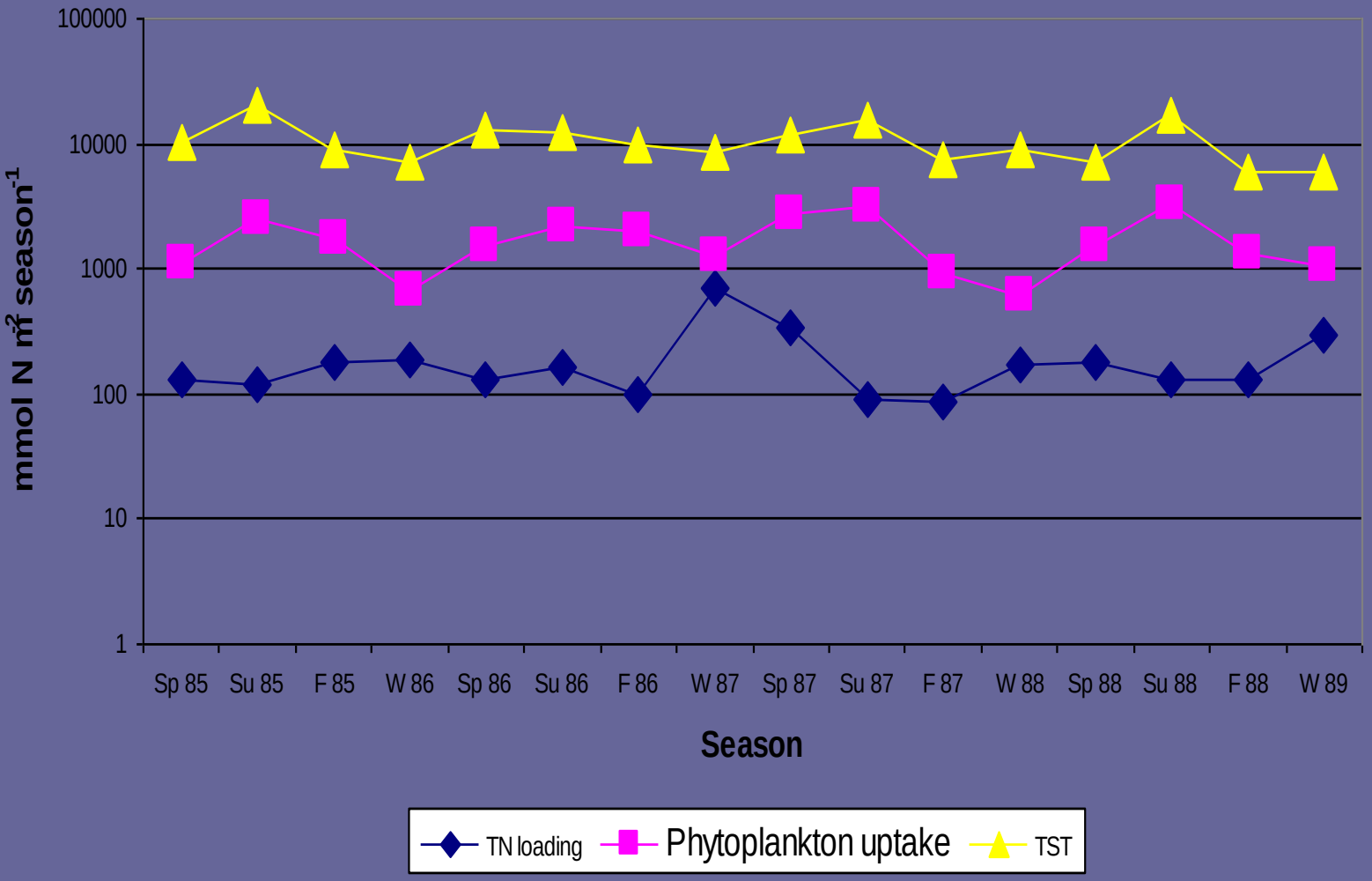
Selected Indices of Network Analysis

- **Total Systems Throughput (TST):** sum of all flows



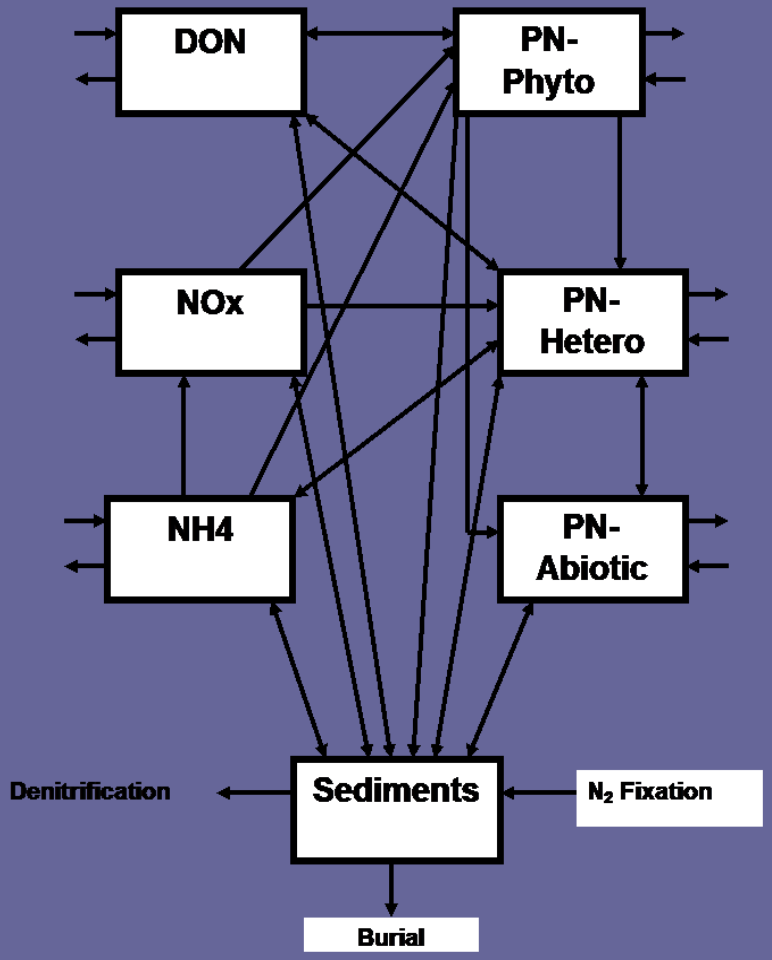
Processing of Nitrogen

(Order of magnitude increases (Loading < PP < TST))



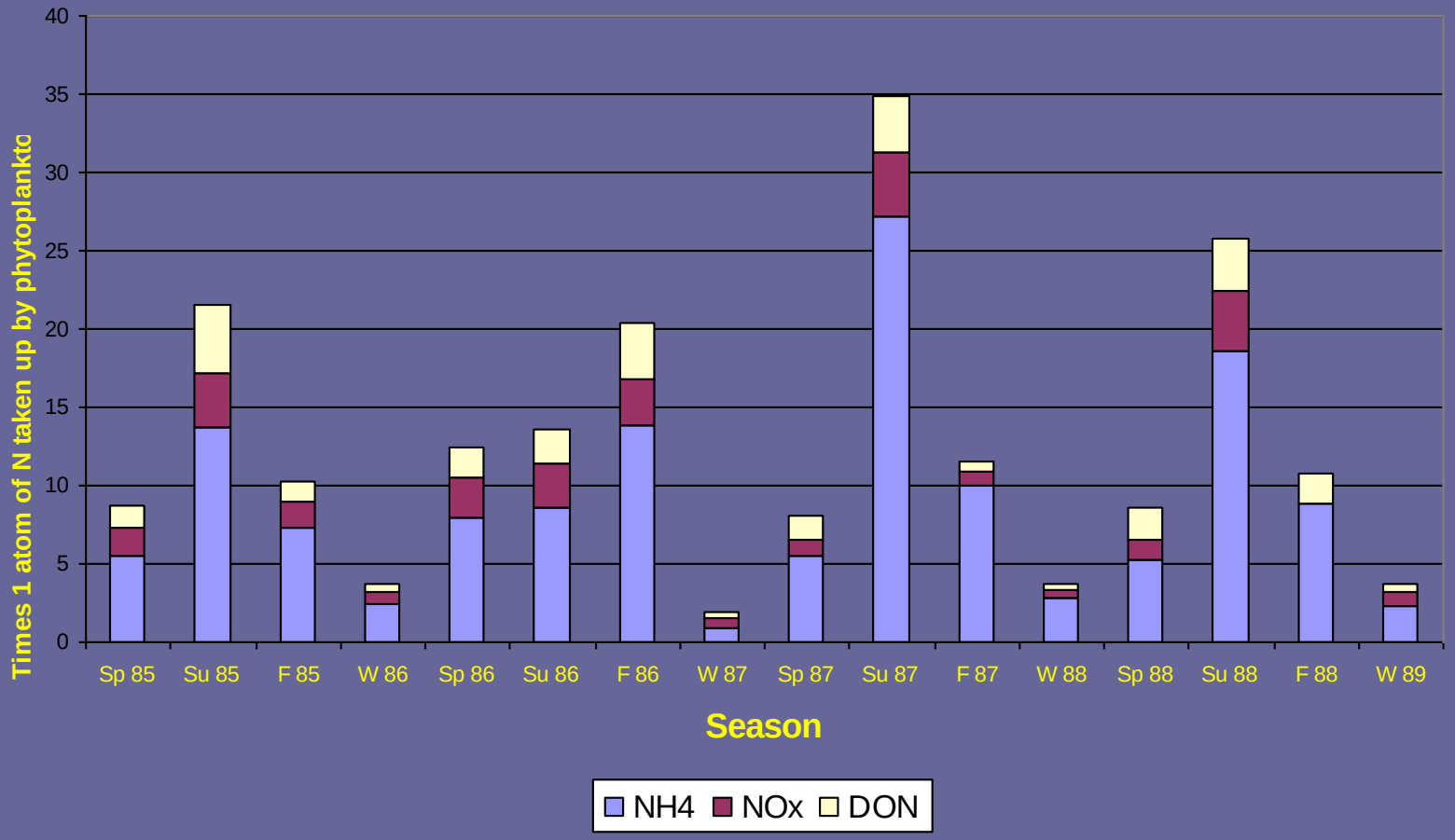
Selected Indices of Network Analysis

- **Frequency of processing:** the number of times an atom passes through a particular process relative to import of an atom by a particular route.



Uptake of N by Phytoplankton based on N Loaded as Nitrate

(N is used 2 to 35 times for PP)

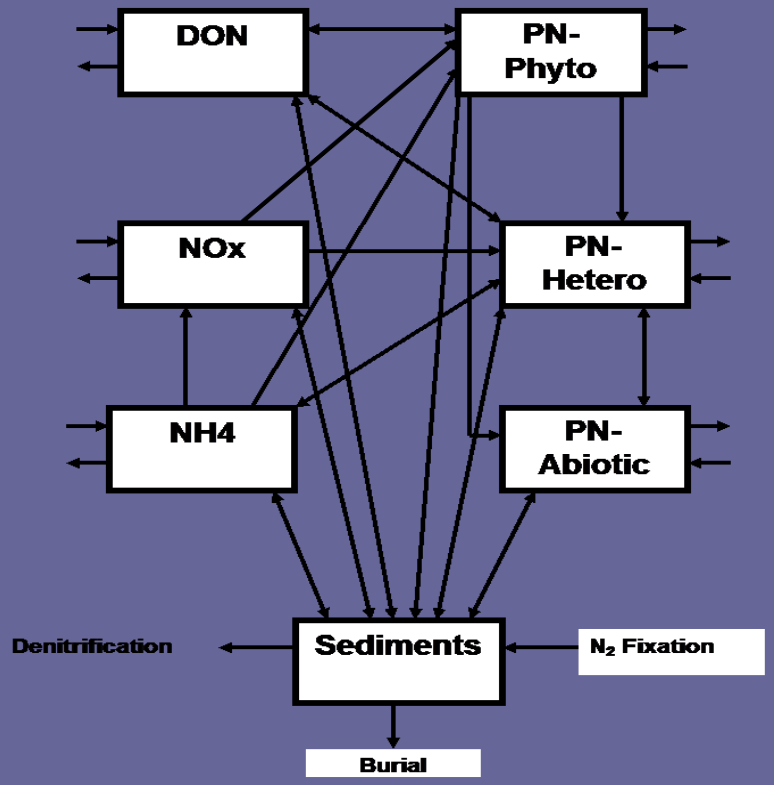


Selected Indices of Network Analysis

- **Finn Cycling Index (FCI):**

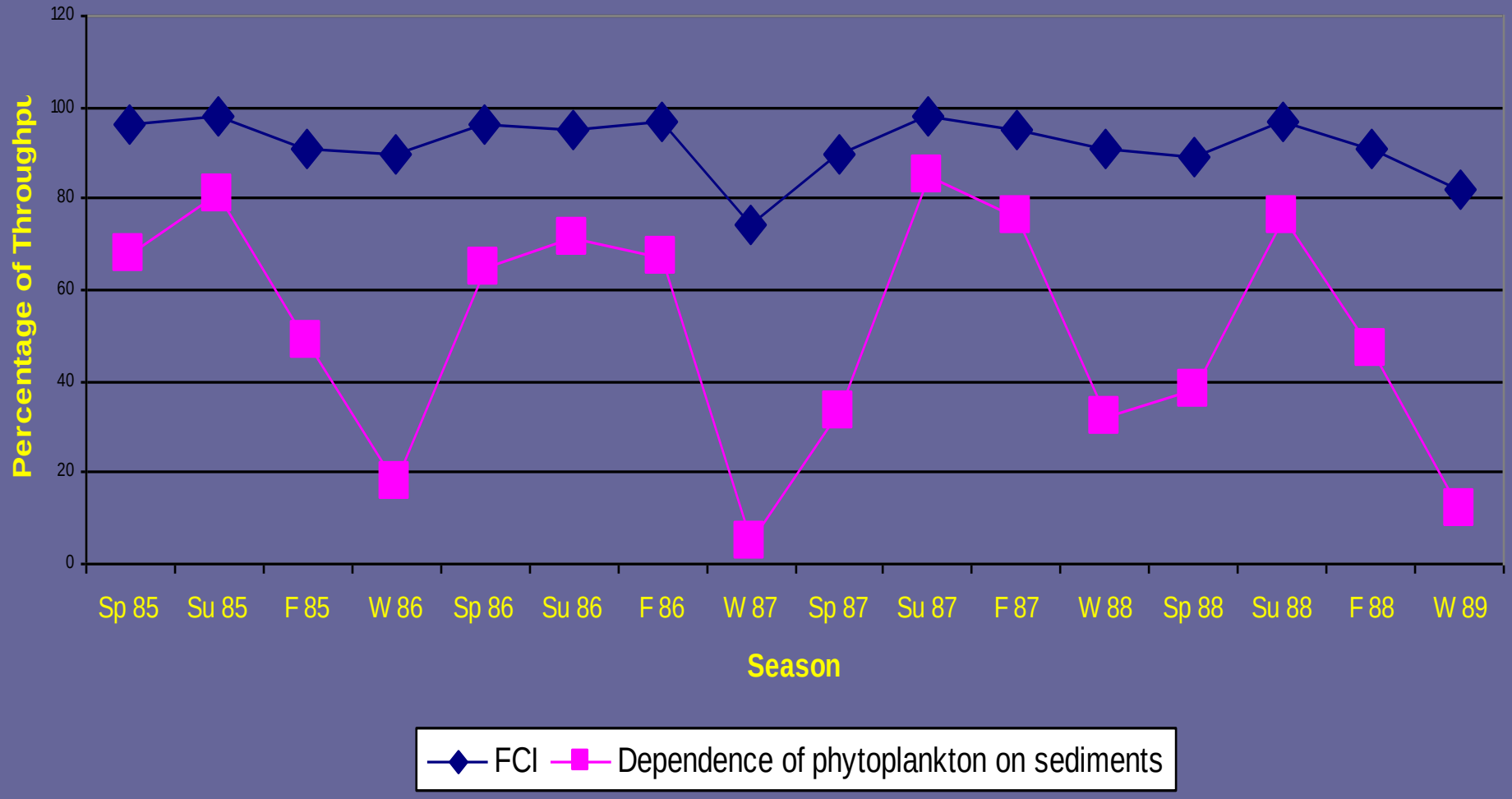
  % of TST involved in internal cycling

Total dependence by one compartment on another: the % of input to a compartment that once resided in another through both direct and indirect pathways.



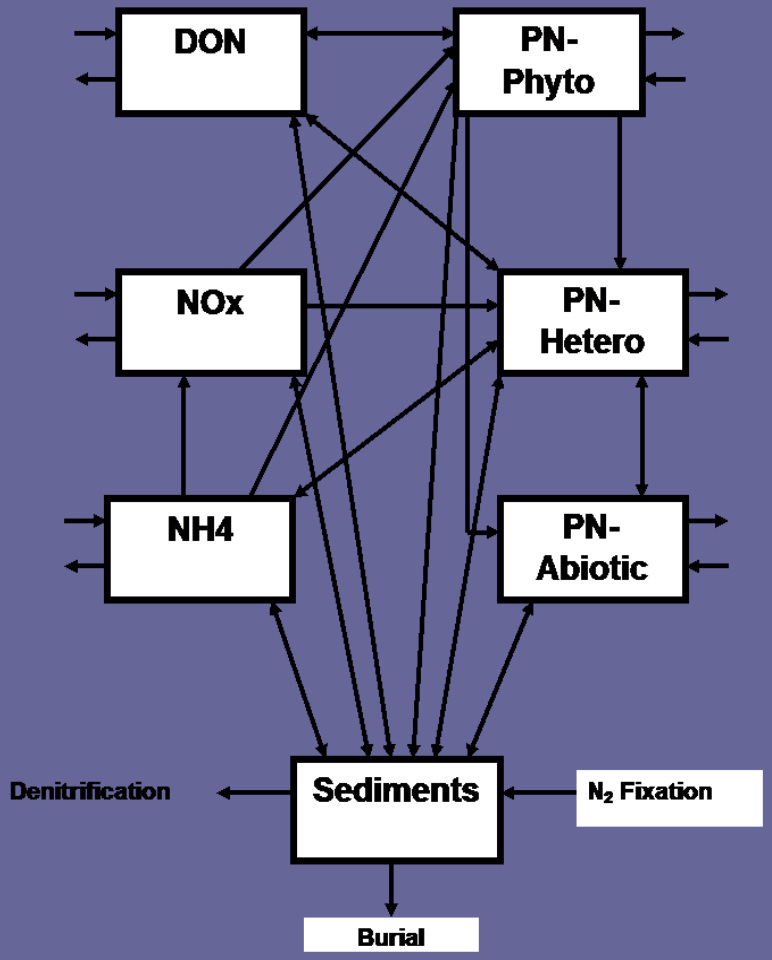
Recycling of Nitrogen

(High recycling with seasonal changes)



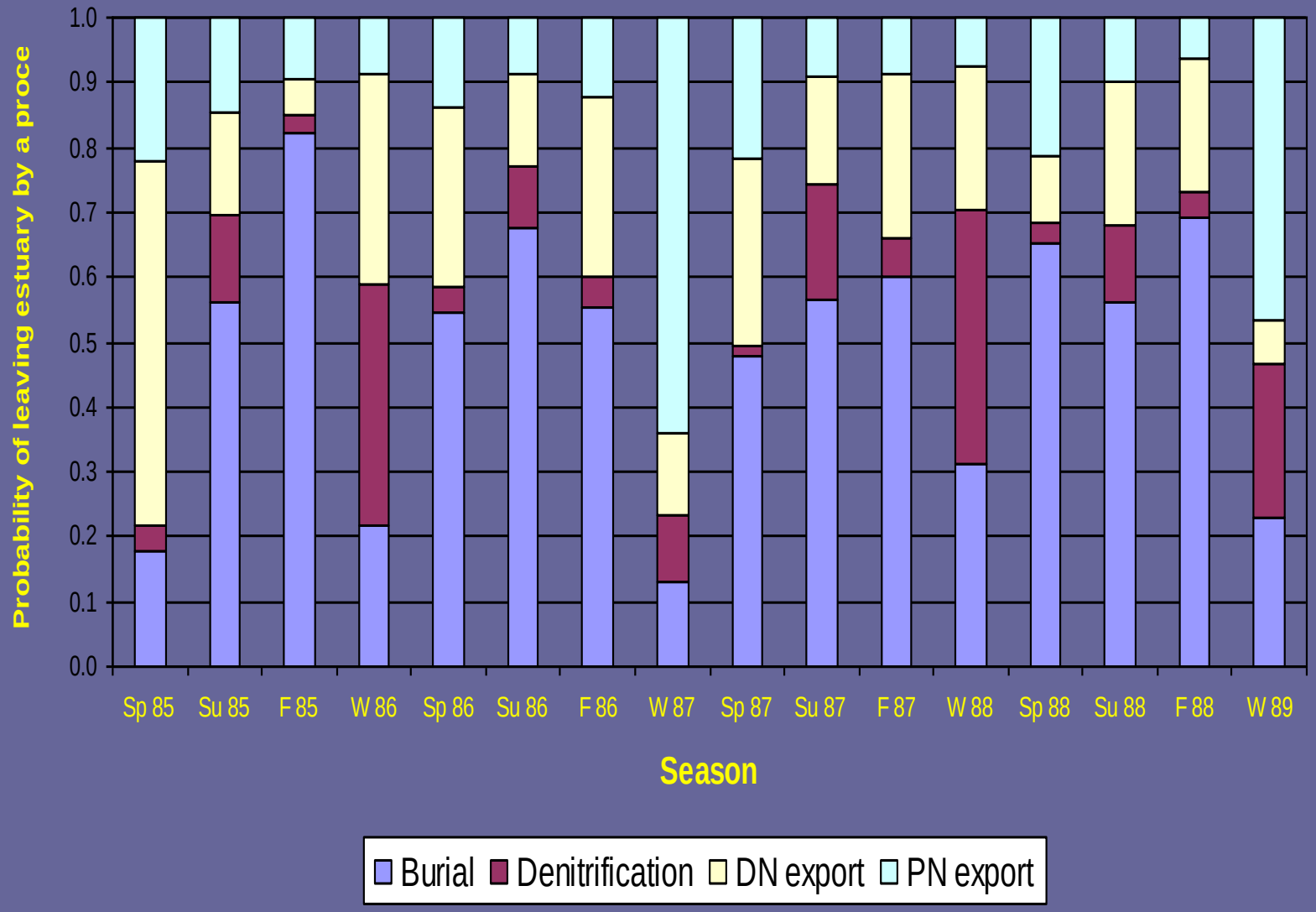
Selected Indices of Network Analysis

- **Probability of path of export:** the probability an atom imported in a particular way exports the system by a particular route.

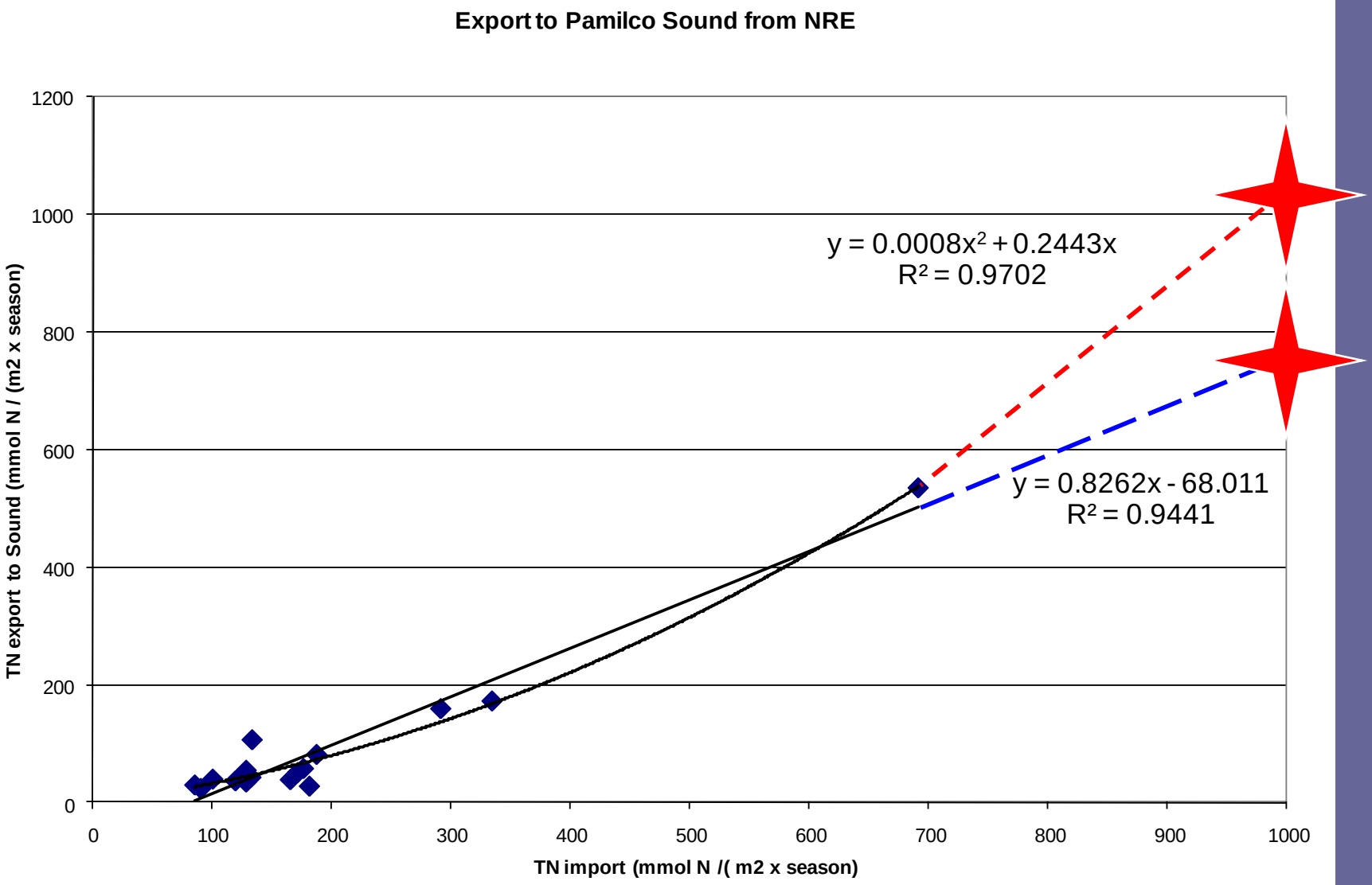


Exports of Loaded Nitrate-N

(Seasonal and flow effects on distribution of exports)



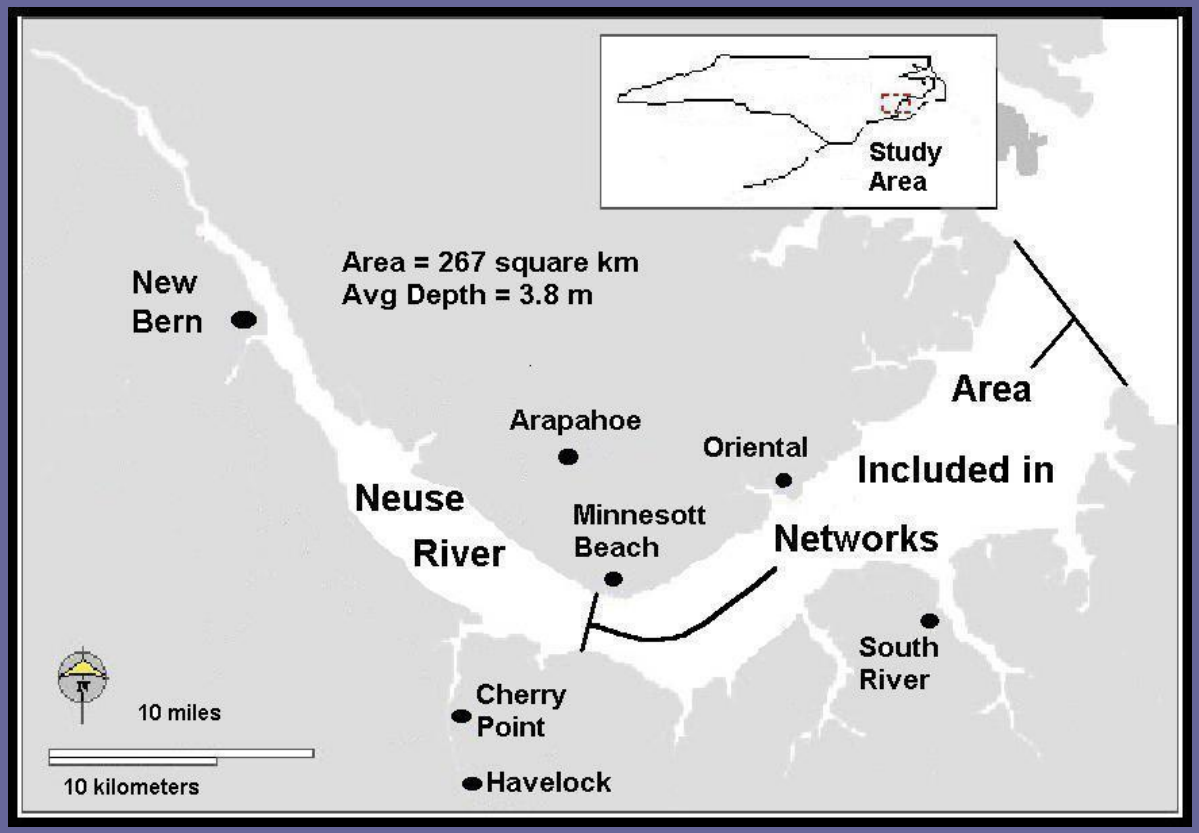
Hurricane Floyd Effects



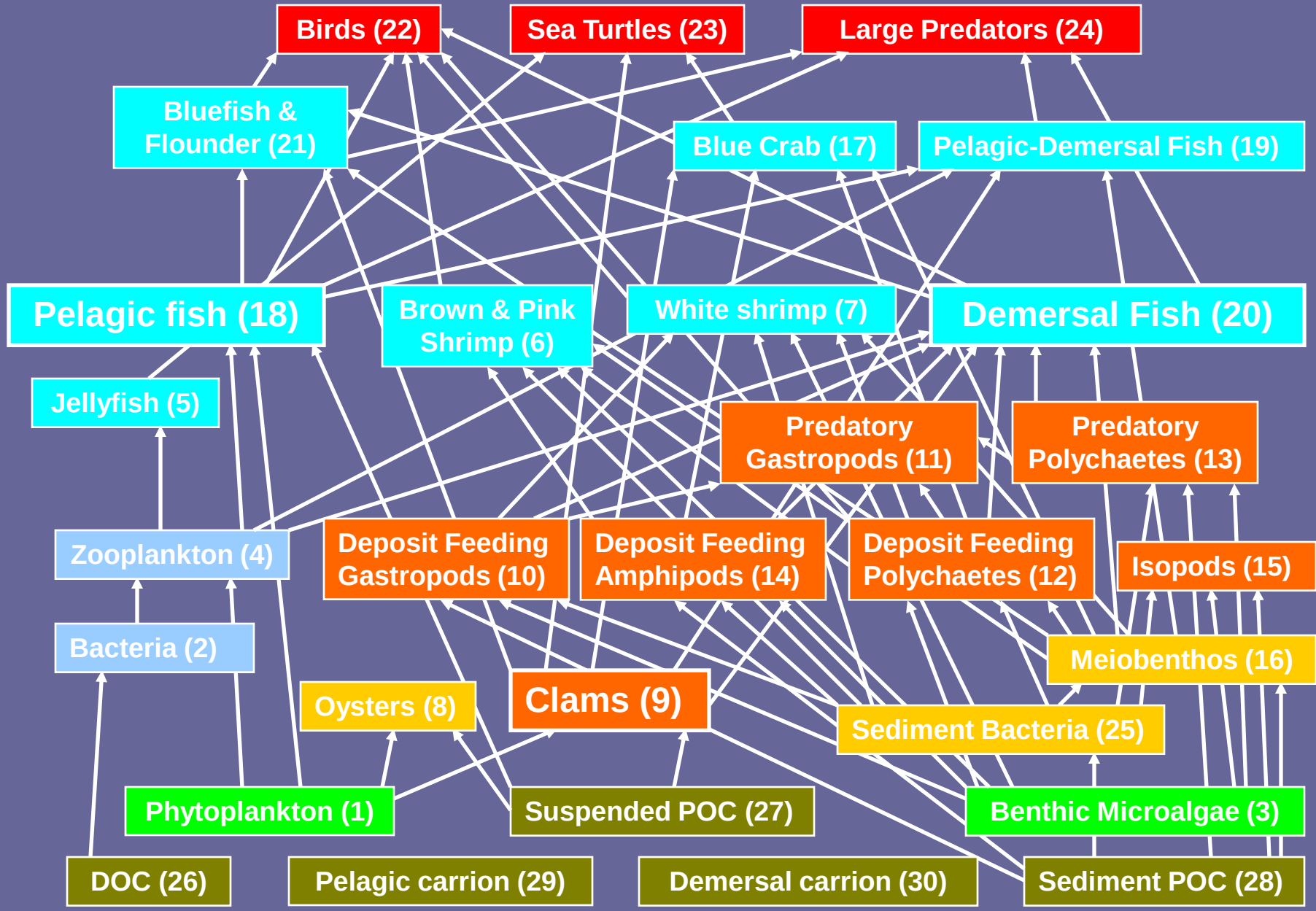
Summary of Nitrogen Cycling in Neuse River Estuary

- Processing of N substantially more than loading = recycled N dominates processing
- Recycling is associated with the short turnover times of microorganisms during the relatively long residence of water within the system
- Primary production disconnected from loading (little correspondence, not shown) = response to loading reduction would be delayed
- NRE can filter N before water enters Pamlico Sound but importance depends on residence time and time of year

Effects of Hypoxia and Fish Kills on the Food Web of the Neuse River Estuary



Baird, D., R. R. Christian, C. H. Peterson, and G. Johnson. 2004. Consequences of hypoxia on estuarine ecosystem function: energy diversion from consumers to microbes. Ecological Applications 14: 805-822.


Birds (22)
Sea Turtles (23)
Large Predators (24)
Bluefish & Flounder (21)
Blue Crab (17)
Pelagic-Demersal Fish (19)
Pelagic fish (18)
Brown & Pink Shrimp (6)
White shrimp (7)
Demersal Fish (20)
Jellyfish (5)
Predatory Gastropods (11)
Predatory Polychaetes (13)
Zooplankton (4)
Deposit Feeding Gastropods (10)
Deposit Feeding Amphipods (14)
Deposit Feeding Polychaetes (12)
Isopods (15)
Bacteria (2)
Meiobenthos (16)
Oysters (8)
Clams (9)
Sediment Bacteria (25)
Phytoplankton (1)
Suspended POC (27)
Benthic Microalgae (3)
DOC (26)
Pelagic carrion (29)
Demersal carrion (30)
Sediment POC (28)

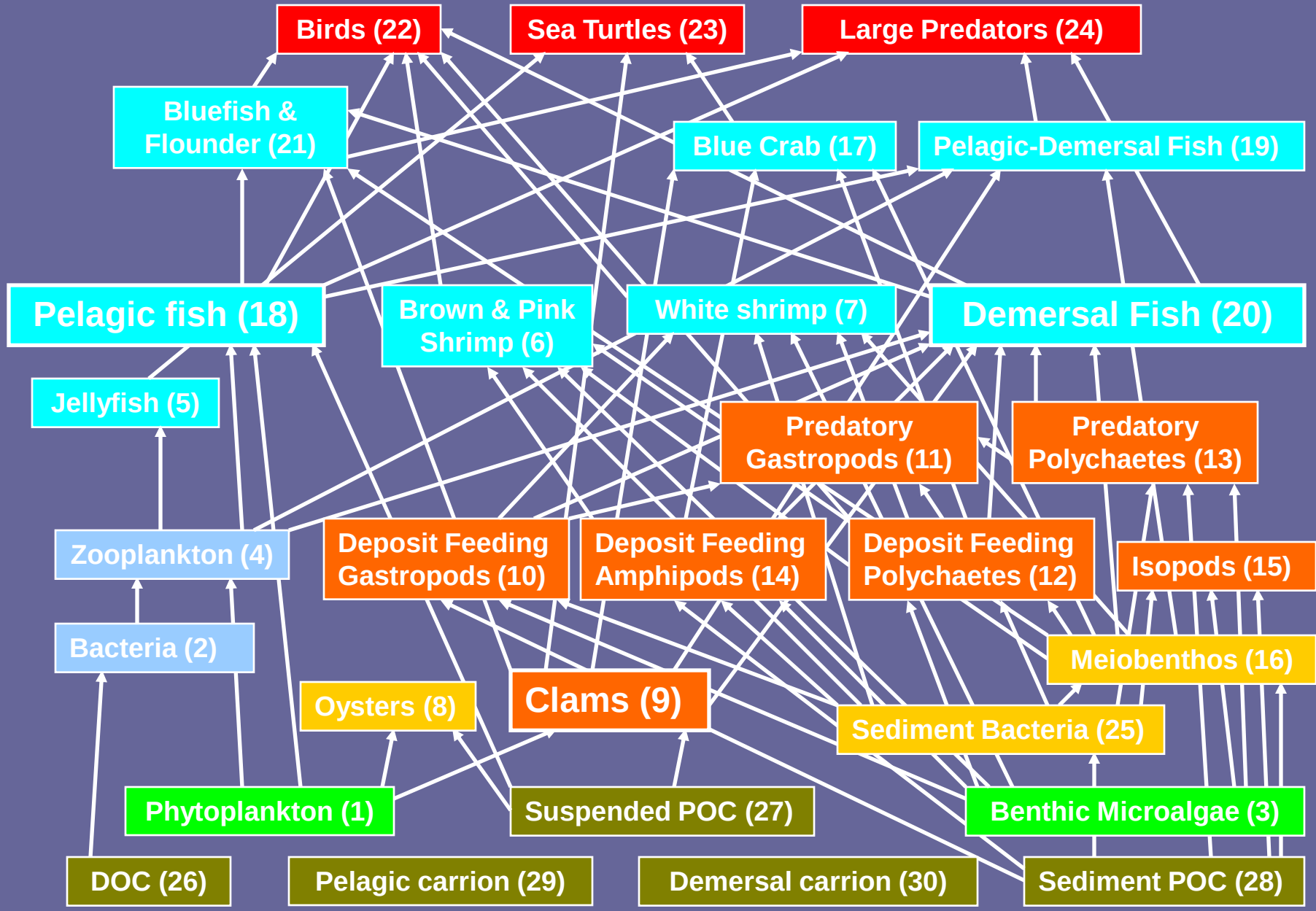
Effects of Hypoxia and Fish Kills on Neuse Food Web

- Provide a reference index of foodweb status for the NRE (not to be discussed)
- Determine effects of hypoxia on benthic/pelagic linkage (indirect effects of eutrophication)
- Place fish kill effects in ecosystem perspective
- Evaluate effects of uncertainty of network analysis (not to be discussed)

NRE foodweb networks and effects of hypoxia

- Four food web networks
  - early and late summer of 1997 & 1998
  - 30 compartments
- Analyzed with NETWRK4 & Ecopath 4.0
- Carbon used as the currency
  - biomass (mgC/m^2) and flows ($mgC/(m^2\ d)$)

Group	Location	Source of Data
Nekton	Neuse	1997 & 1998 DMF Surveys
Macrobenthos	Neuse	Luettich et al. 2000
Phytoplankton	Neuse	Luettich et al. 2000
Benthic Microalgae	Neuse	Johnson, Unpublished Data 1998
Free Living Bacteria	Neuse	Christian et al. 1984
Sediment Bacteria	Ches Bay	Baird and Ulanowicz 1989
Zooplankton	Neuse	Mallin and Paerl 1994
Oysters	Neuse	Grabowski, Unpublished Data 1996
Meiobenthos	Ches Bay	Baird and Ulanowicz 1989
Birds	Neuse	Parnell et al. 1993
Sea Turtles	Neuse	Epperly et al. 1995
Large Predators	Neuse	Schwartz 1995; Gannon, Unpub Data 1990s
Detritus	Neuse	Christian, Unpublished Data 1980s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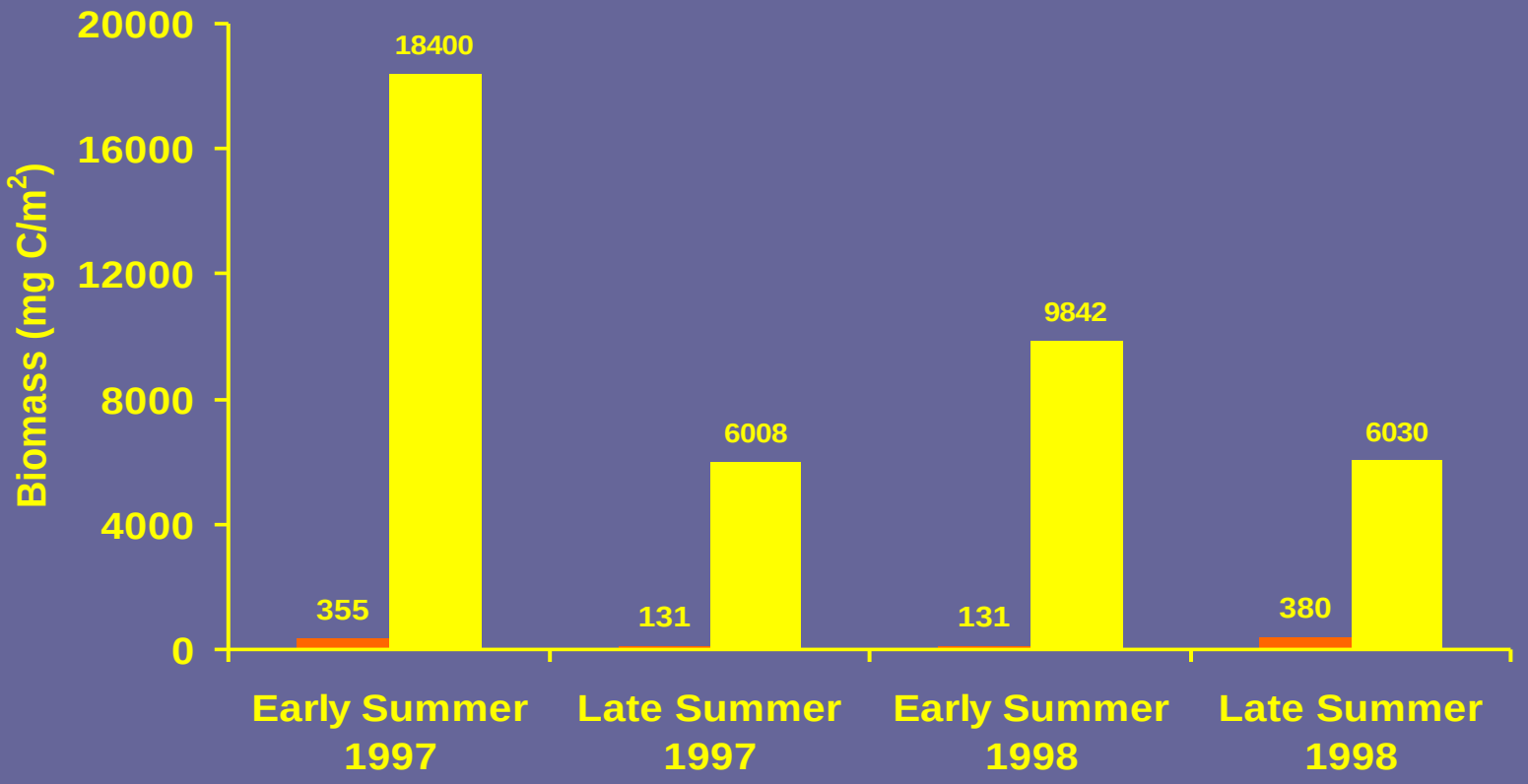
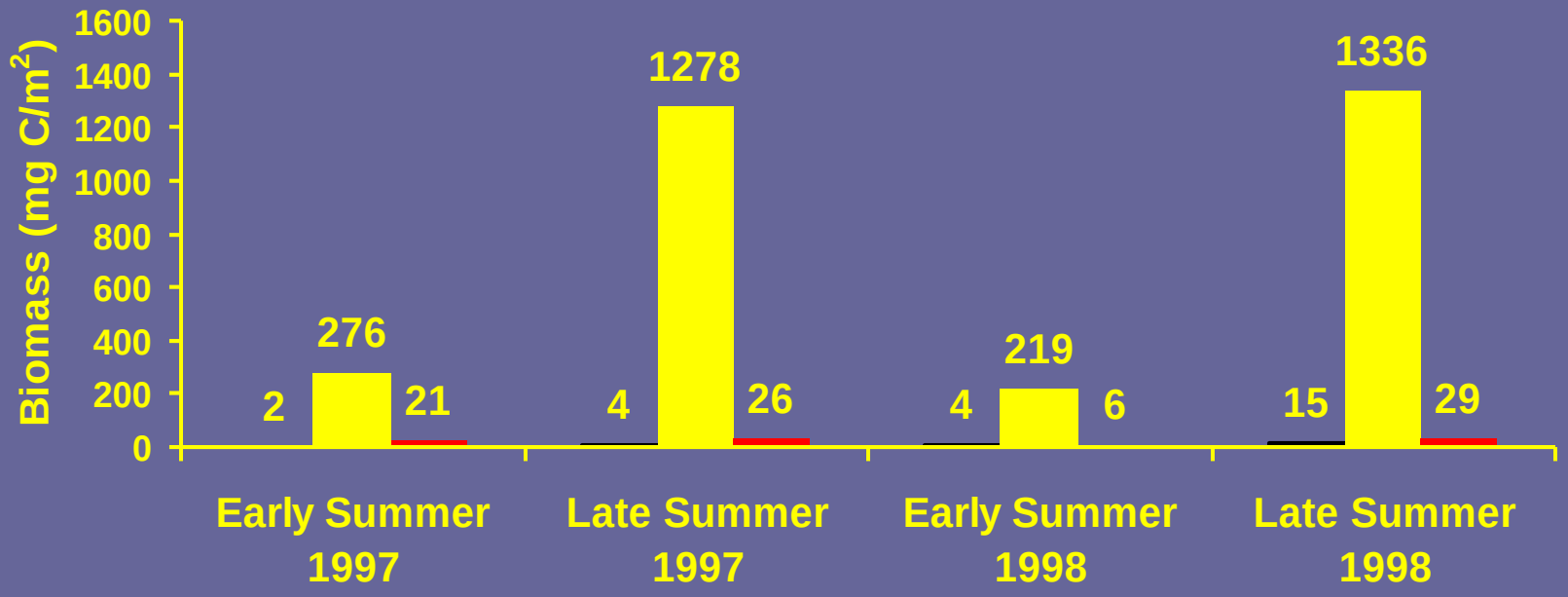
Biomass of "Easily Measured" Groups of Macrofauna Used in Reference Foodweb Networks (*Macoma* spp. dominate)



Biomass of "Easily Measured" Groups of Nekton Used in the Reference Foodweb Networks (Demersal fish dominate)



Effects of Fish Kills and Die-off of Benthos

- **Approach**
  - **Compare two years with different degrees of hypoxia (1997 worse than 1998)**
  - **3 types of die-offs simulated: pelagic fish (menhaden), demersal fish (spot), clam (*Macoma spp*)**

- **Response variables**
  - **Ecosystem-level**
  - **Population bioenergetic**

Ecosystem –level Response Summary

- At the scale of the entire lower NRE, ecosystem-level attributes were often minimally affected by fish kills and benthic die-offs
- Ecosystem effects involved less carbon/energy passing to higher trophic levels and more dissipation by microorganisms (long-term eutrophication effect?)
- Such results are supported by nitrogen dynamics and importance of recycling

Smaller-scale Response Summary

- Effects at the compartment level if standing stocks are low (Increased Ecotrophic Efficiency = pressure on prey production and potential for food limitation on predator)

- Limitations of Analysis:
  - Scale: lower NRE vs. local impacts
  - Migration
  - Alterations in Diet
  - Lack of time dependent dynamics