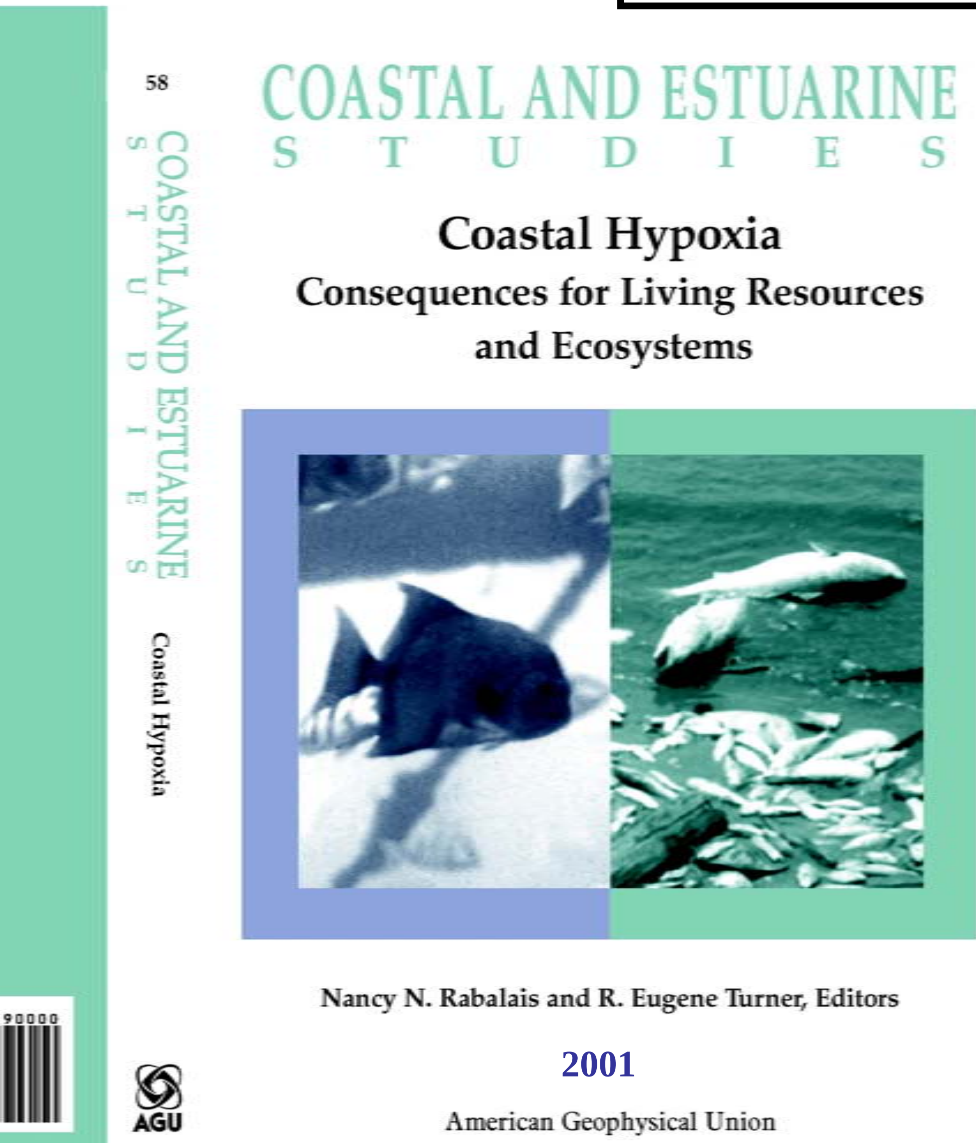
# SYNTHESIS

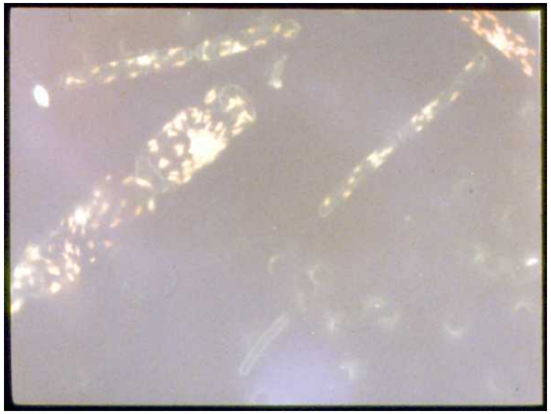



| | |
|---|---|
| Donald M. Baltz | Carrie J. McDaniel |
| Denise L. Breitburg | Nancy H. Marcus |
| Louis E. Burnett | James N. Nance |
| John F. Caddy | Leif Pihl |
| Edward J. Chesney | Emil Platon |
| Daniel J. Conley | Sean P. Powers |
| J. Kevin Craig | Jennifer Purcell |
| Larry B Crowder | Naureen Azia Qureshi |
| Mary Beth Decker | Nancy N. Rabalais |
| Robert J. Diaz | Kevin A. Raskoff |
| Quay Dortch | Rutger Rosenberg |
| John W. Fleeger | Barun K. Sen Gupta |
| William M. Graham | Joseph W. Smith |
| Charlotte D. Gray | Lorene E. Smith |
| James G. Hanifen | William B. Stickle |
| Donald E. Harper, Jr. | R. Eugene Turner |
| Tyrrell A. Henwood | John M. Ward |
| Alf B. Josefson | Markus A. Wetzel |
| Dubravko Justić | Marsh J. Youngbluth |
| Walter R. Keithly, Jr. | Roger J. Zimmerman |
| Sarah E. Kolesar | |

1. Increased nutrient loading results in increased incidence or size of hypoxia
2. Behavioral and physiological responses to hypoxia by individual organisms
   a) nekton
   b) zooplankton
   c) epibenthos
   d) benthic organisms
3. Benthic community response to hypoxia
4. Commercial fisheries species response to hypoxia
   a) menhaden
   b) shrimp
   c) other large nekton
5. Sea turtle and marine mammal responses to hypoxia
6. Food web responses to hypoxia or to causes of hypoxia
   a) by primary producer community
   b) by secondary producer or higher
   c) jellyfish
7. Officer and Ryther's [1980] prediction supported (regarding Si:N loading ratio)
8. Evidence for rapid decline in resource after period of gain (a catastrophic decline)
9. Societal recognition of the effects of hypoxia on fisheries
   a) recognize possible effects
   b) implemented management to reduce nutrient loading

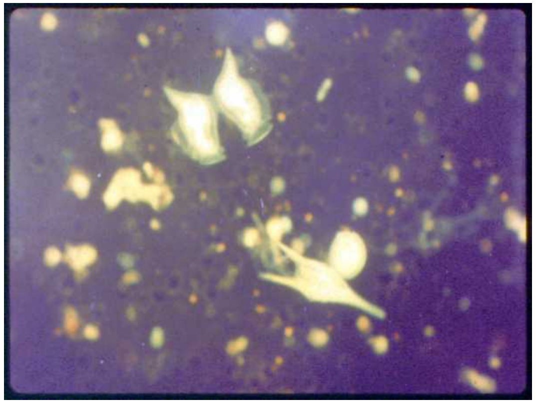
# Evidence of Increased Diatom production, as N ↑
# Evidence of Silica Limitation, as Si↓ & Si:N of 1:1


←Shifts from Heavily Silicified Diatoms



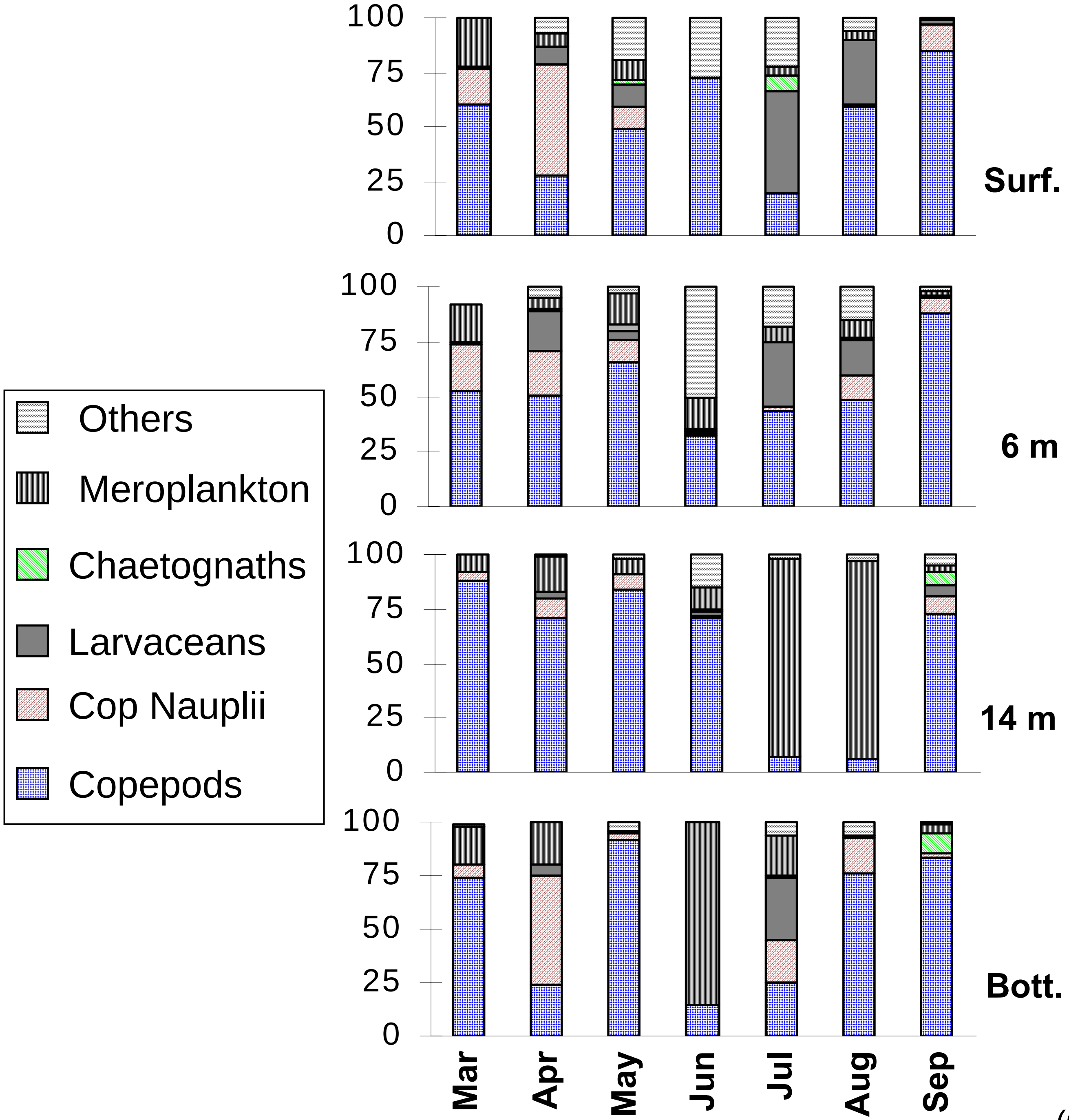
To Lighlty Silicified Diatoms→

& Non-Silicified, Flagellates→

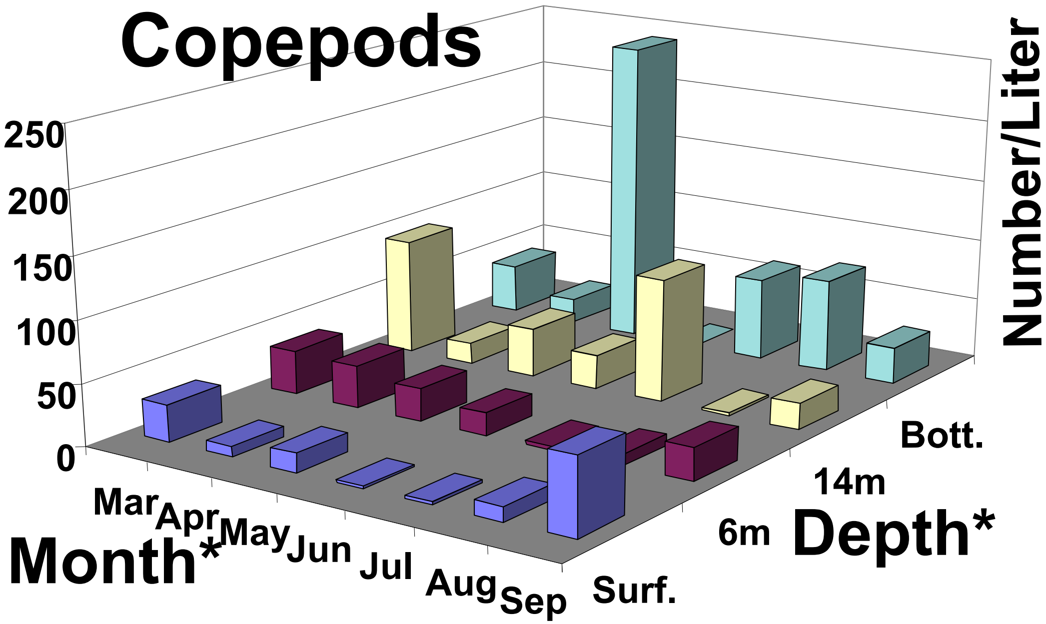


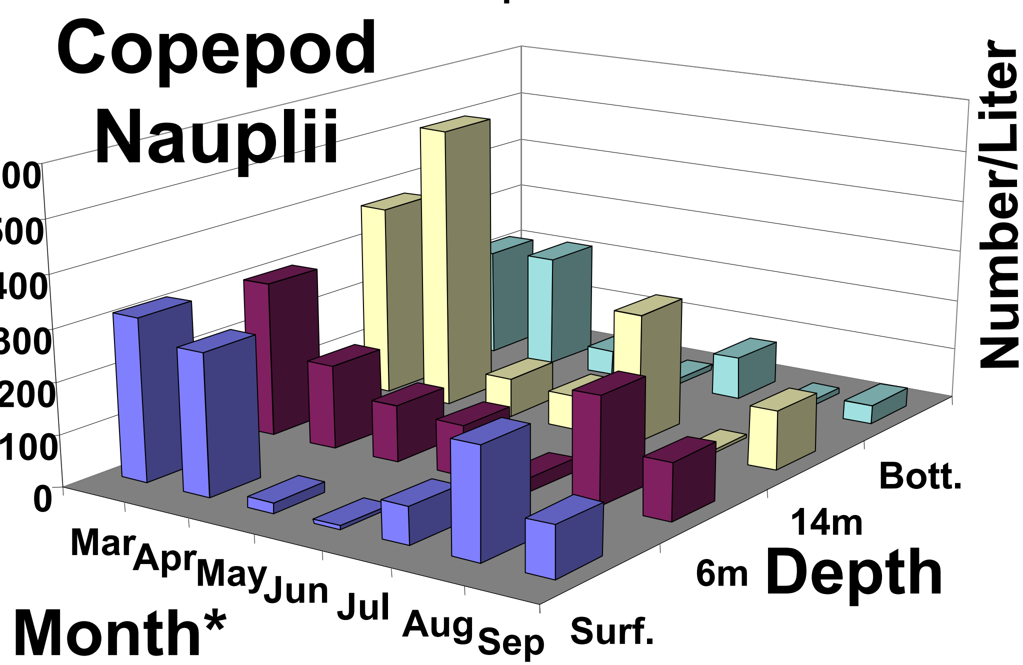
| Si:N | Phytoplankton | Consequences |
|---|---|---|
| >1 | Sinking Diatoms | Persistent Hypoxia |
| +1 | Non-sinking Diatoms | Seasonal Hypoxia |
| | Non-Diatoms | Sporadic Harmful Algal Blooms |
| | Non-Diatoms | Frequent Harmful Algal Blooms |
| <1 | Non-sinking Diatoms | Algal Blooms |

(Turner & Rabalais 1994; Turner et al. 1998; Dortch et al. 2001)



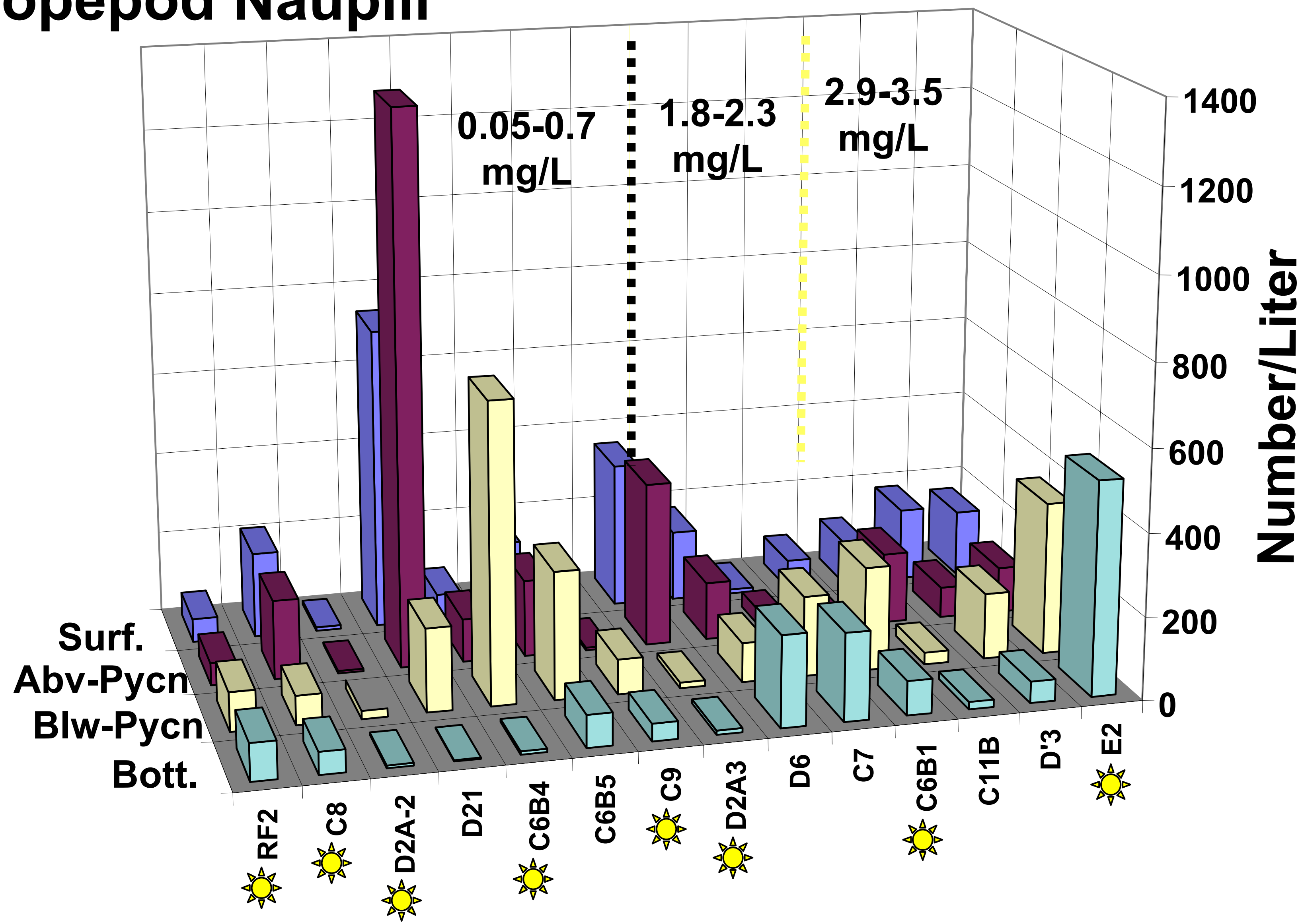

(Qureshi & Rabalais 2001)




(Qureshi and Rabalais 2001)

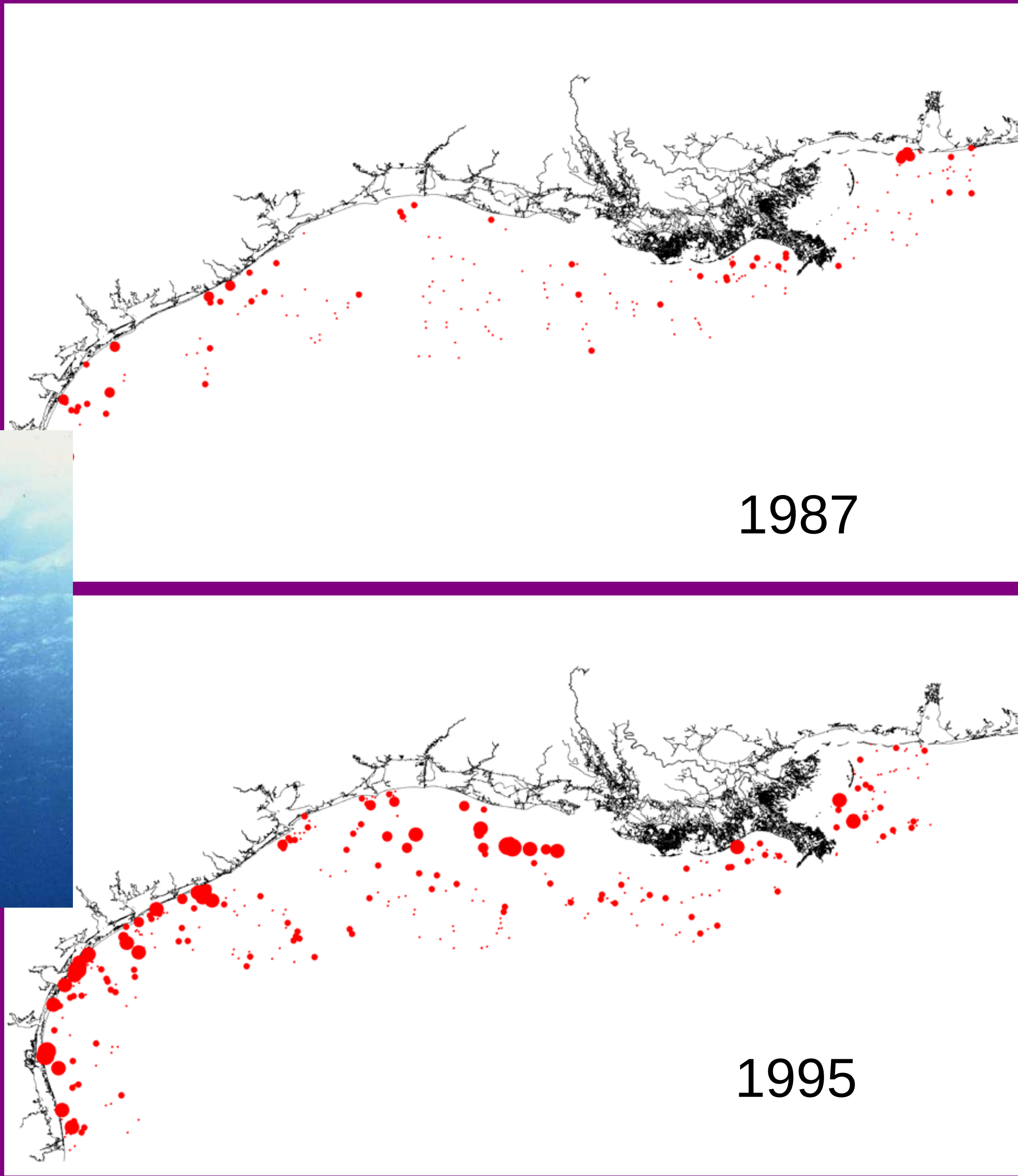
# Copepod Nauplii




(Qureshi and Rabalais 2001)

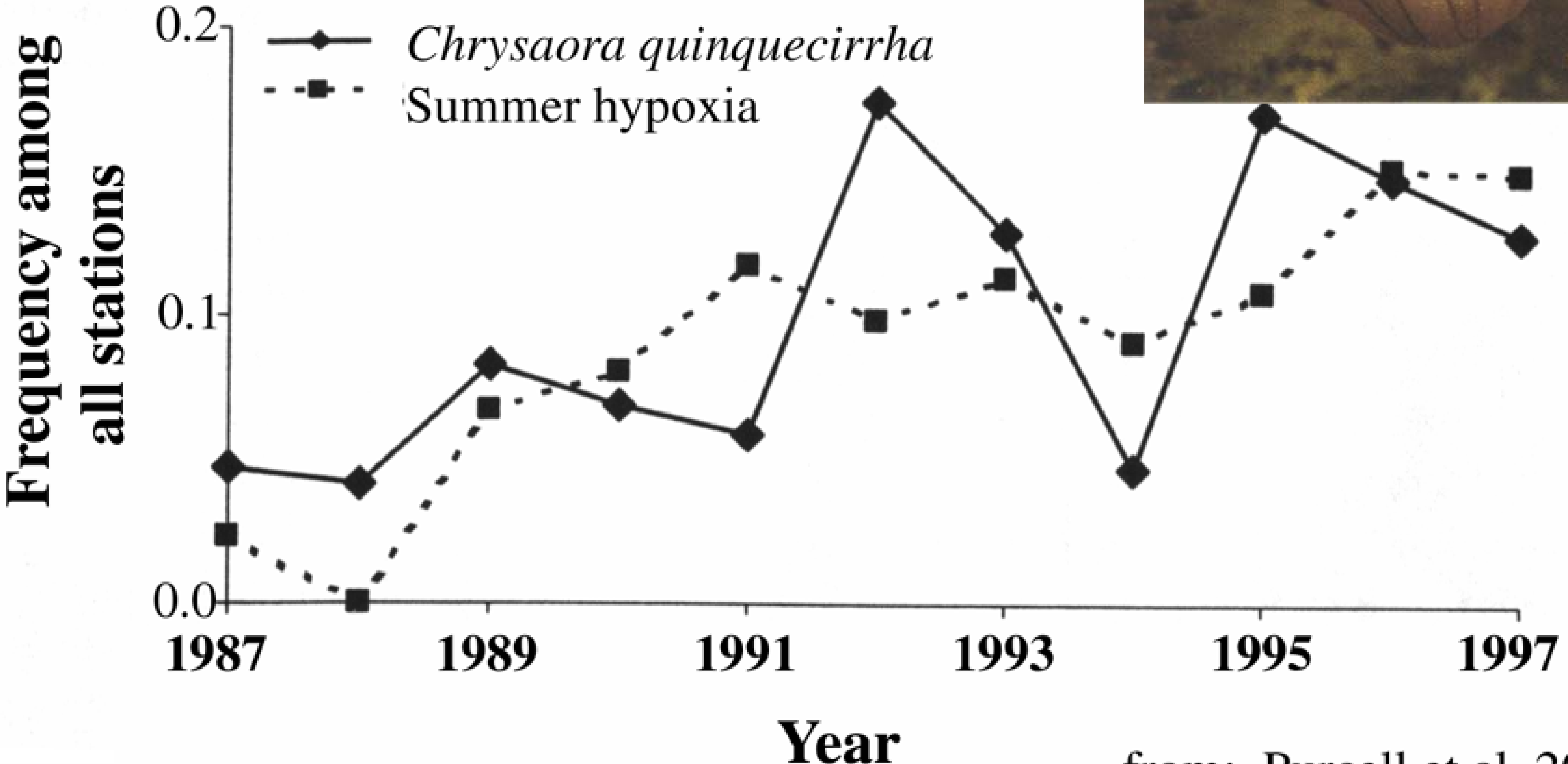
# Jellyfish abundance: an indicator of altered food webs

*Aurelia* moon jelly

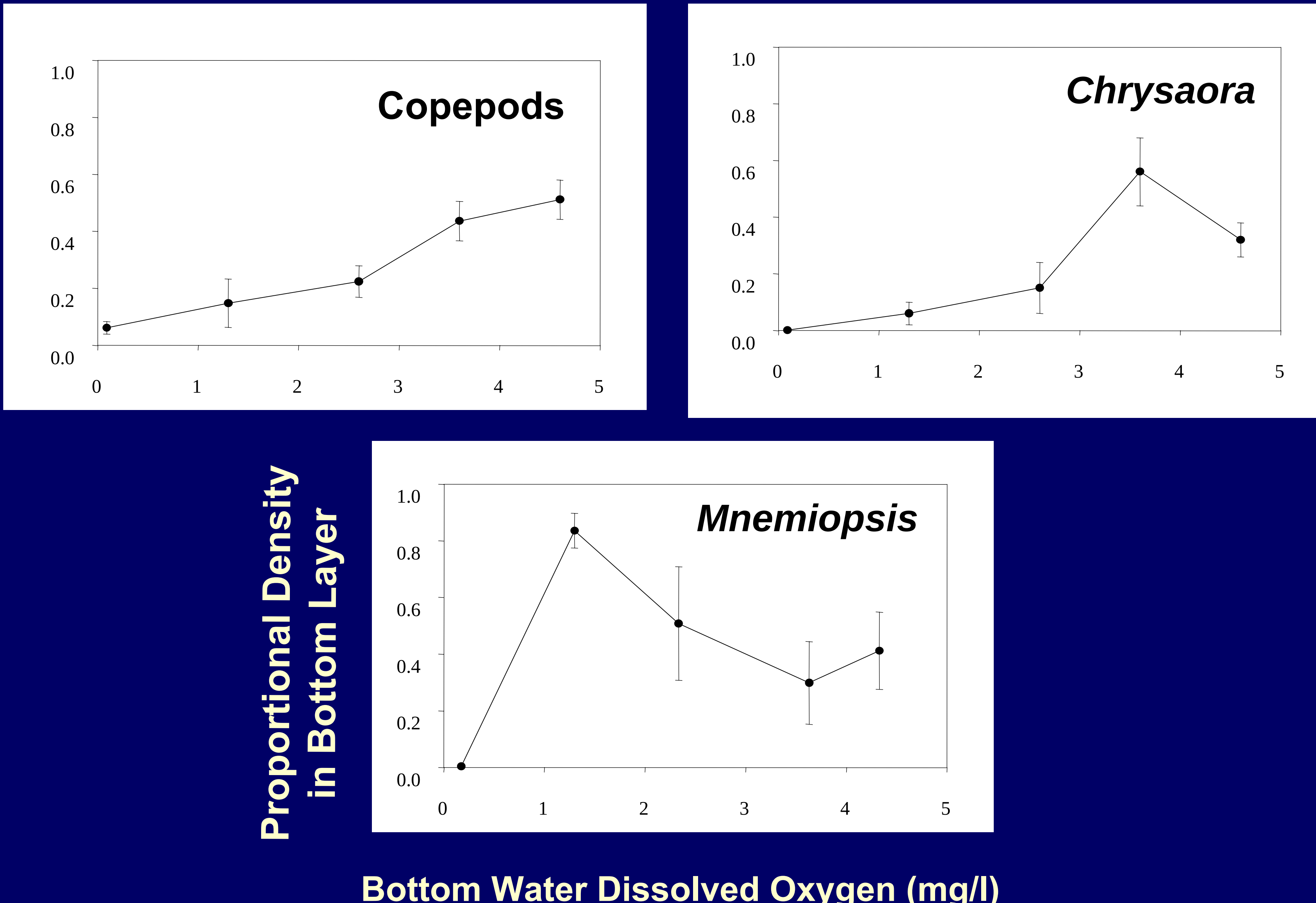



Source: M. Graham, DISL

# Jellyfish abundance: an indicator of altered food webs




from: Purcell et al. 2001

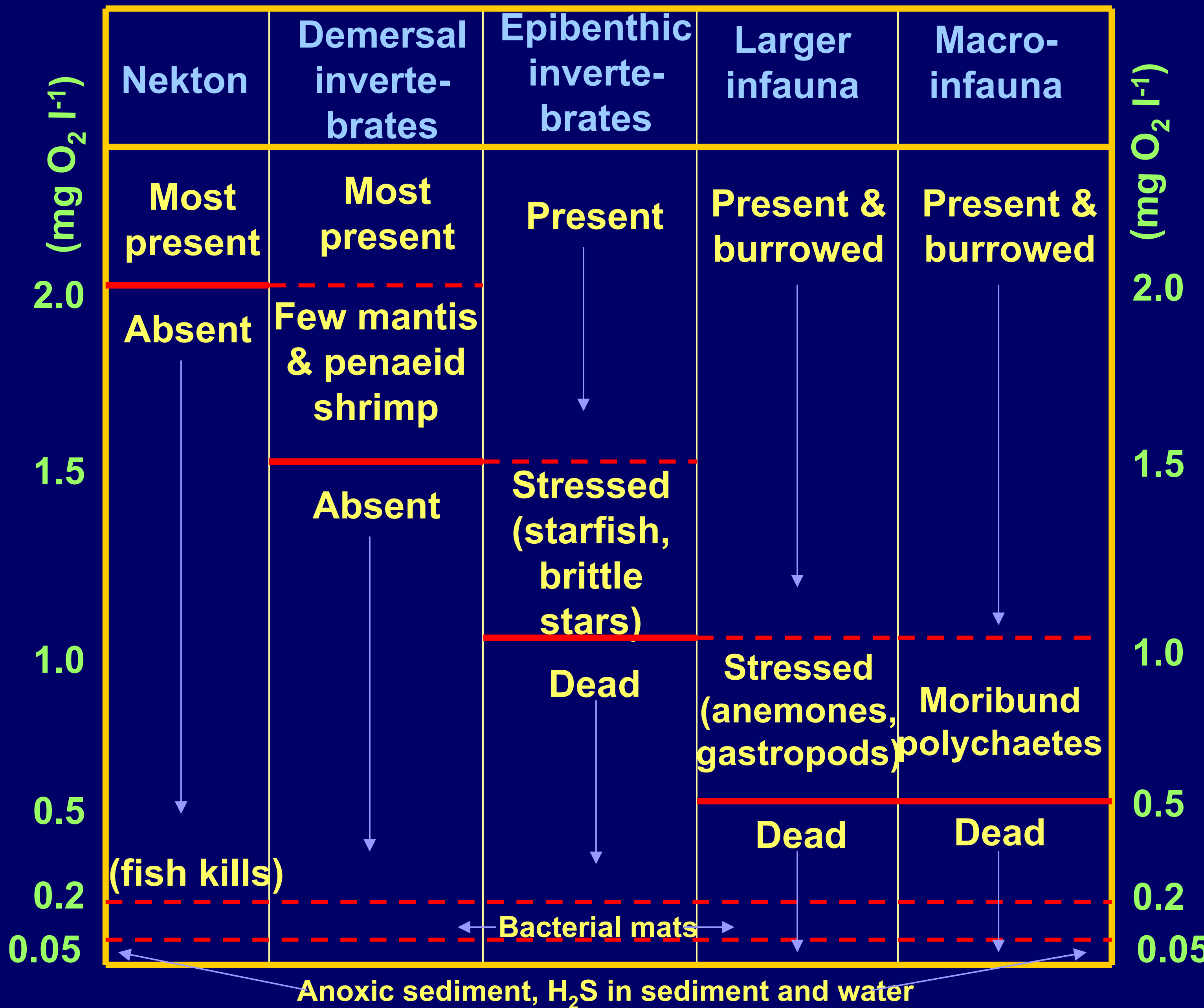



(Purcell et al. 2001)

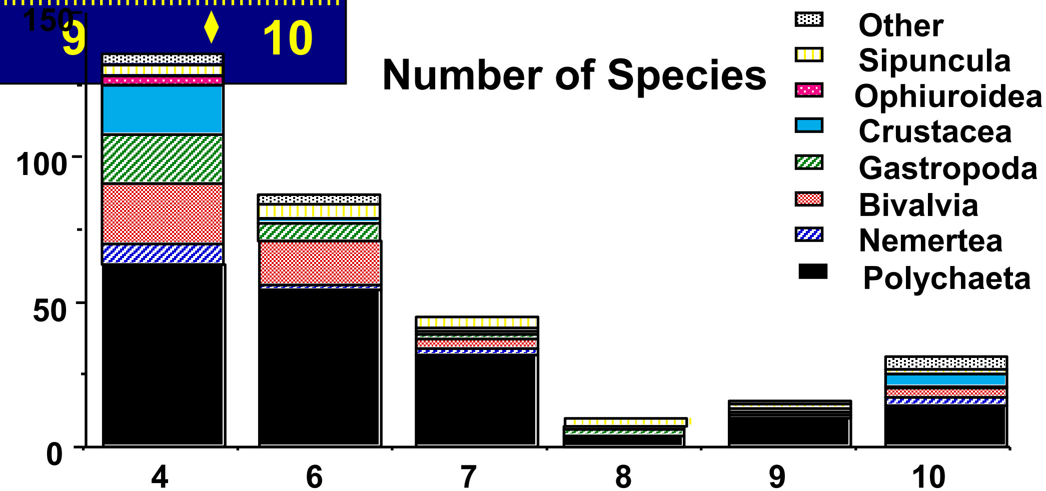
TABLE 1. Behavioral and physiological responses of different organisms to hypoxia.

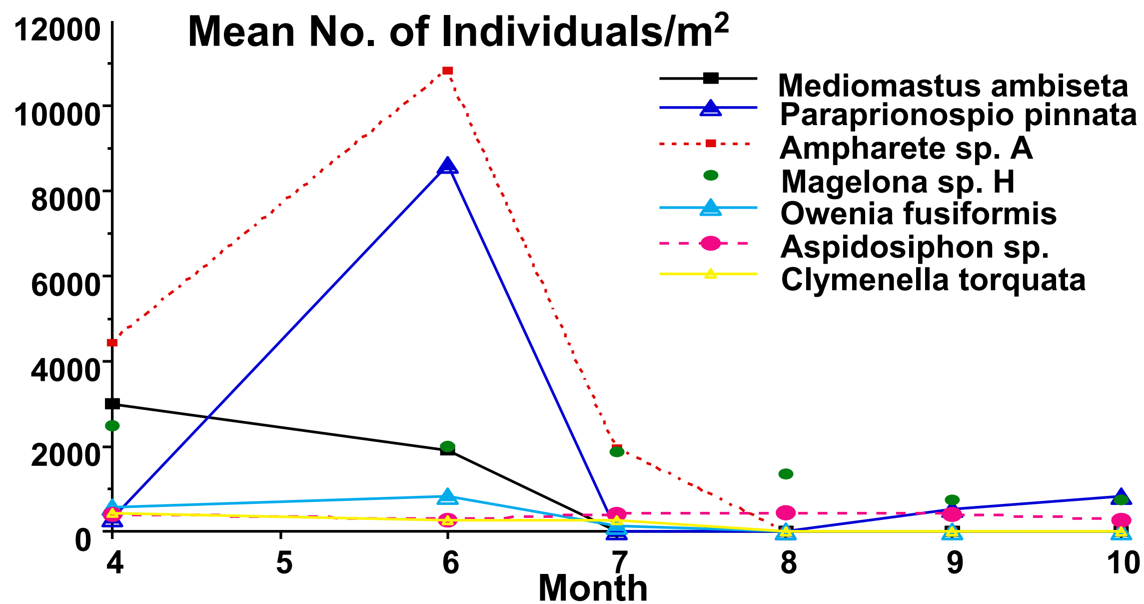
| Organism | Response to Hypoxia | Reference |
|---|---|---|
| Shrimp | | |
| *Penaeus aztecus* | detect and avoid | Renaud, 1986 |
| *Penaeus setiferus* | detect and avoid | Renaud, 1986 |
| *Penaeus monodon* | decrease hemocyte phagocytosis | Direkbusarakom & Danayadol, 1998 |
| *Penaeus stylirostris* | decrease total hemocyte count | Le Moullac et al., 1998 |
| | increased mortality induced by *Vibrio alginolyticus* | Le Moullac et al., 1998 |
| Crabs | | |
| *Callinectes sapidus* | detect and avoid | Das & Stickle, 1994 |
| | decrease feeding | Das & Stickle, 1993 |
| | reduce growth rate | Das & Stickle, 1993 |
| | **Acute Hypoxia** | |
| | increase ventilation rate | Batterton & Cameron, 1978 |
| | increase heart rate | deFur & Pease, 1988 |
| | slight increase in cardiac output | deFur & Pease, 1988 |
| | **Chronic Hypoxia** | Das & Stickle, 1993 |
| | decrease oxygen consumption | deFur & Pease, 1988 |
| | no change in ventilation | deFur & Pease, 1988 |
| | no change in heart rate | deFur et al., 1990 |
| | increase hemocyanin $O_2$ affinity and concentration | |
| *Callinectes similis* | detect and avoid | Das & Stickle, 1994 |
| | increase oxygen consumption | Das & Stickle, 1993 |
| | decrease feeding | Das & Stickle, 1993 |
| Gastropod Molluscs | | |
| *Stramonita haemastoma* | reduce growth rate | Das & Stickle, 1993 |
| | large reduction in metabolism | Liu et al., 1990 |
| | decrease oxygen consumption | Das & Stickle, 1993 |
| Bivalved Molluscs | | |
| *Crassostrea virginica* | switch to anaerobic | Stickle et al., 1989 |
| | metabolism | Stickle et al., 1989 |
| | small reduction in metabolism | Boyd & Burnett, 1999 |
| | decrease production of reactive oxygen species | |

(Burnett and Stickle 2001)




(Rabalais, Harper & Turner, 2001)


(Rabalais et al., 2001)

# Characteristics of Louisiana Shelf Benthos Subjected to Seasonally Severe Hypoxia

- Reduced species richness
- Severely reduced abundances (but never azoic)
- Low biomass
- Limited taxa (none with direct development)
- Characteristic resistant infauna (e.g., a few polychaetes and sipunculans)
- Limited recovery following abatement of oxygen stress

(Rabalais et al., 2001b)

| Order/Genus | Severe hypoxia Settlement Traps | Severe hypoxia Sediment | Normoxic Settlement Traps | Normoxic Sediment |
|---|---|---|---|---|
| Enoplida | | | | |
| *Dolicholaimus* | • | — | — | — |
| *Halalaimus* | • | — | — | • |
| *Nemanema* | — | — | — | • |
| *Oncholaimus* | • | — | — | — |
| *Viscosia* | • | — | — | — |
| Chromadorida | | | | |
| *Cyartonema* | • | — | — | • |
| *Leptolaimus* | — | — | — | • |
| *Microlaimus* | • | — | — | — |
| *Neochromadora* | • | — | — | — |
| *Paracanthonchus* | • | — | — | • |
| *Prochromadorella* | • | — | — | — |
| *Pselionema* | • | — | — | — |
| *Sabatieria* | — | — | — | • |
| *Spirinia* | • | — | — | — |
| *Synonchiella* | • | — | — | — |
| Monhysterida | | | | |
| *Ascolaimus* | — | — | — | • |
| *Cobbia* | • | — | — | — |
| *Daptonema* | • | •[a] | — | • |
| *Metadesmolaimus* | • | — | — | — |
| *Odontophora* | • | — | — | • |
| *Sphaerolaimus* | • | — | — | — |
| *Terschelingia* | • | — | — | • |
| *Parodontophora* | • | — | — | — |

[a] represented by a single specimen

**Nematodes were often collected (in settlement traps) from the water column above hypoxic or anoxic sediments**

**In normoxic conditions, they were found in the sediments.**

(Wetzel et al. 2001)

•Most benthic recruitment is via meroplanktonic larvae.

•Amphipods and harpacticoid copepods rely on direct development and are characteristically absent from hypoxic areas.

•Benthic polychaete larvae are distributed throughout the water column regardless of low oxygen conditions.

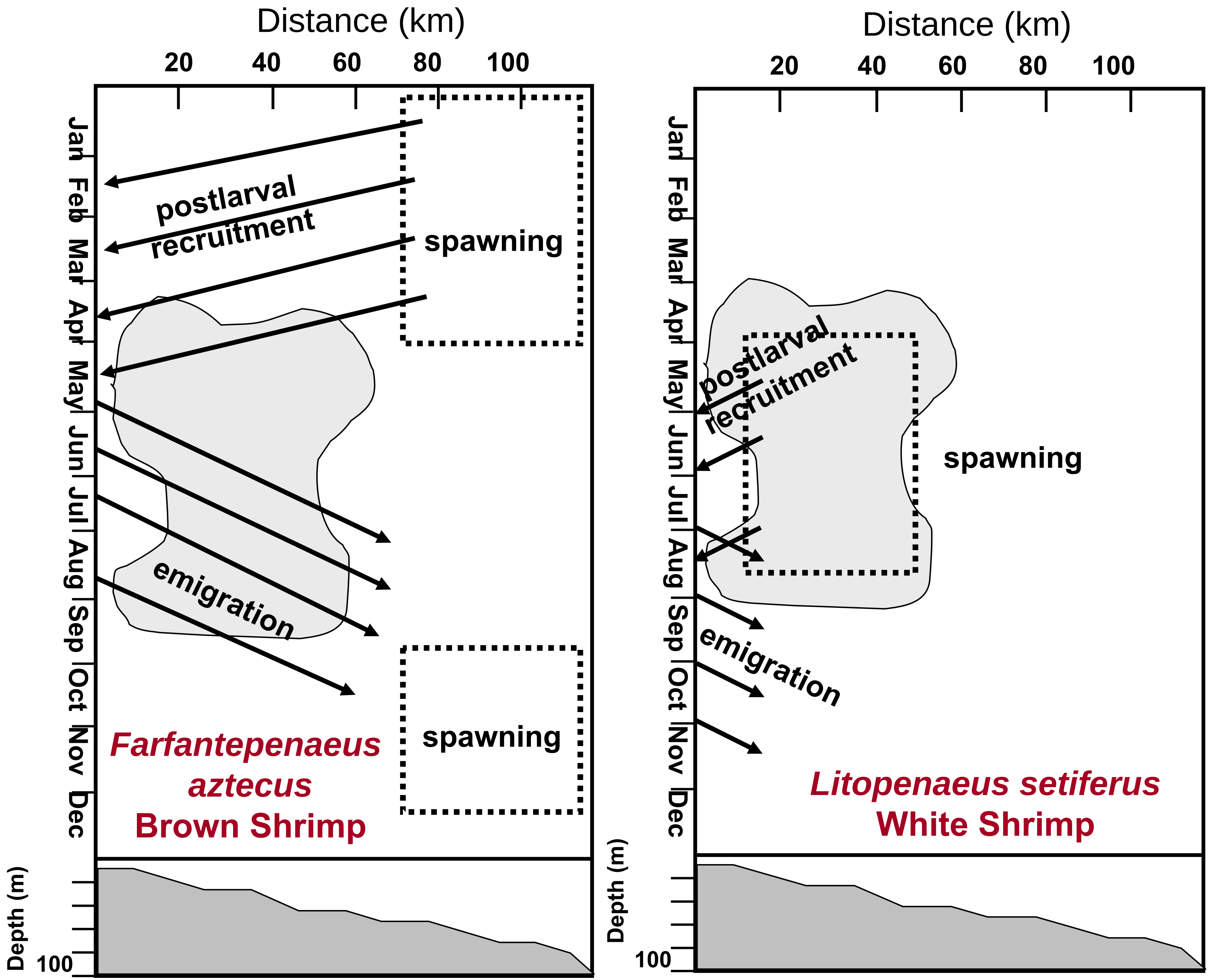
•*Paraprionospio pinnata*, delayed settlement and remained in the water column until oxygen values returned to a level above 2.0 mg $l^{-1}$.

•Barnacle cyprid larvae and holoplankton (e.g., chaetognaths) were reduced in densities below the pycnocline when oxygen concentrations were low.

•Species composition and abundance of organisms in the sediment reflected patterns of pelagic larval abundance.

•The supply of meroplanktonic larvae appears to determine the recovery population.

•Recovery of pericarideans, molluscs and echinoderms takes longer.




(source: N. Rabalais, LUMCON)

Roger J. Zimmerman and James M. Nance, 2001, Effects of Hypoxia on the Shrimp Fishery of Louisiana and Texas, 293-310 in N. N. Rabalais and R. E. Turner (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems.* Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

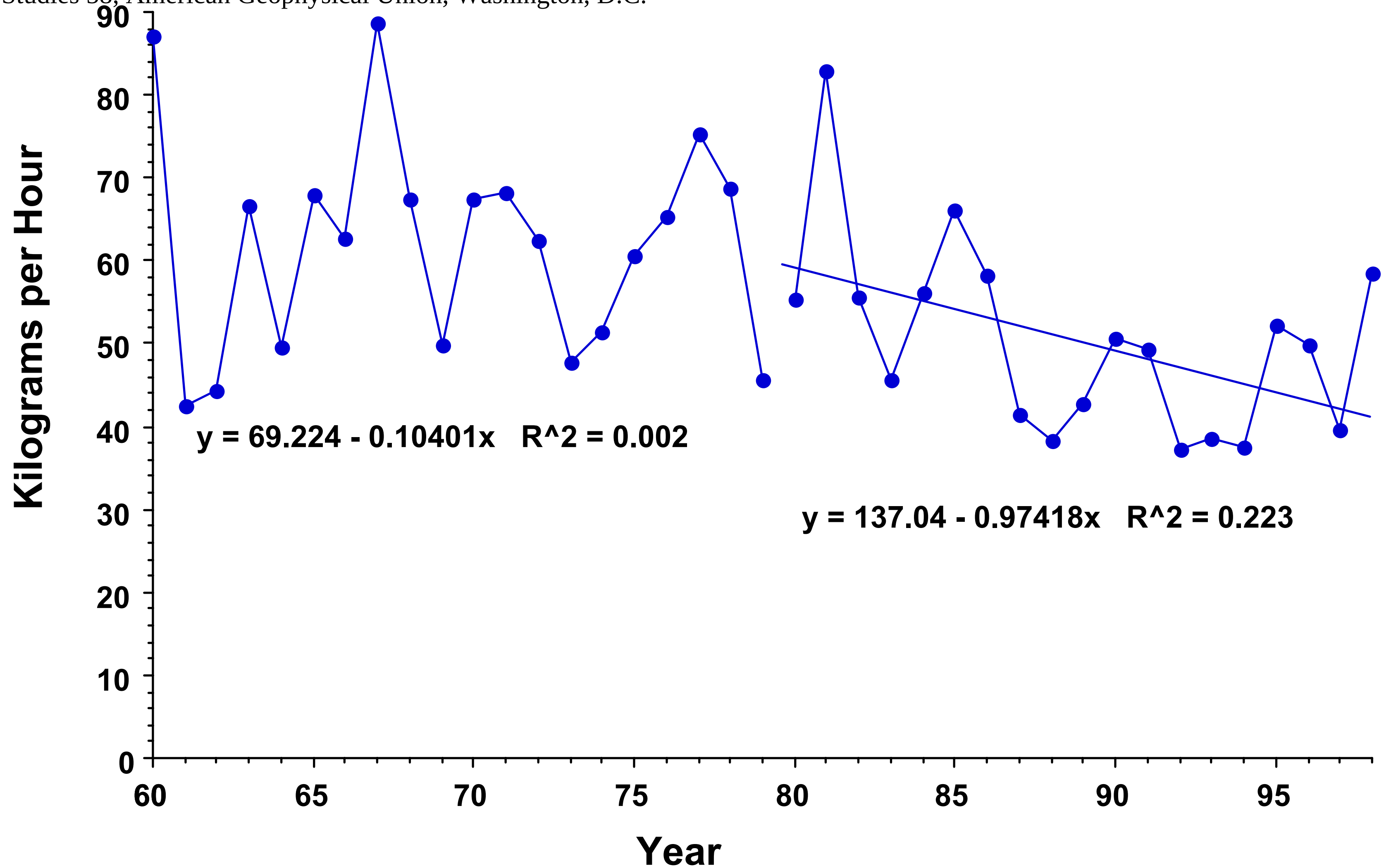



Figure 7. Trend in annual brown shrimp catch per unit effort (CPUE) from Texas and Louisiana from 1960 through 1998.

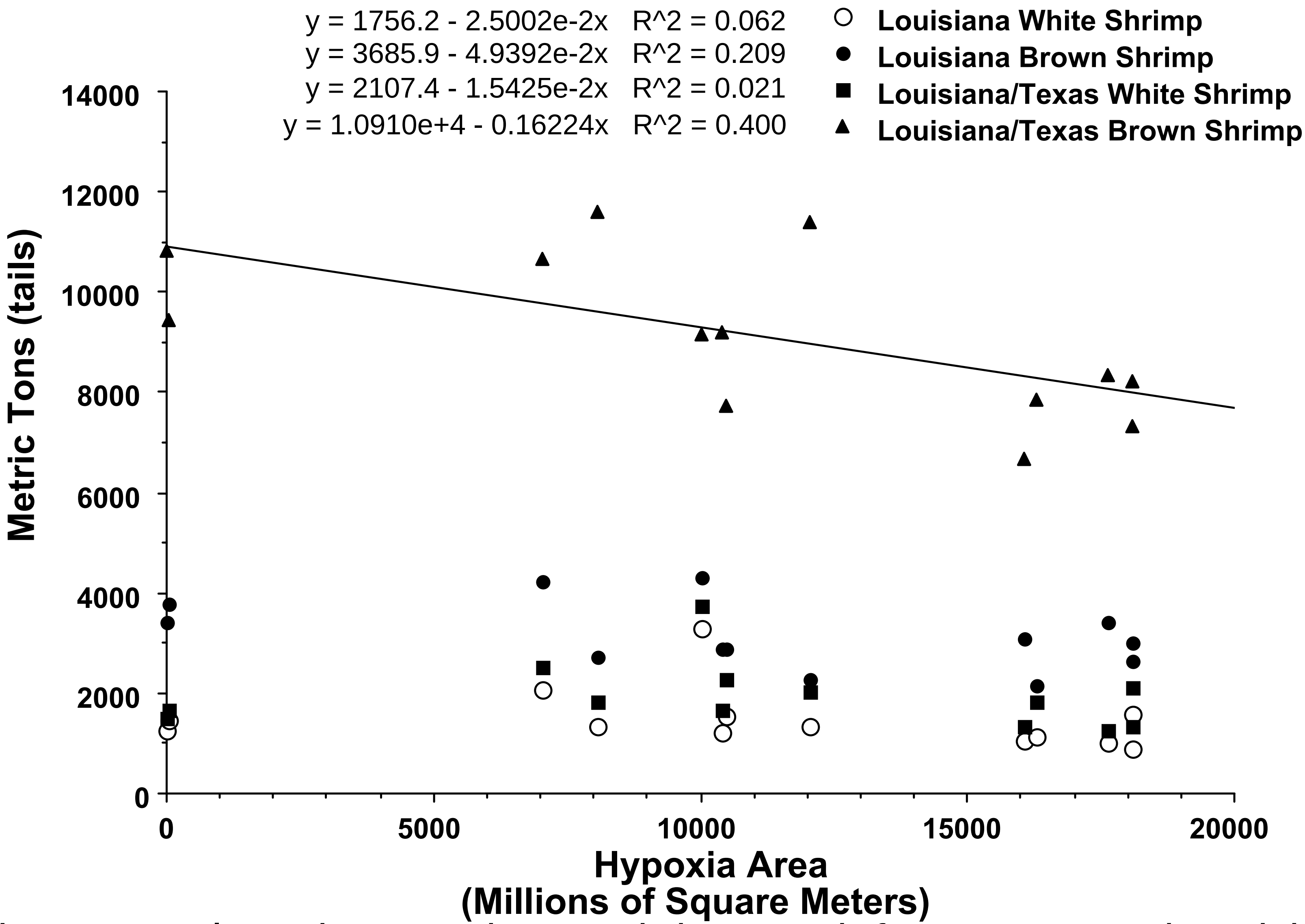
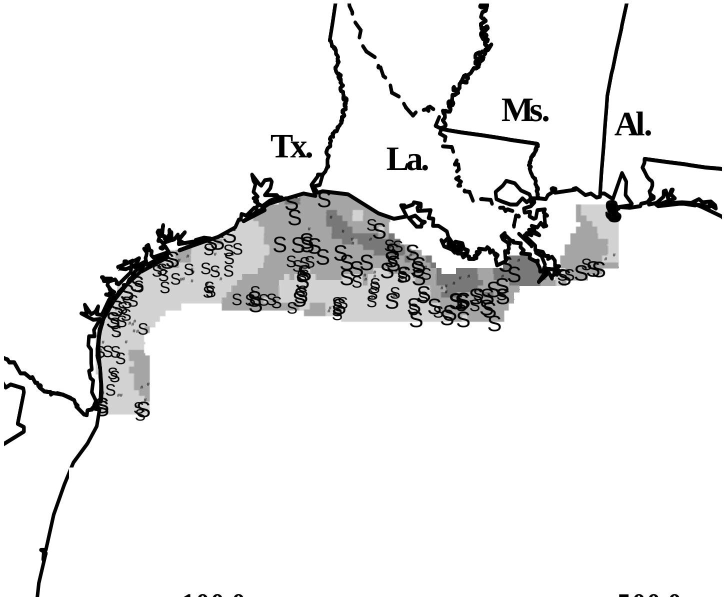
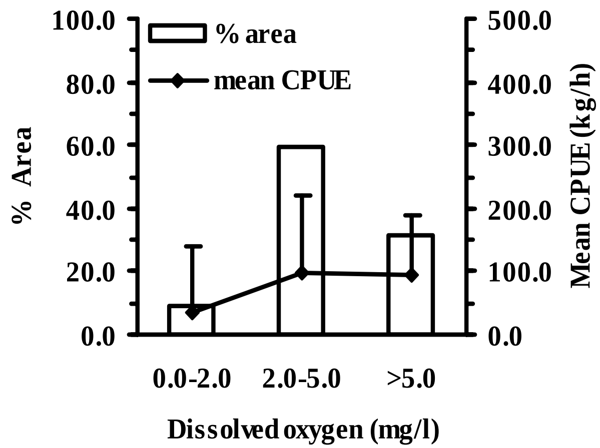
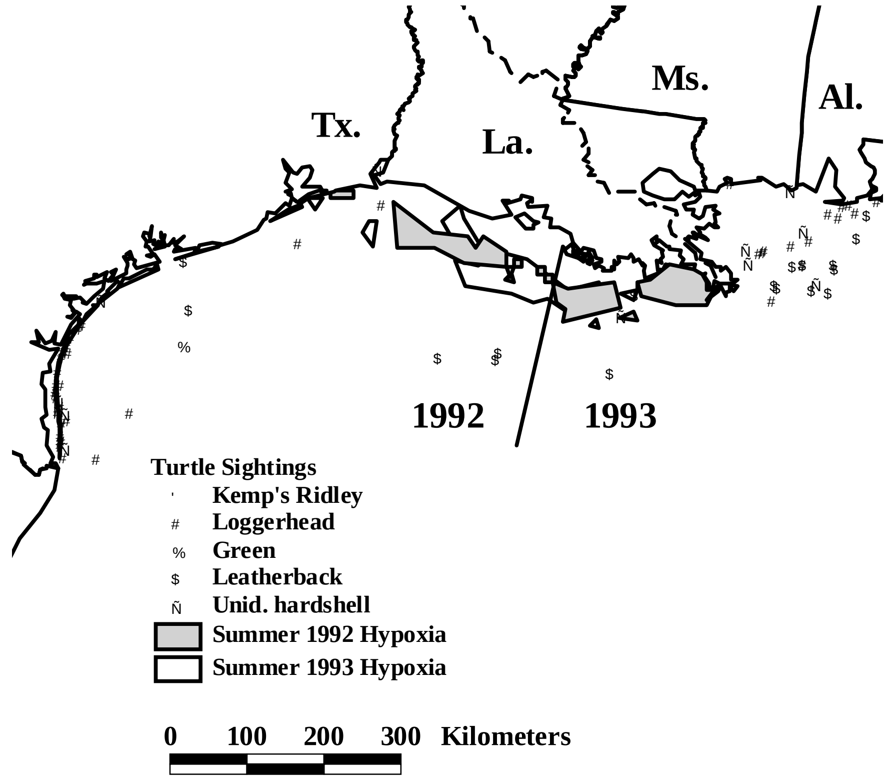



Figure 6. July and August brown shrimp catch from Texas and Louisiana versus relative size of the hypoxic zone on the Louisiana shelf during the years from 1985 through 1997.

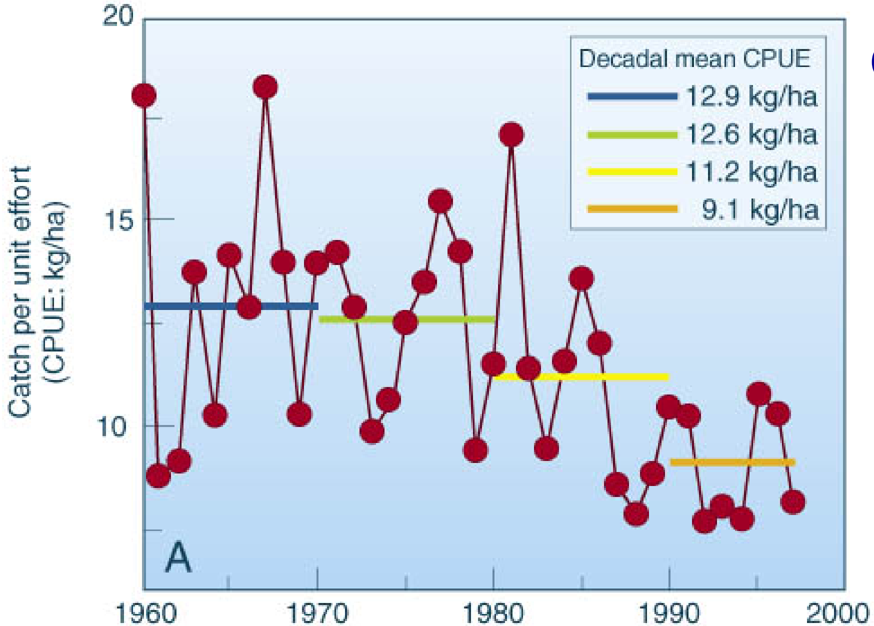
Roger J. Zimmerman and James M. Nance, 2001, Effects of Hypoxia on the Shrimp Fishery of Louisiana and Texas, 293-310 in N. N. Rabalais and R. E. Turner (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems.* Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.




(Craig et al. 2001)



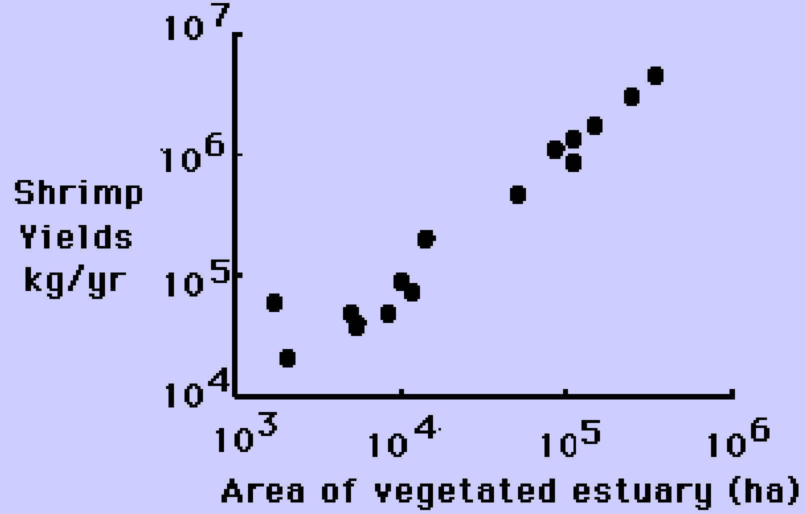

(Downing et al. 1999)

**River discharge ↑**
**Salinity in nursery area ↓**
**Preferable nursery habitat for brown shrimp ↓**
**More hypoxia ↑**
**Suitable habitat for brown shrimp offshore ↓**

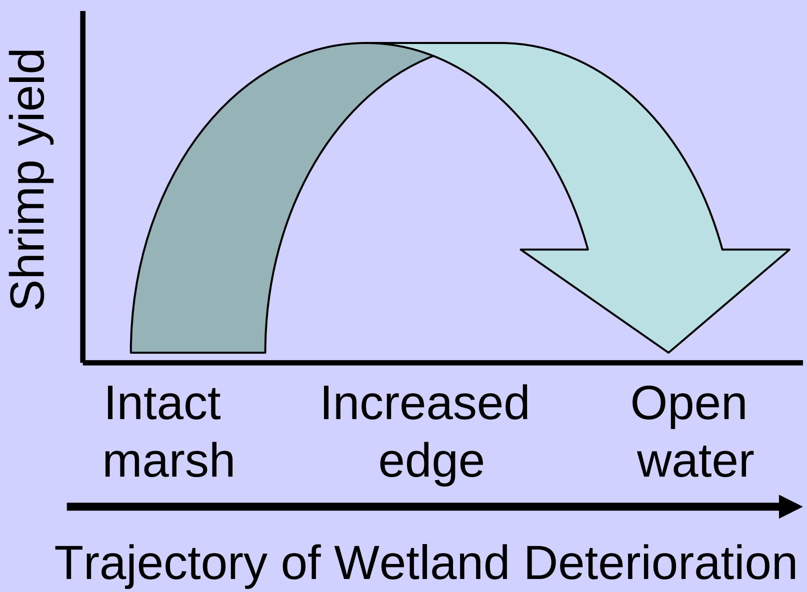
**…and the ultimate predator**

**River discharge ↓**
**Salinity in nursery area ↑**
**Preferable nursery habitat for brown shrimp ↑**
**Less hypoxia ↓**
**Suitable habitat for brown shrimp offshore ↑**

Source: N. N. Rabalais, LUMCON




**Gulf of Mexico shrimp landings (annual) and the area of wetland in each estuary (Turner, 1977)**




Photos: N. N. Rabalais, LUMCON

•Fishery yields have remained strong for the northern Gulf over the last 40 years. But….

•Menhaden production in years with widespread hypoxia were lower (log book analysis). (Smith 2001)

•Effects of hypoxia on distributions of nekton. (Several authors)

•Pattern of pelagic species becoming more abundant and some dominant demersal species declining in prominence within trawl bycatch, particularly between the 1930s and 1989. (Chesney and Baltz 2001)

•Other effects on nekton are probable.

•Other impacts of greater magnitude may have more significant effects than hypoxia on the community structure and secondary production of nekton.

•The effects of hypoxia on the nekton in the northern Gulf may be buffered by characteristics of the basin, the fauna and the ecosystem. These characteristics may partially offset some of the negative impacts of hypoxia seen in other systems by providing spatial and temporal refuges for demersal nekton.

# SUMMARY

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COASTAL AND ESTUARINE STUDIES

Coastal Hypoxia

Consequences for Living Resources and Ecosystems

- Many of the behavioral responses of invertebrate and vertebrate prey and predators to hypoxia documented for the Gulf of Mexico shelf are consistent with those in other areas.

- These developments are observed in many other coastal ecosystems, to lesser or greater degrees of detail, but in no substantially or distinctly different ways.

- The species may be different and the degree of hypoxia or duration may vary among regions, but these broadly described patterns are familiar patterns for many stressed ecosystems, including the Baltic, Black Sea and the northern Gulf of Mexico.

Nancy N. Rabalais and R. Eugene Turner, Editors

2001

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