Disruption of Fish Reproduction in Hypoxic Coastal Waters: Potential Impacts on Coastal Fisheries Worldwide

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Hypoxia

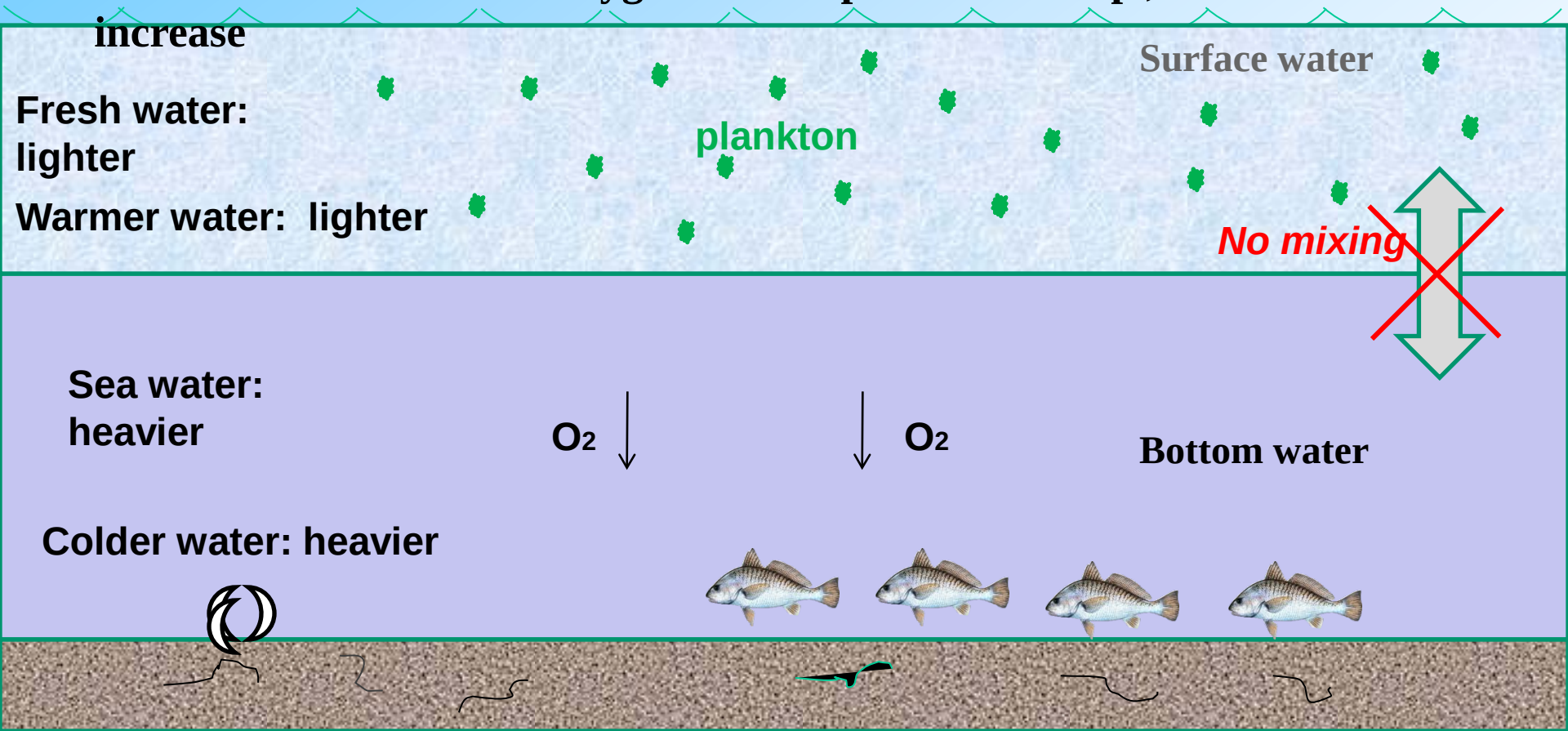
Hypoxia – when dissolved oxygen ≤ 2.0mg/l, (~ 30% of normal oxygen levels), too low to support most marine life.

Anoxia – occurs when the bacteria use up the rest of the oxygen, suffocating even themselves.

How coastal hypoxic zones form

1.Stratification of water column

- oxygen in water column used by marine organisms,
- bottom layer cannot be re-oxygenated
- seasonal increase in oxygen consumption with temp., biomass increase

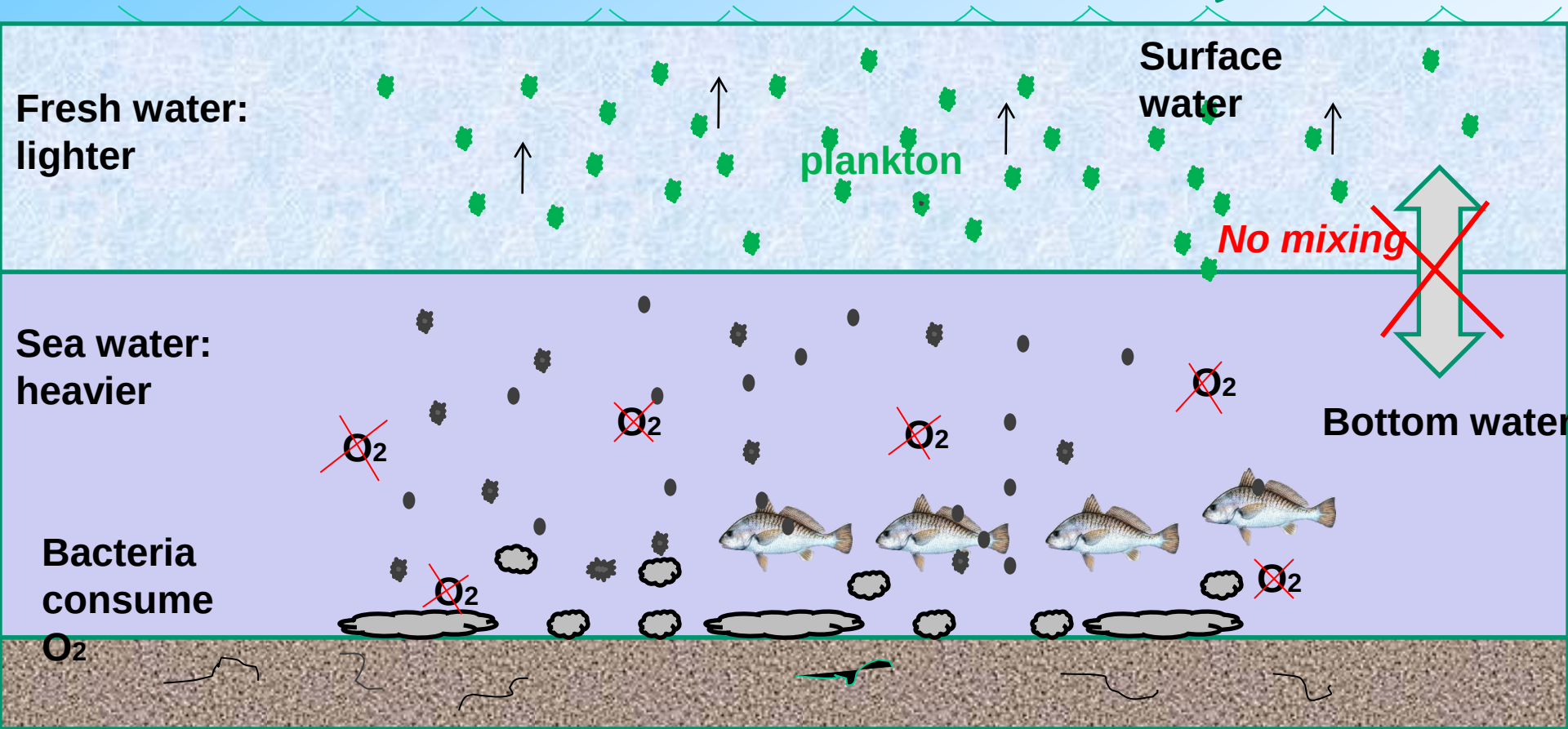


How coastal hypoxic zones form

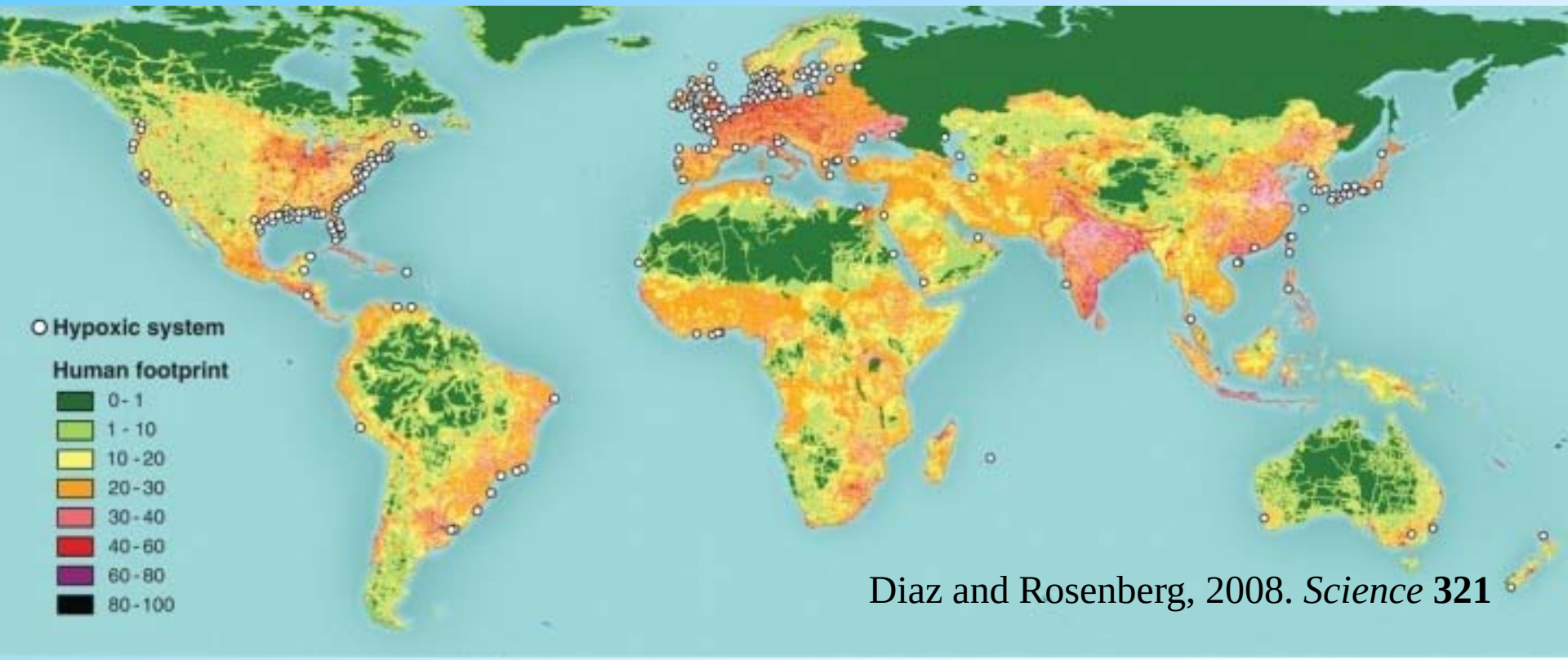
2. Increased nutrient load- eutrophication

- plankton production increases
- dead plankton and waste products fall into bottom layer
- bacteria digest dead organisms, waste – consuming remaining O_2

Nitrogen, phosphorous from fertilizers, etc.



Global distribution of hypoxic systems associated with anthropogenic nutrient inputs



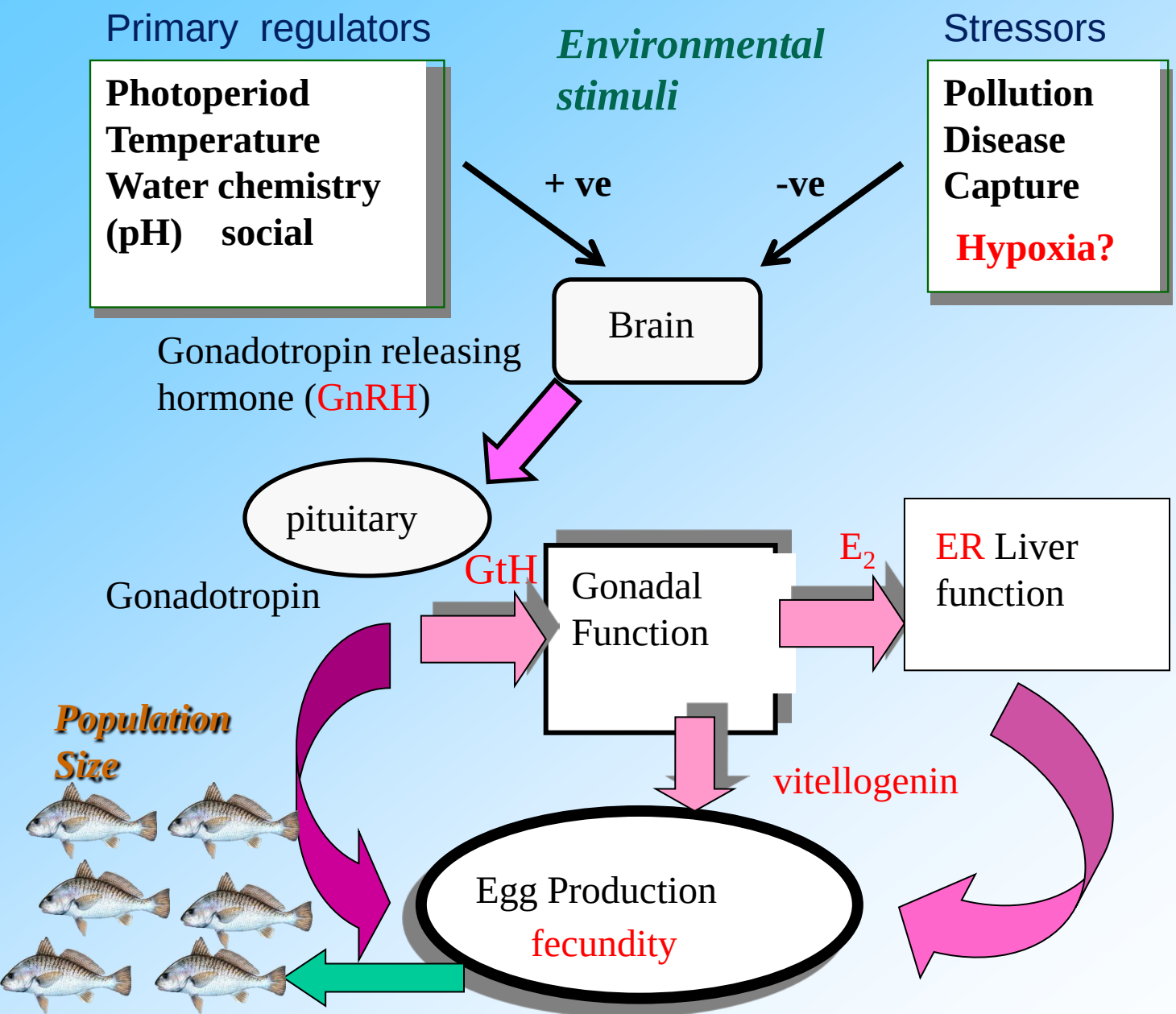
Diaz and Rosenberg, 2008. *Science* **321**

- **hypoxic regions have tripled in past 30yrs- Major Global Change**
- **over 400 coastal hypoxic regions worldwide, covering 250,000 km^2**
- **Major concern – Long-term ecological impacts unknown**

Assessment of long term effects of increased coastal hypoxia on marine ecosystems and fishery resources

- **Necessary for the development of effective management strategies**
- **Requires knowledge of longterm biological effects of exposure to sublethal hypoxic conditions in marine organisms**
- **However, information lacking on hypoxia effects on physiological processes that affect fisheries stocks such as reproduction**

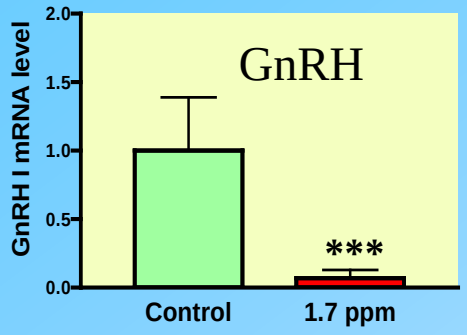
Control of the Reproduction in Fish

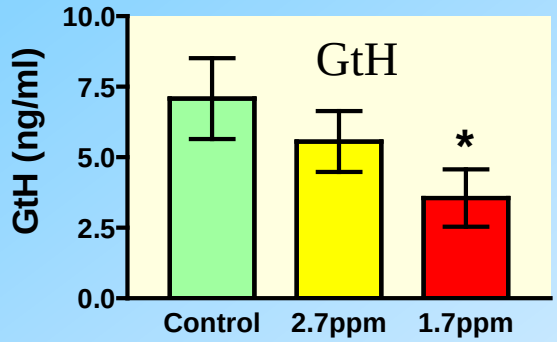


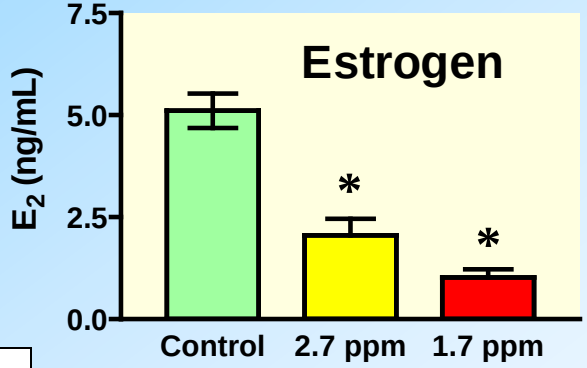
Sensitive stages:

- **sex differentiation**
- **Puberty**
- **egg and sperm production and gonadal growth**
- **egg and sperm maturation, reproductive success**

Laboratory studies: **Effects of chronic hypoxia on egg production and endocrine function**







GnRH

GtH

Gonadal Function

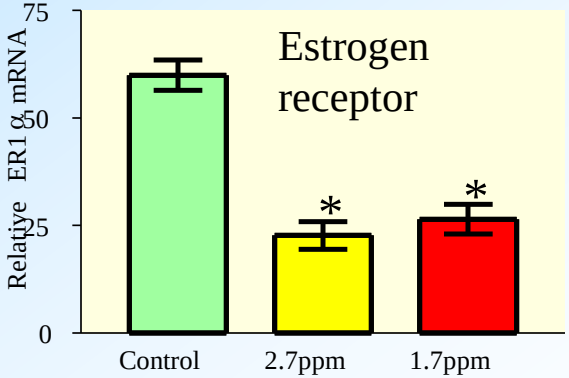
E_2

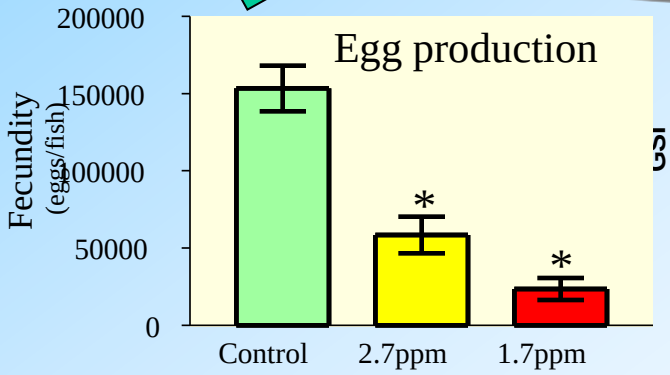
ER Liver function

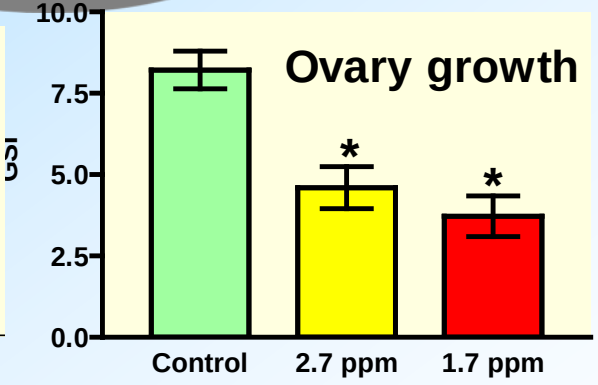
vitellogenin

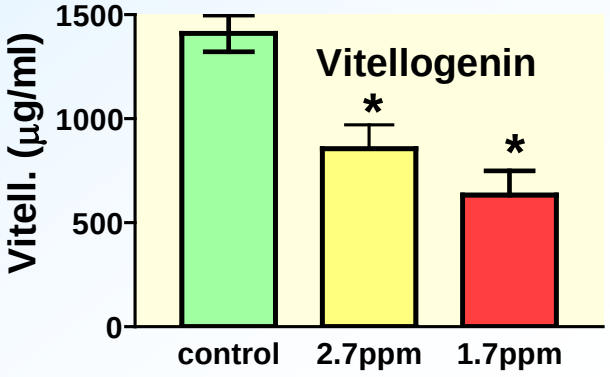
Egg Production
fecundity

Model predicts decreased population size



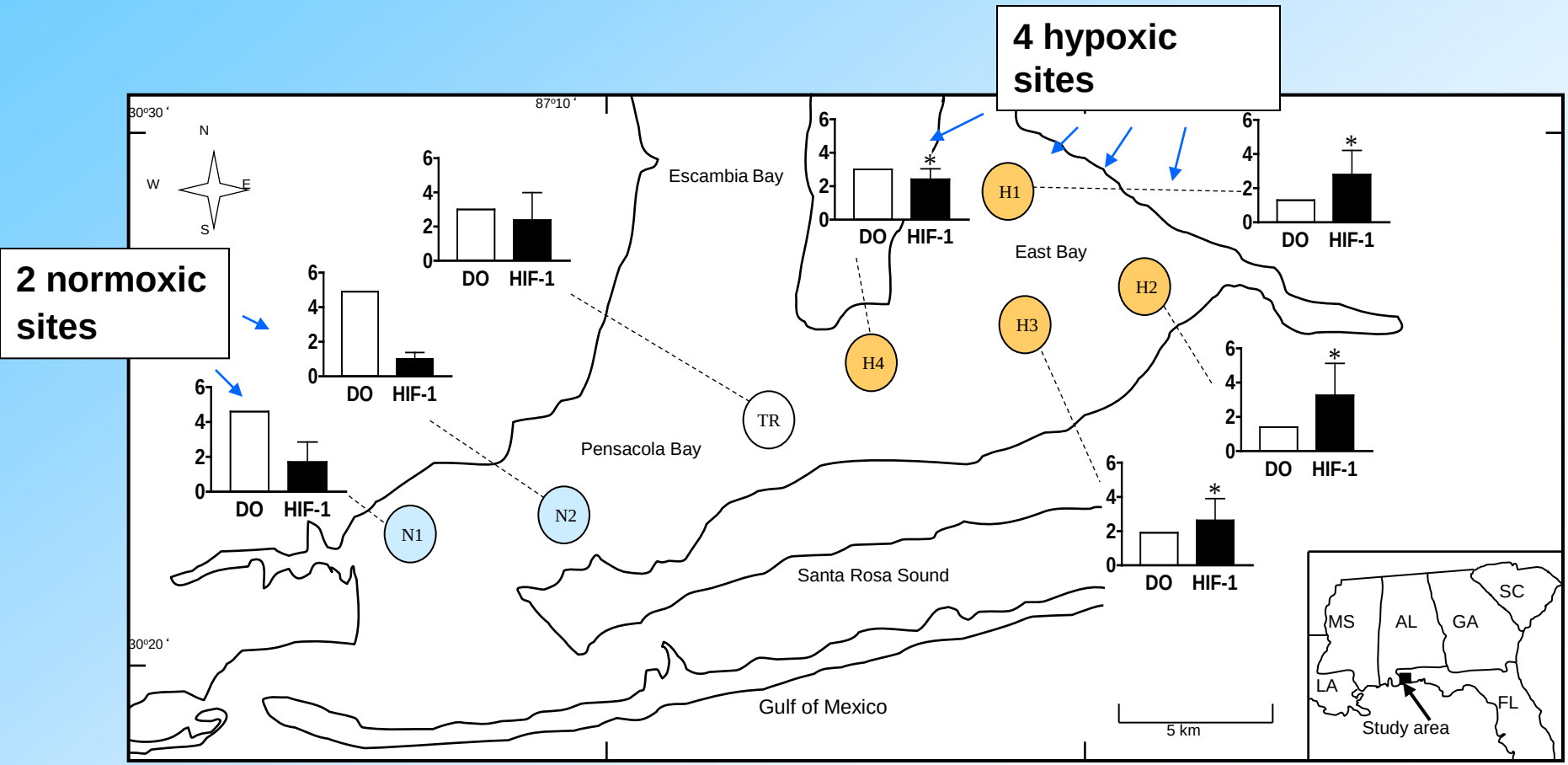






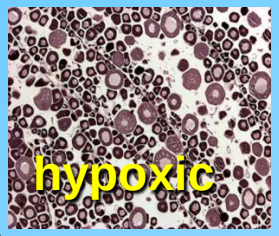
Question: Does environmental hypoxia exposure disrupt reproduction in Atlantic croaker?

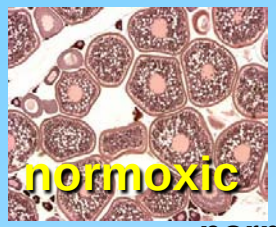
Estuarine Hypoxia: High rainfall in 2003 resulted in extensive and persistent hypoxia throughout East Bay, Florida

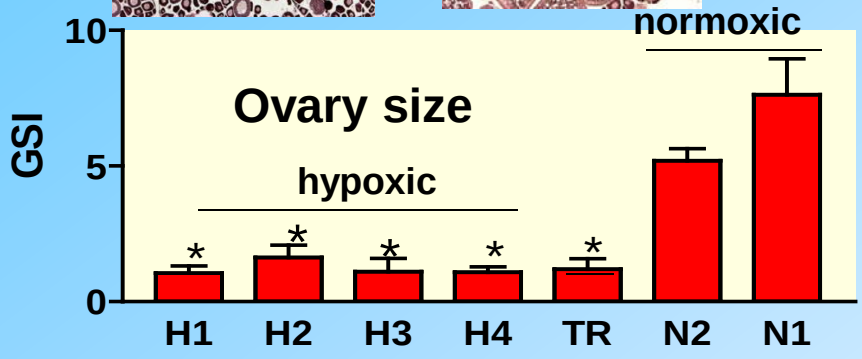


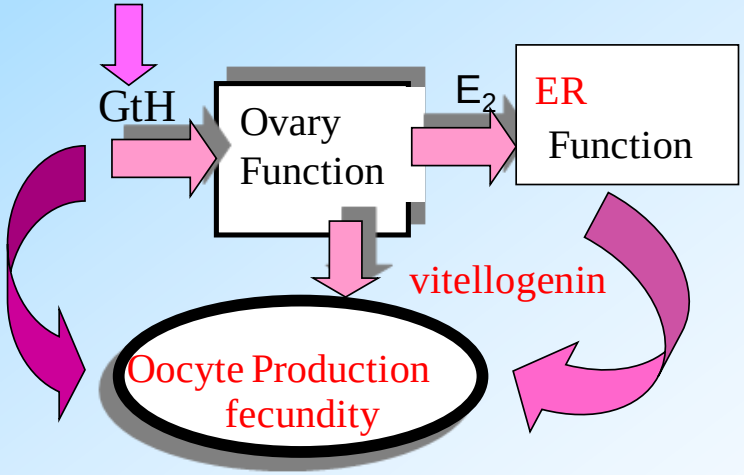
Thomas et al., Proceedings of the Royal Society, London B. 2007

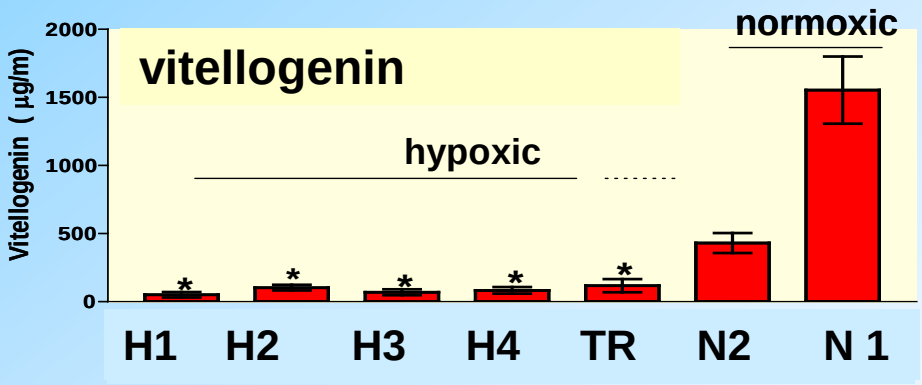
Hypoxia in Estuaries: **Hypoxia exposure causes reproductive dysfunction in females**

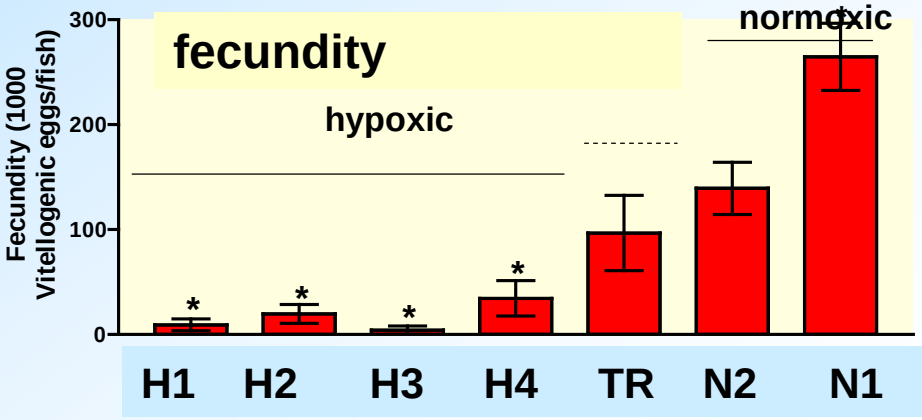










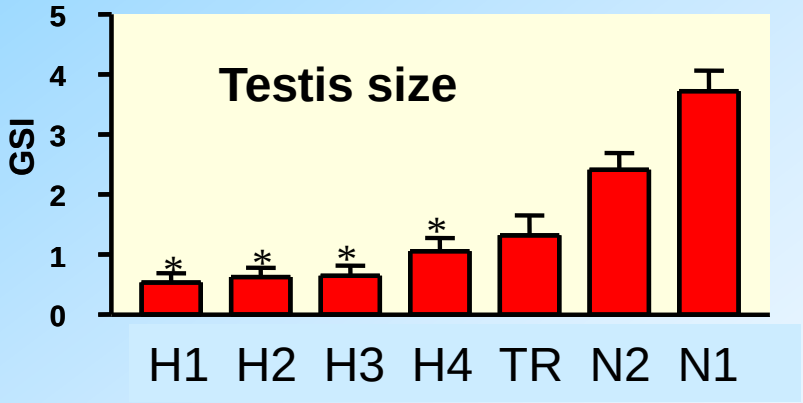


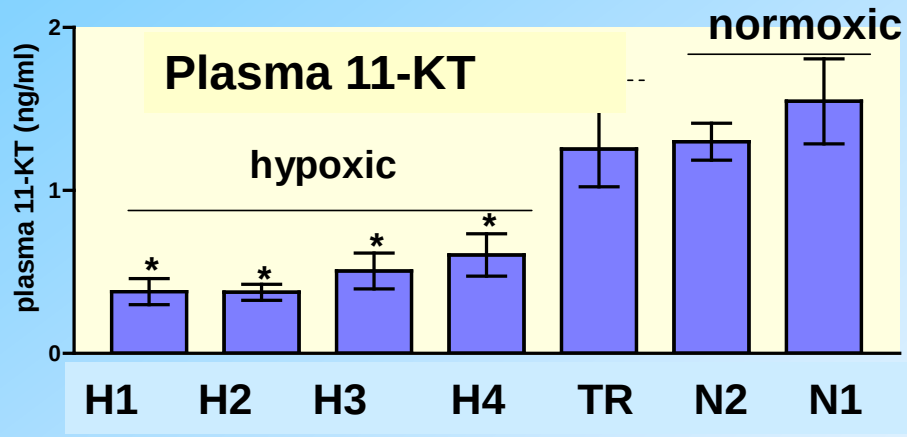
egg production and endocrine function impaired at hypoxic sites

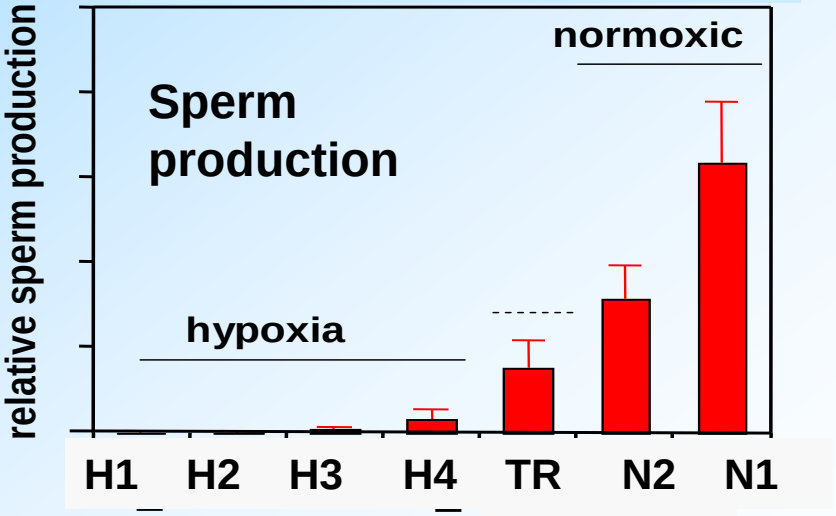
Similar to endocrine impairment seen in laboratory studies

Hypoxia in Estuaries: **Hypoxia exposure also causes reproductive dysfunction in males**

Spermatogenesis impaired







1st evidence for reproductive /endocrine impairment in fish exposed to environmental hypoxia

Question:

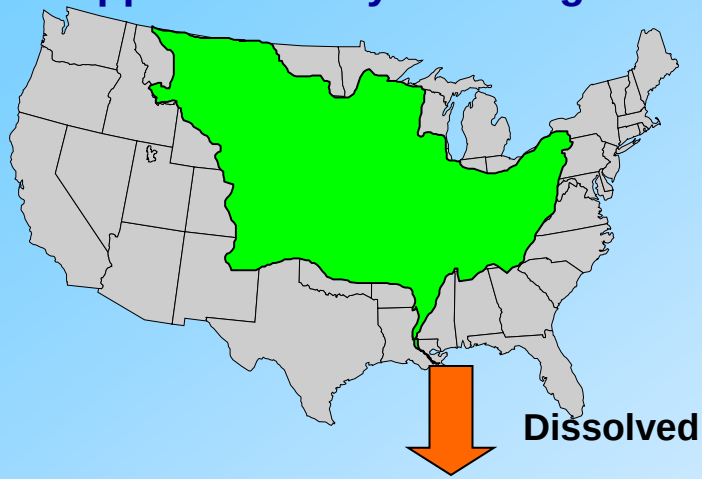
Does large scale hypoxia cause similar reproductive impairment in fish in the Gulf of Mexico hypoxic zone covering 1000s of square miles

- much greater potential impact on fisheries

Hypoxia in the northern Gulf of Mexico

2nd largest coastal hypoxic zone in the world

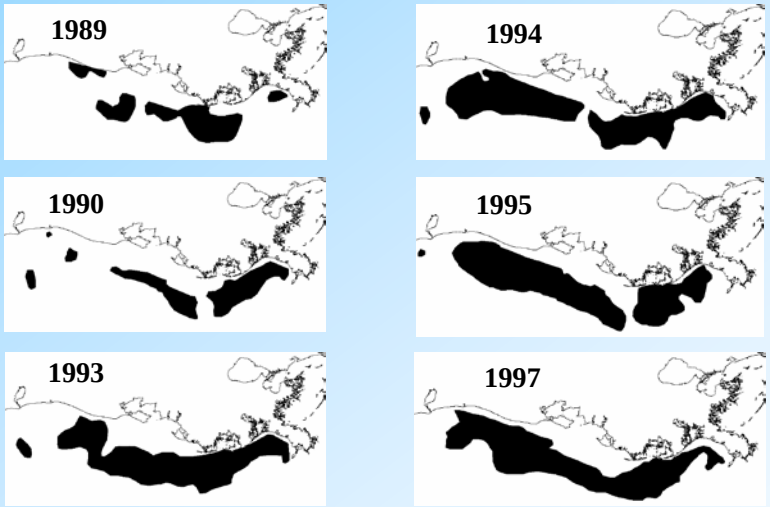
Mississippi-Atchafalaya Drainage Basin



- "top 10" river flow- stratification
- drains 41% of continental US
- Nitrogen loading tripled since 1950s

eutrophication

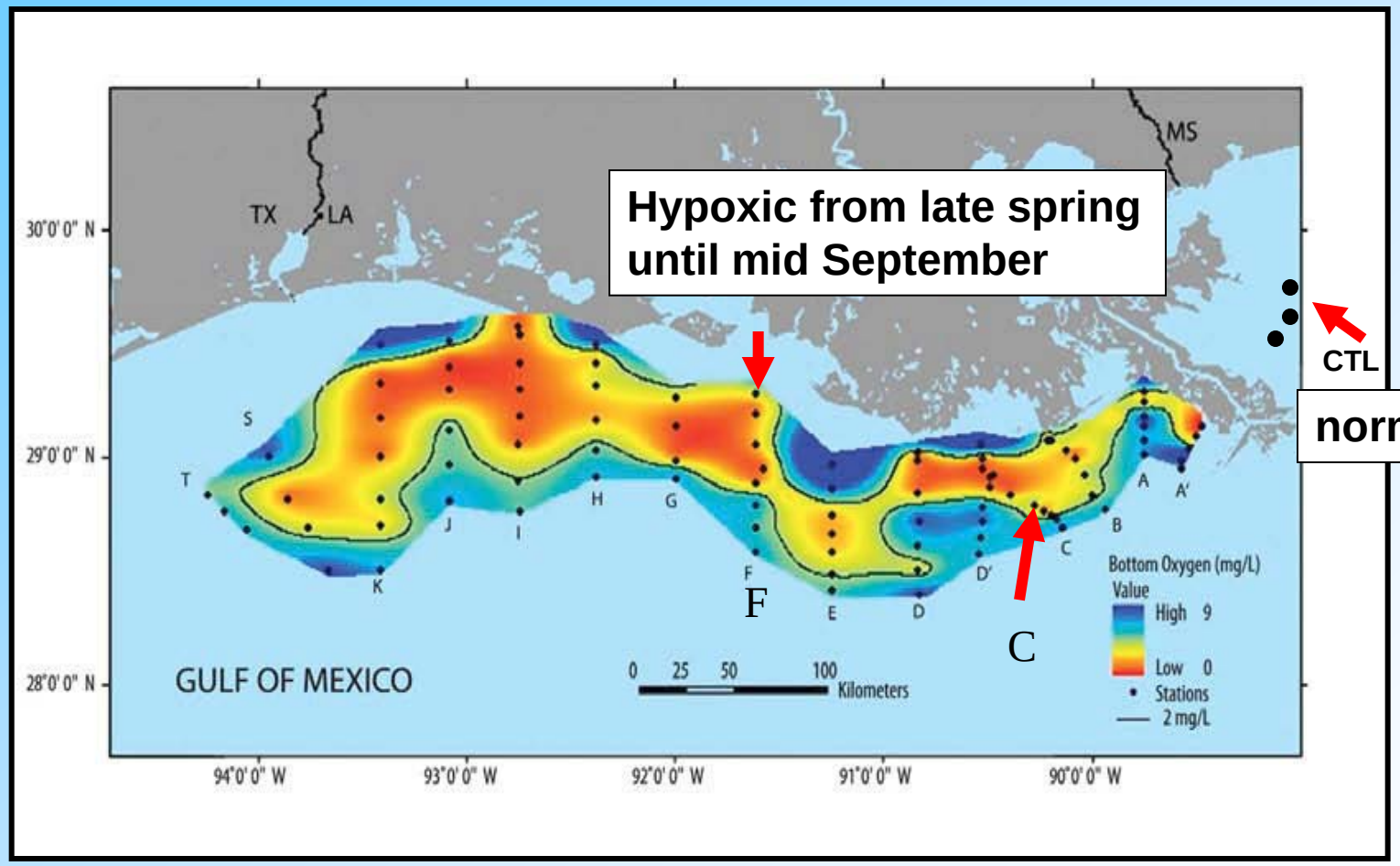
Dissolved oxygen ≤ 2.0 mg



Mapping since mid 1980's:
increased from 5,000 km2 - 16,000 km2

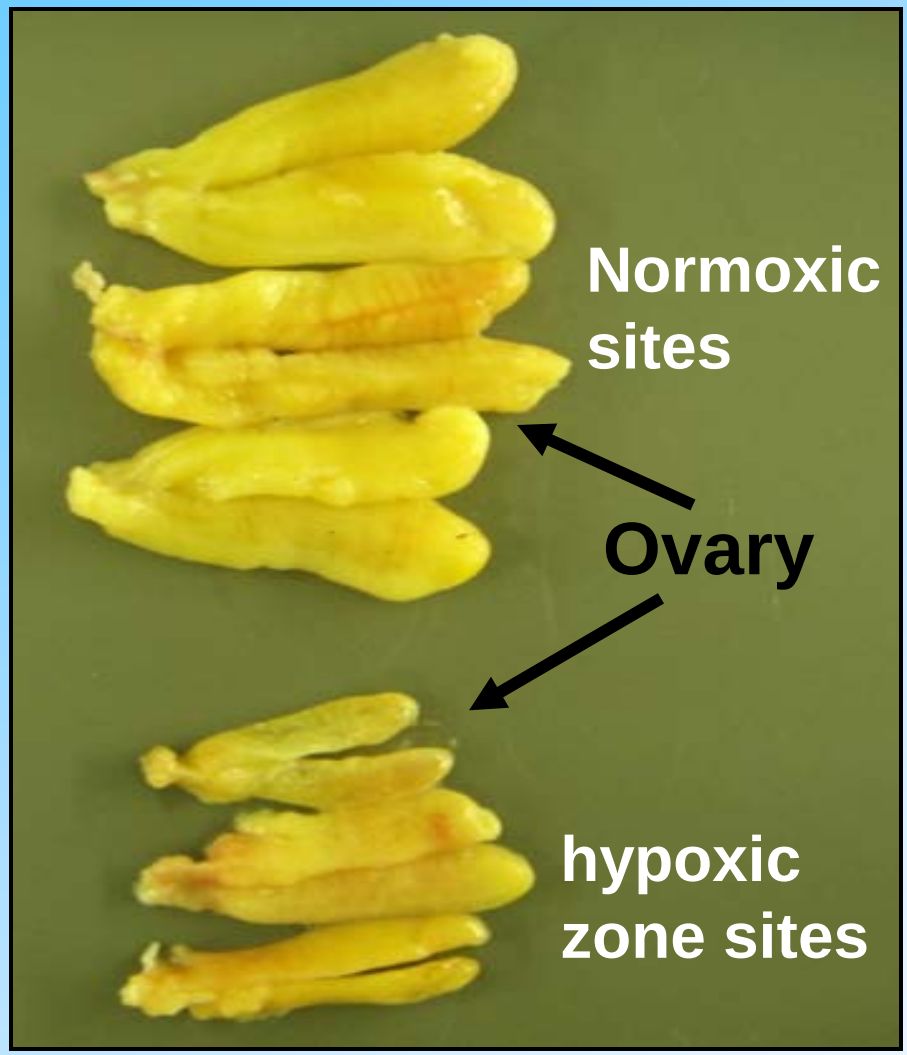
Dissolved oxygen ≤ 2.0 mg

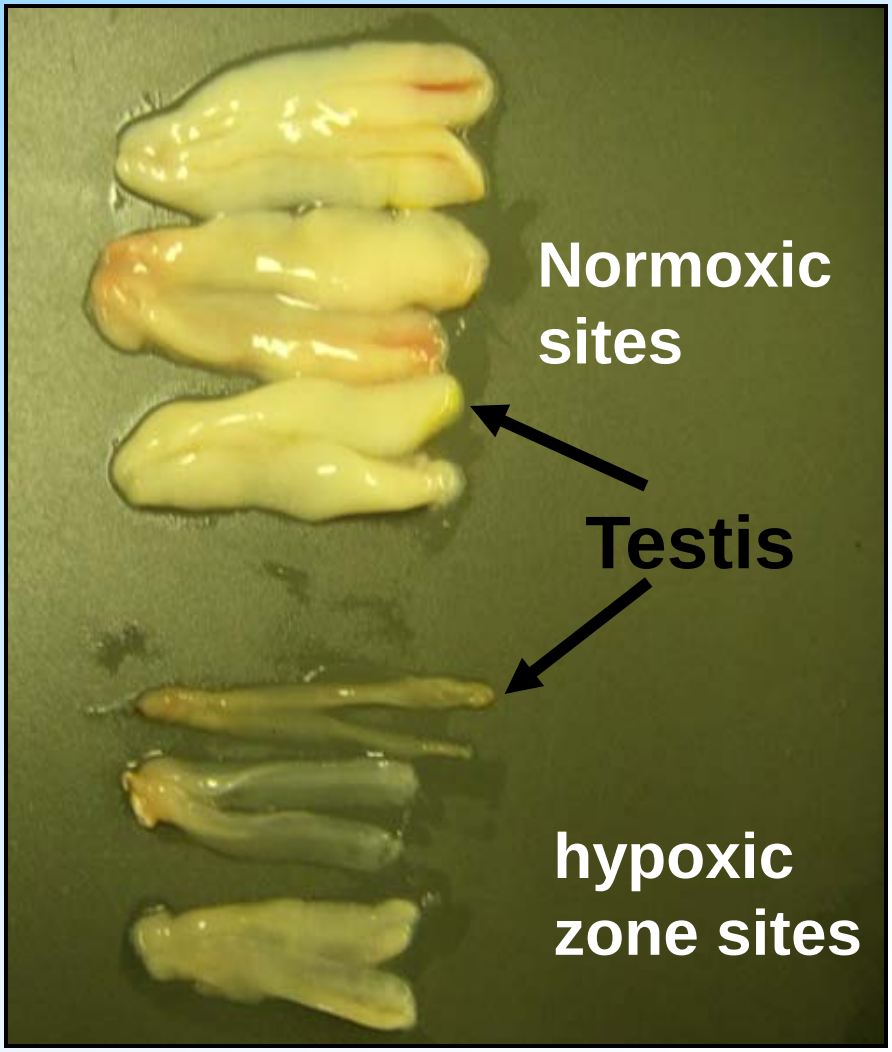
Hypoxic region on Louisiana continental shelf- 2006-2008



In fall 2007 : 3 control sites and 6 hypoxic sites along two transects 120km apart were sampled

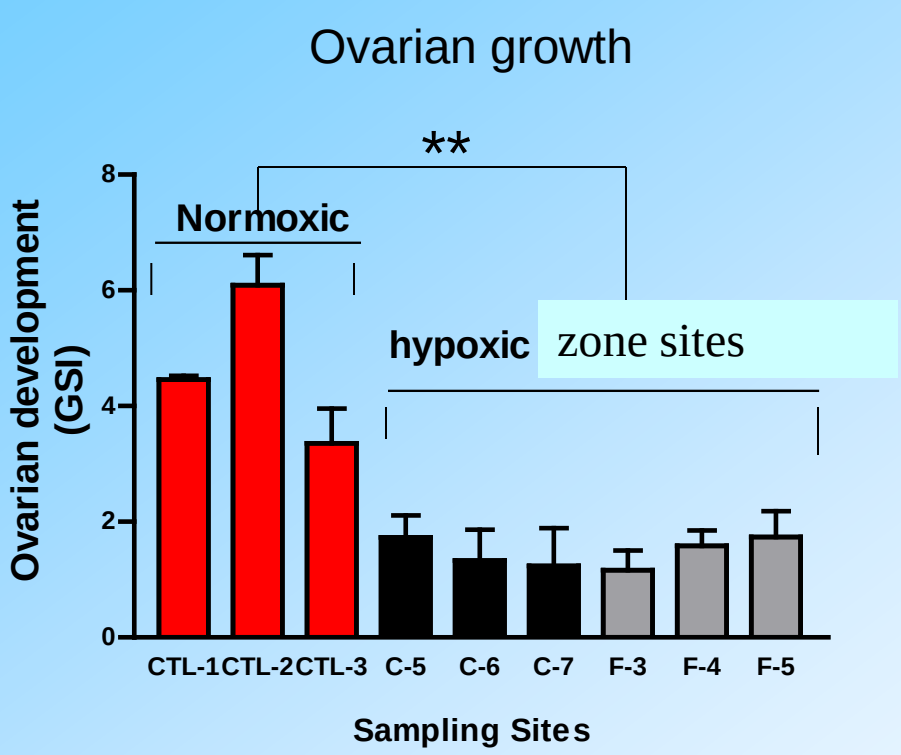
Fall 2007 Croaker gonads undeveloped at hypoxic sites

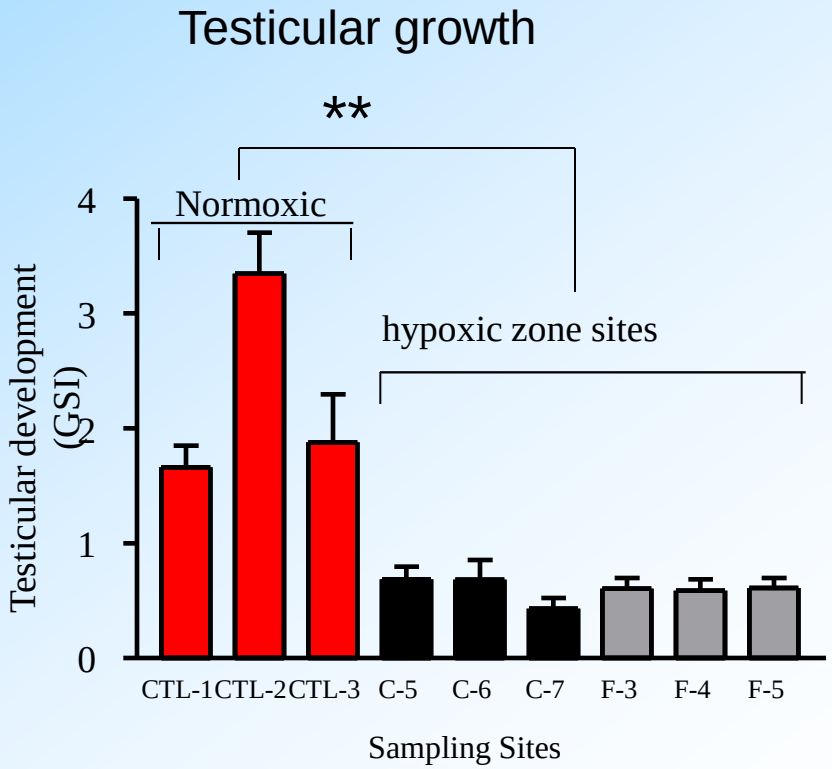




Fall 2007

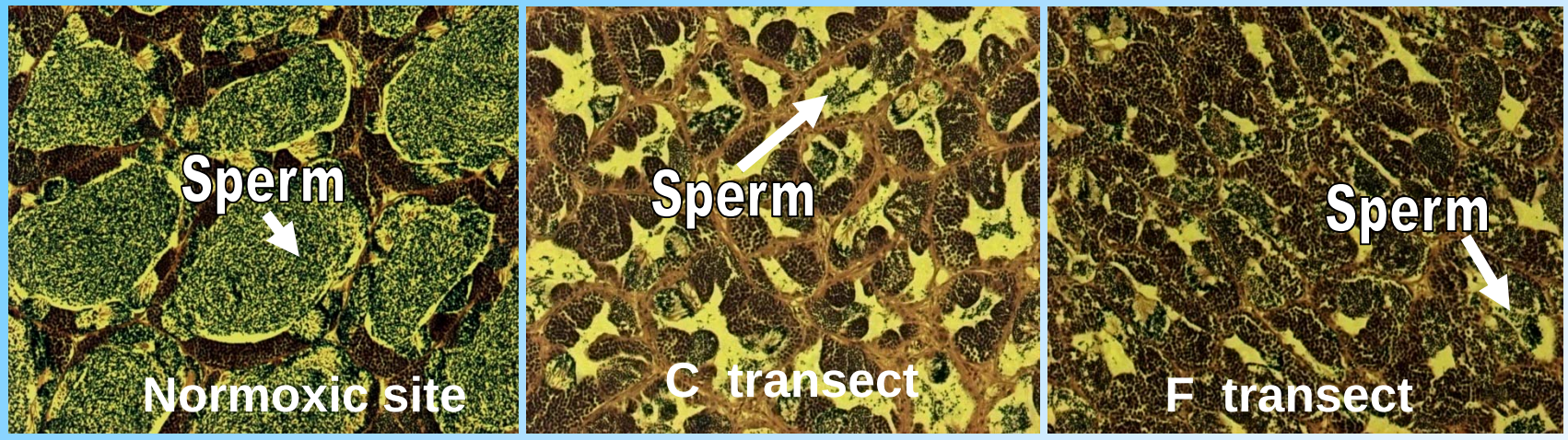
Gonadal growth impaired at hypoxic sites in both females and males



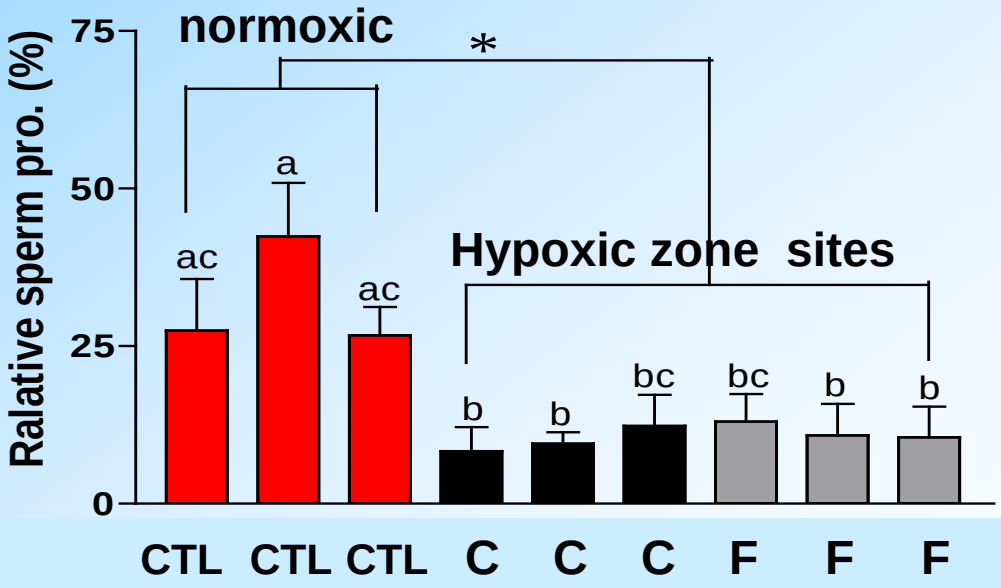


Thomas & Rahman, Proceedings of the Royal Society, London B. 2011

2007,2008 Reproductive impairment in males at hypoxic sites



Sperm production



Spermatogenesis and sperm production decreased at hypoxic zone sites

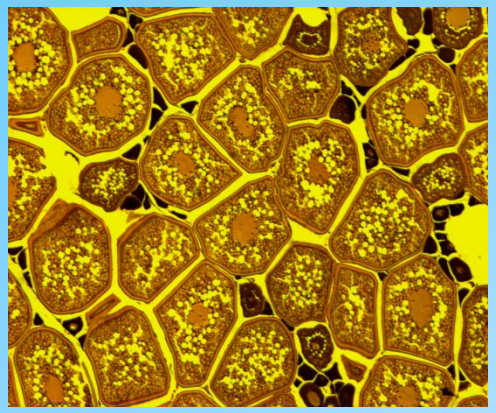
2007 Reproductive impairment in females at hypoxic sites

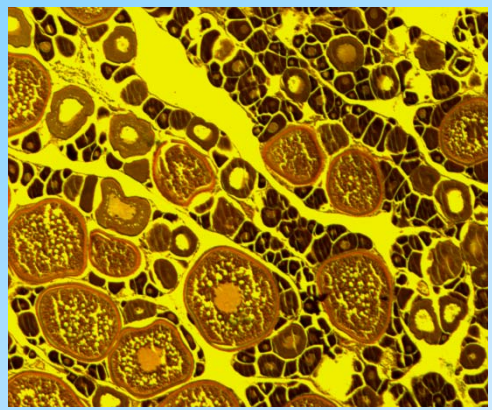
Normoxic site

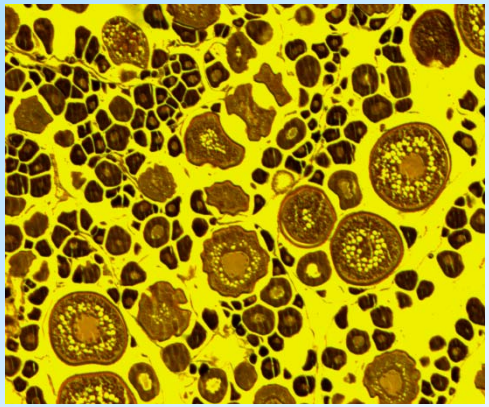
hypoxic zone sites

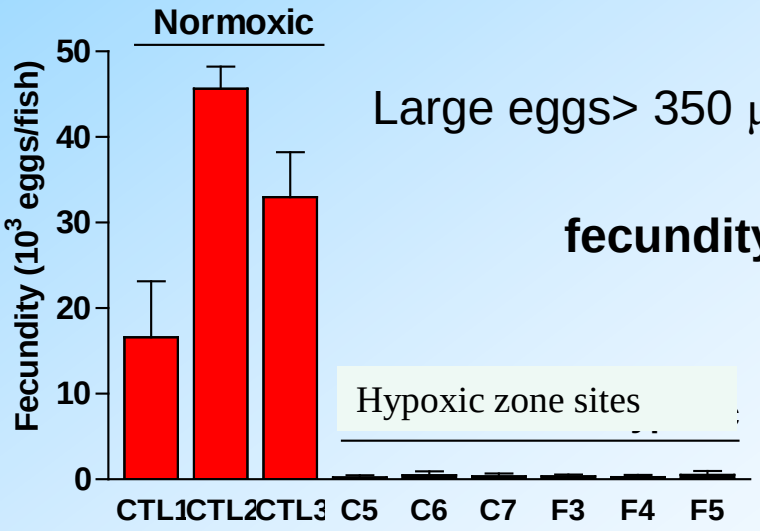
C transect

F transect







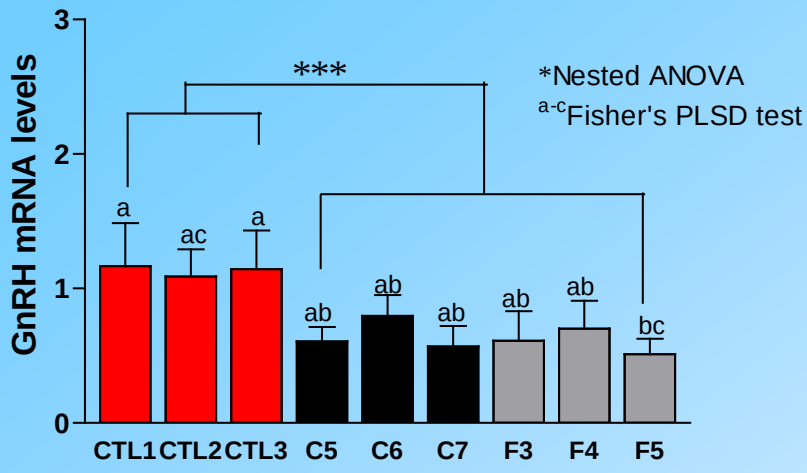


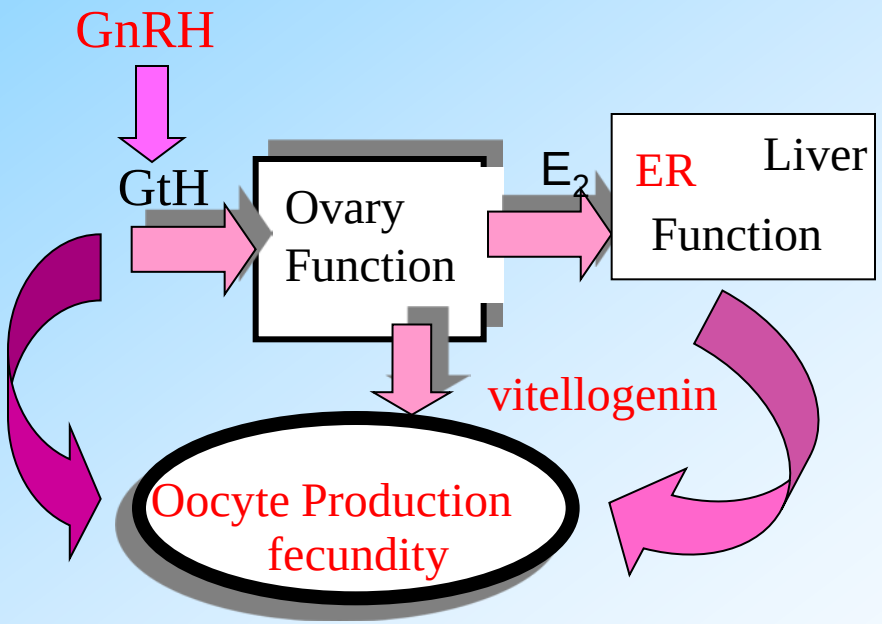
Large eggs> 350 μm

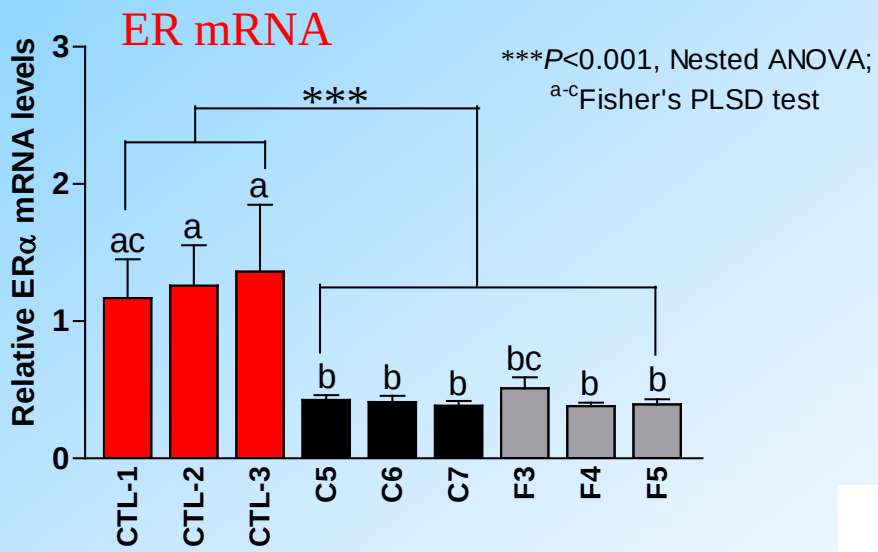
fecundity

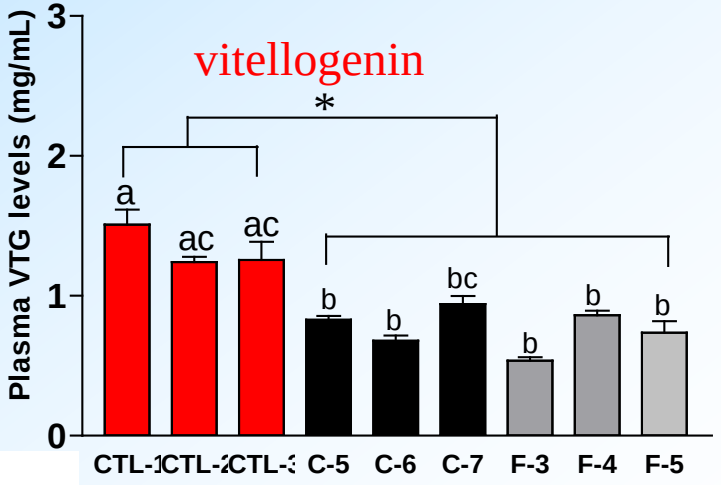
Very few mature eggs (low fecundity) at hypoxic zone sites

Fall 2007 Endocrine function decreased at hypoxic sites







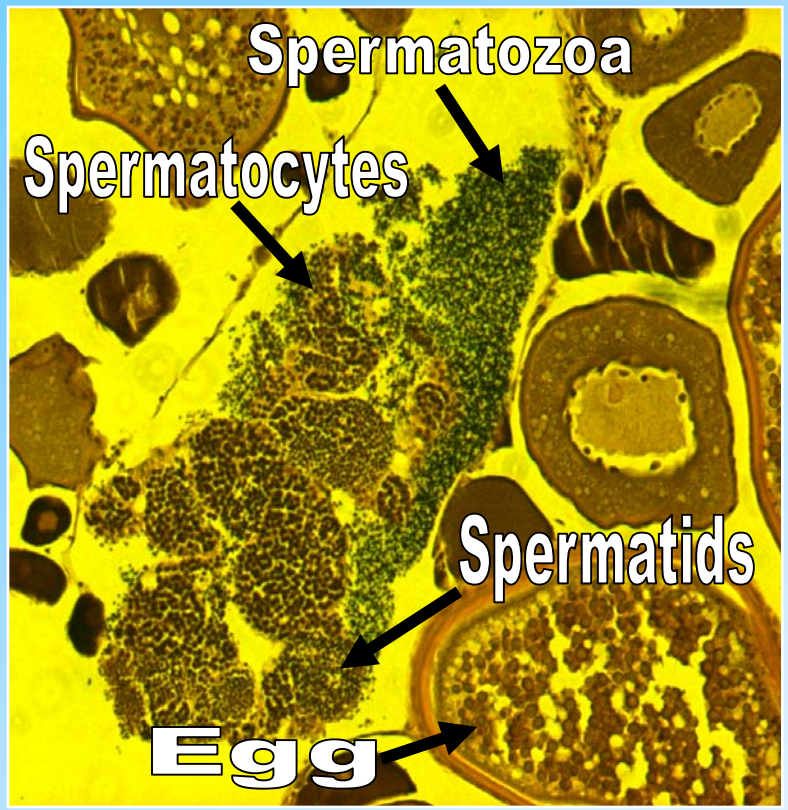


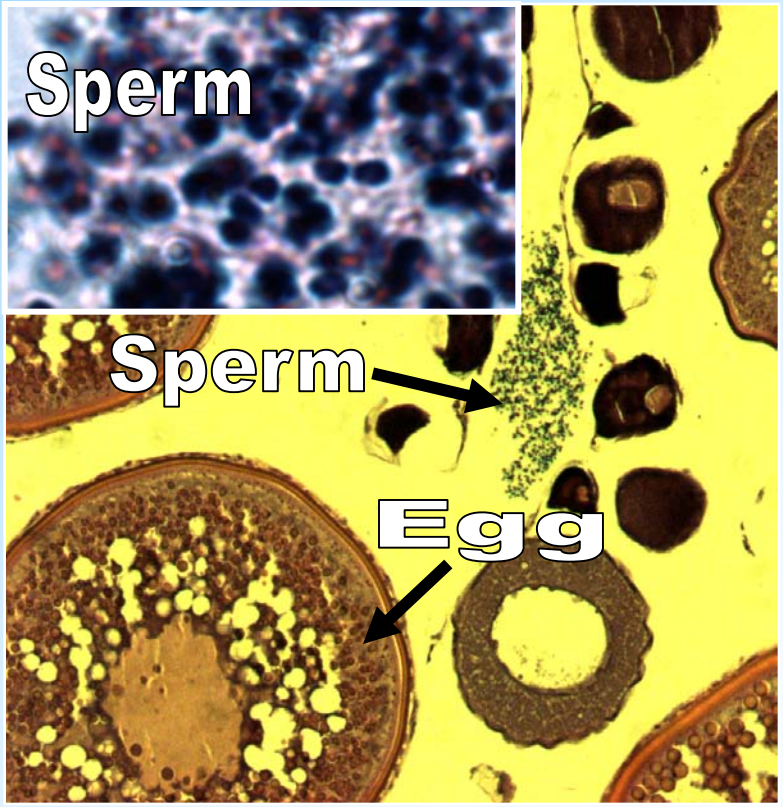
Reproductive impairment due to endocrine disruption at hypoxic sites

2006, 2007

Evidence for Ovarian Masculinization

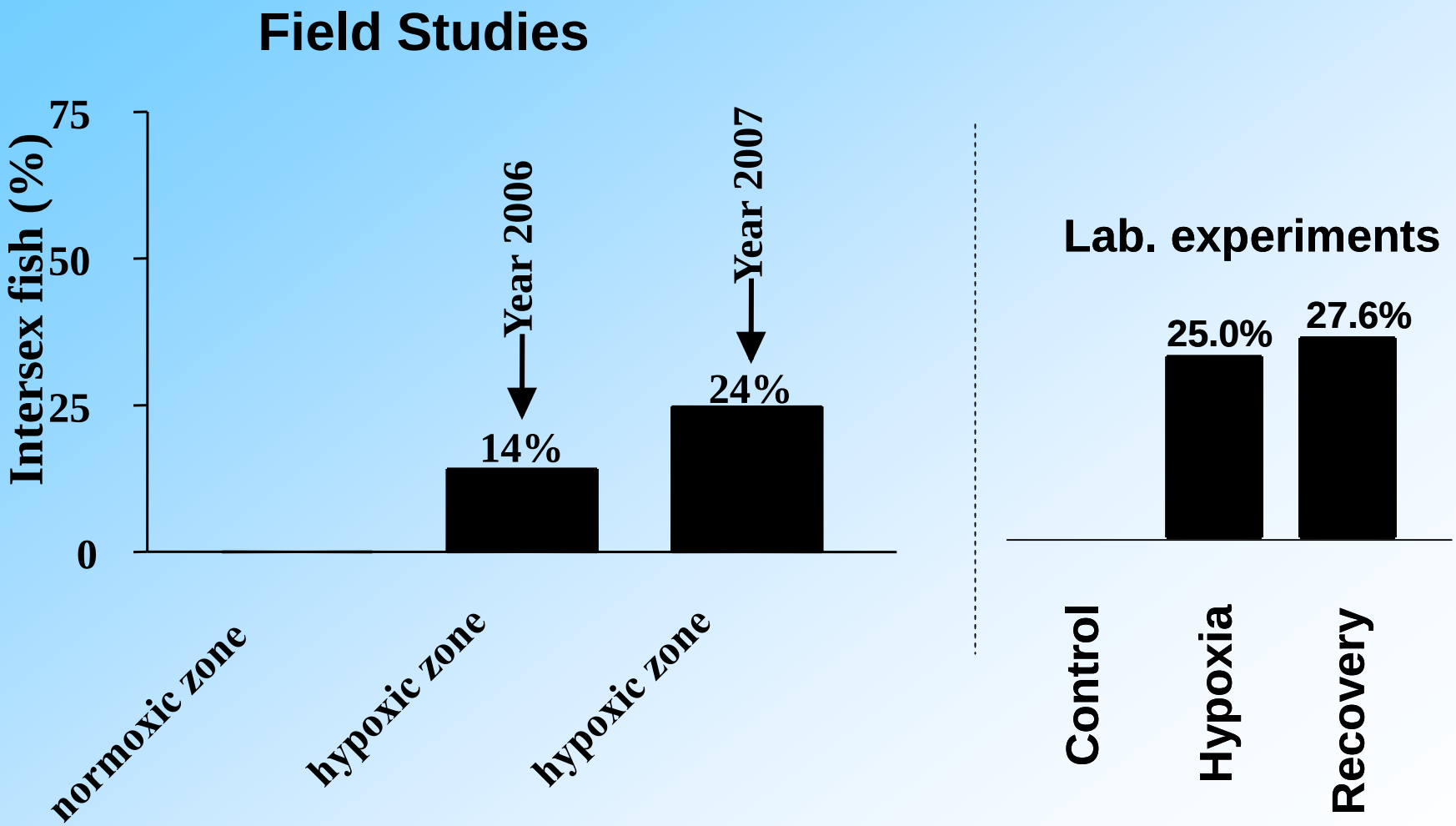
Some ovaries from hypoxic zone sites contain spermatogenic cells:





Suggests masculinization under hypoxic conditions

Percent ovaries masculinized



Suggests masculinization caused by hypoxia exposure

How does hypoxia cause the croaker ovary to produce sperm?

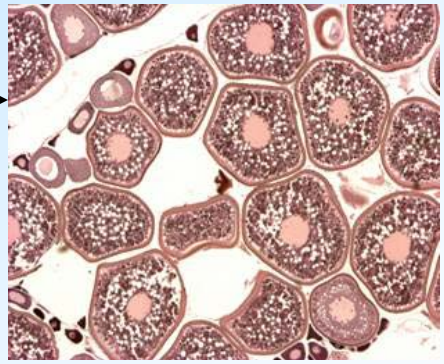
HYPOTHESIS: HYPOXIA

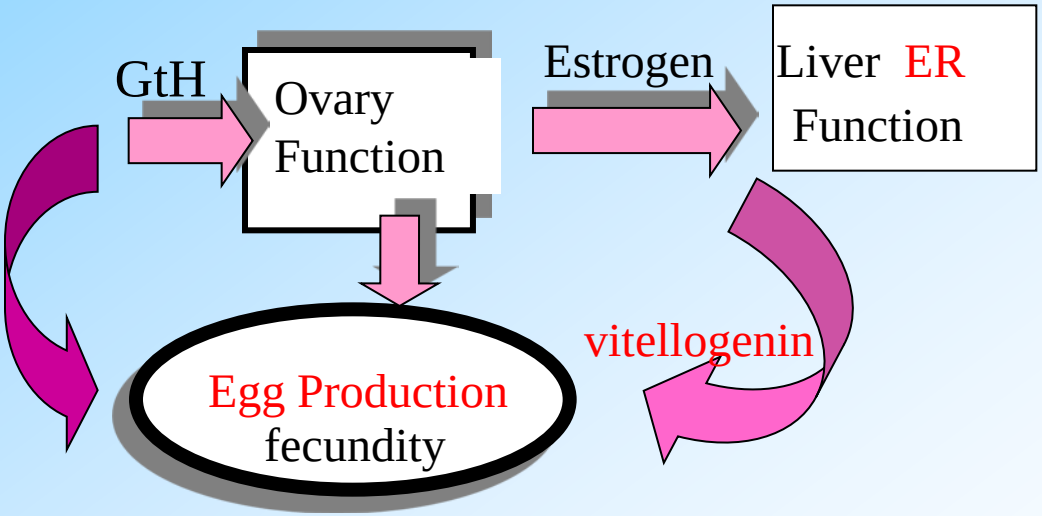
Enzyme aromatase

Sperm production

Androgens
(testosterone)

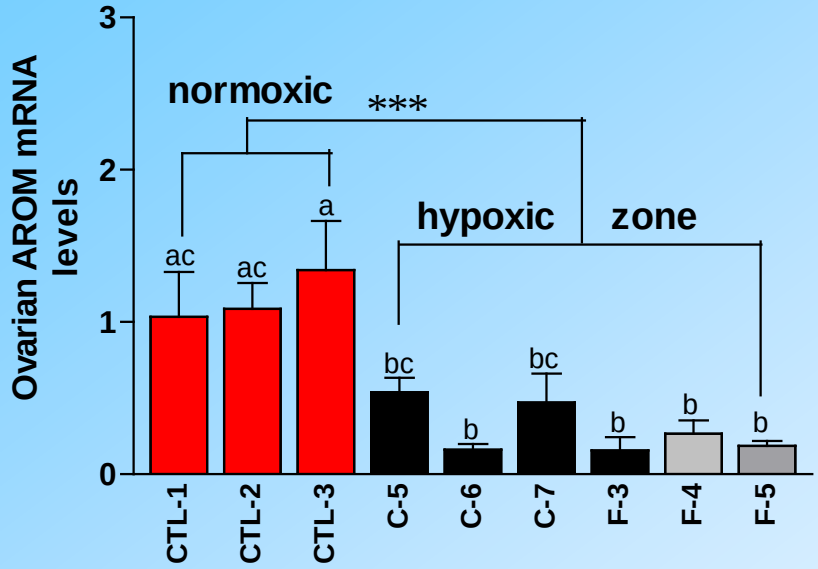
Egg production



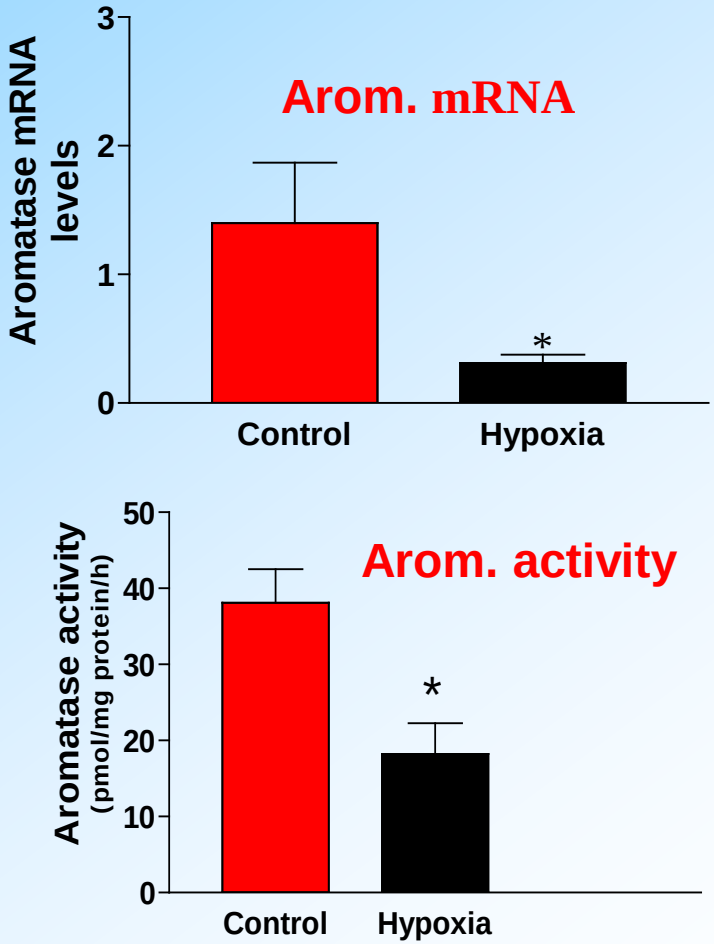


Aromatase mRNA levels in females

2007 field studies

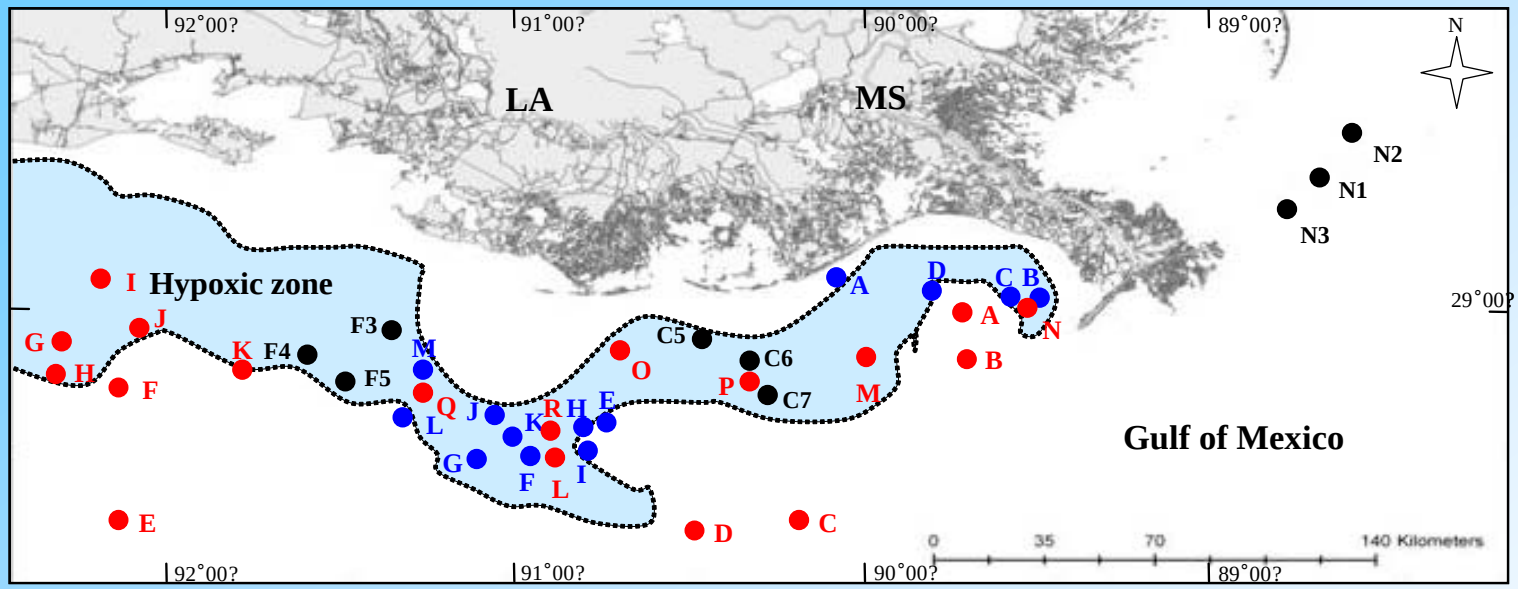


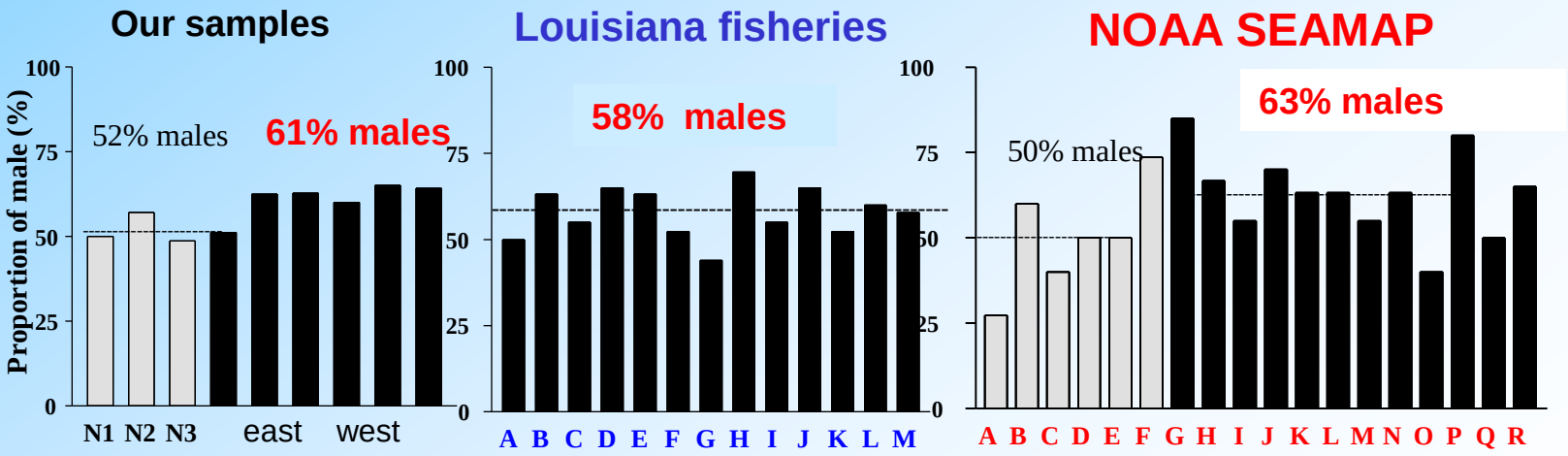
Lab study-ovaries



Aromatase, decreased expression at hypoxic sites- could be related to masculinization

Sex ratio of Atlantic croaker





Consistent male bias in sex ratio in fish from hypoxic zone

Conclusions: hypoxia field studies in northern Gulf of Mexico

- **Egg and sperm production, endocrine function greatly impaired in both male and female croaker at hypoxic sites 120km apart, ~ 3-4000km^2**

- **Evidence for intersex -masculinization of female gonads; male skewed sex ratio**

- **Results support hypothesis: hypoxia in the northern Gulf of Mexico significantly decreases egg and sperm production in croaker**

Funded by NOAA NGOMEX research program

Potential Long-term Effects of Hypoxia-induced Decline in Reproductive Output on Fish Population Size.

Determining long term effects difficult

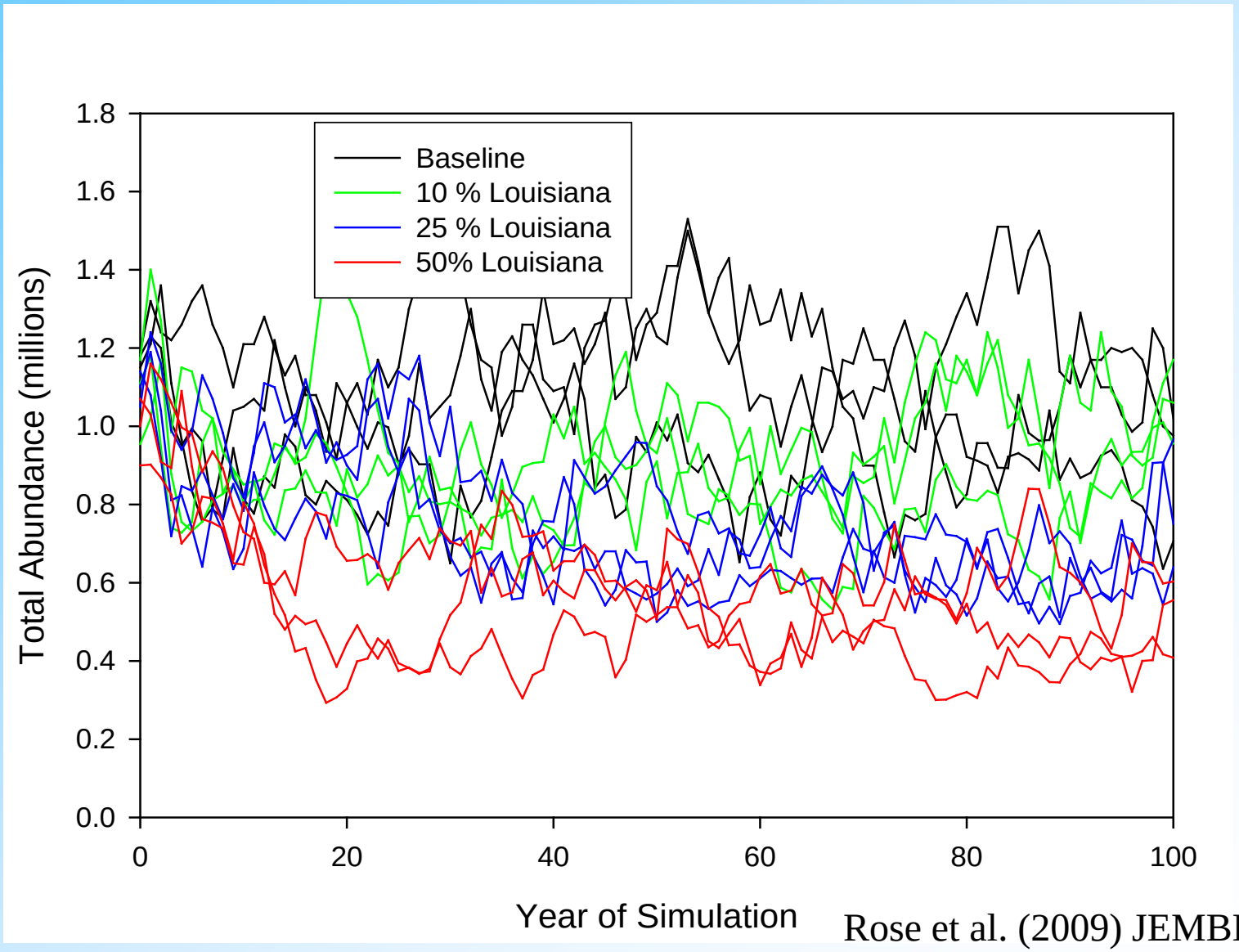
- Population affected by multiple factors that vary together and have interactive effects

-Separation of hypoxia effects from other factors is difficult. e.g fishing by catch

Population Modeling is a valuable approach

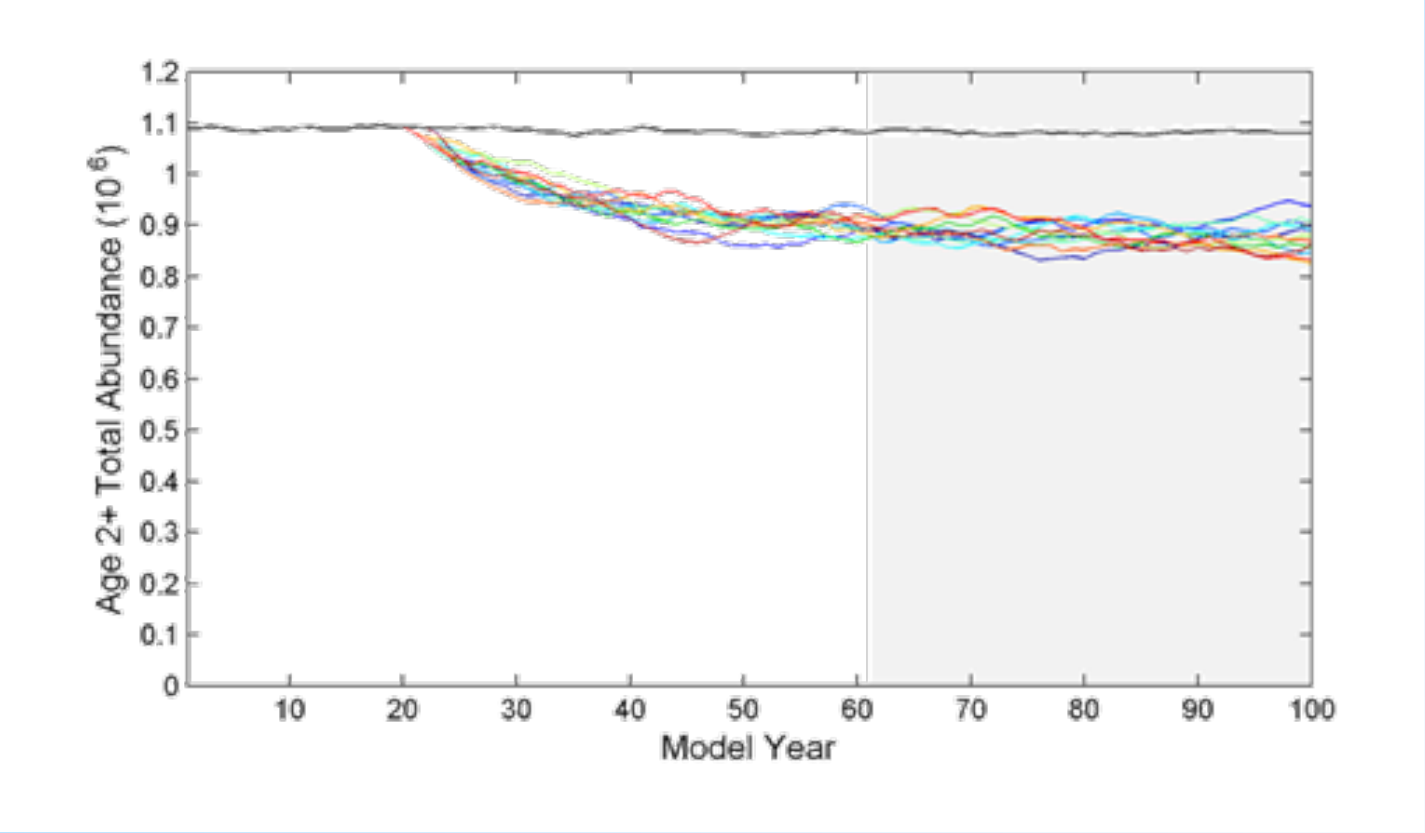
Modeling allows for systematic evaluation of multiple factors in a controlled world

Modeling Results 1- Predicted Decline in Louisiana Population Size if 25-50% Croaker Exposed to Hypoxia



Rose et al. (2009) JEMBE

Modeling 2- A Second Model also Predicts a Decline in Croaker Population Size—Dr. Kenneth Rose



Average age 2+ abundance for model years 61-100 ranged from 81-83% of baseline abundance (17-19% reduction)

- Less dramatic decline than predicted in other simulation

Does Increased Hypoxia in Coastal Regions Threaten Fishery Stocks over the Long-term ?

-Most extensive study conducted on a coastal fish species, croaker, predicts long-term population decline.

-Hypoxia-induced reproductive impairment has been observed in other aquatic species. But information lacking on reproductive effects on coastal marine species.

- Difficult to detect hypoxia effects on size of fish populations from current stock assessments. Relevant data lacking. Clear evidence for a few fisheries.

Conclusion: Critical to examine commercially important marine fish in other coastal hypoxic regions worldwide for evidence of reproductive impairment in order to predict the long-term population effects