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

Fresh water: lighter
Sea water: heavier

Warmer water: lighter
Colder water: heavier

Surface water
Bottom water

No mixing

O₂  ↓  O₂
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 O₂

Nitrogen, phosphorous from fertilizers, etc.

Fresh water: lighter

Surface water

Sea water: heavier

Bottom water

Bacteria consume O₂

No mixing
Global distribution of hypoxic systems associated with anthropogenic nutrient inputs

- Hypoxic regions have tripled in past 30yrs - Major Global Change
- Over 400 coastal hypoxic regions worldwide, covering 250,000 km²
- 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

Primary regulators

Photoperiod
Temperature
Water chemistry (pH)
Social

Environmental stimuli

Stressors

Pollution
Disease
Capture
Hypoxia?

Gonadotropin releasing hormone (GnRH)

pituitary

pituitary

GtH

Gonadal Function

Egg Production

Egg Production fecundity

Sensitive stages:
- sex differentiation
- Puberty
- egg and sperm production and gonadal growth
- egg and sperm maturation, reproductive success

Brain

+ ve

- ve

Gonadal Function

ER Liver function

E2

vitellogenin
Gonadal Function

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

Model predicts decreased population size

Egg Production

Gonadotropin-Releasing Hormone (GnRH)

Gonadotropin (GtH)

Estrogen

Estradiol (E2)

Vitellogenin (vitellogenin)

Egg production

Ovary growth

Vitellogenin receptor

Relative ERI1 mRNA

Egg production (eggs/fish)

Fecundity (eggs/fish)

GSI

Ovary growth

Control 2.7 ppm 1.7 ppm

0 50 100 150 200

Relative ERI1 mRNA

Control 2.7 ppm 1.7 ppm

0 25 50 75

Egg production

Control 2.7 ppm 1.7 ppm

0 50000 100000 150000 200000
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

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

Similar to endocrine impairment seen in laboratory studies.

Egg production and endocrine function impaired at hypoxic sites.
Hypoxia in Estuaries: Hypoxia exposure also causes reproductive dysfunction in males

Spermatogenesis impaired

Plasma 11-KT

Testis size

Sperm production

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
Mississippi-Atchafalaya Drainage Basin

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

Dissolved oxygen \( \leq 2.0 \text{ mg} \)

Mapping since mid 1980’s:
- increased from 5,000 km\(^2\) to 16,000 km\(^2\)

Dissolved oxygen \( \leq 2.0 \text{ mg} \)
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

Normoxic sites

Ovary

hypoxic zone sites

Normoxic sites

Testis

hypoxic zone sites
Gonadal growth impaired at hypoxic sites in both females and males

**Ovarian growth**

- Normoxic sites
- Hypoxic zone sites

**Testicular growth**

- Normoxic sites
- Hypoxic zone sites

2007,2008 Reproductive impairment in males at hypoxic sites

Sperm production

Spermatogenesis and sperm production decreased at hypoxic zone sites
Reproductive impairment in females at hypoxic sites

Normoxic site

hypoxic zone sites

C transect

F transect

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

Fecundity (10^3 eggs/fish)

Large eggs > 350 μm

Hypoxic zone sites

CTL1 CTL2 CTL3 C5 C6 C7 F3 F4 F5
Fall 2007 Endocrine function decreased at hypoxic sites

GnRH mRNA

*Nested ANOVA

\(^{a-c}\)Fisher's PLSD test

GnRH

GtH

Ovary

Function

E\(_2\)

ER

Liver

Function

vitellogenin

Oocyte Production
fecundity

Relative ER\(_{\alpha}\) mRNA levels

*** \(P<0.001\), Nested ANOVA; \(^{a-c}\)Fisher's PLSD test

Plasma VTG levels (mg/mL)

Reproductive impairment due to endocrine disruption at hypoxic sites
Some ovaries from hypoxic zone sites contain spermatogenic cells:

Suggests masculinization under hypoxic conditions

2006, 2007

Evidence for Ovarian Masculinization
Percent ovaries masculinized

Field Studies

Suggests masculinization caused by hypoxia exposure
How does hypoxia cause the croaker ovary to produce sperm?

**HYPOTHESIS:** HYPOXIA

![Diagram showing the relationship between GtH, Ovary Function, Estrogen, Liver ER Function, and Egg Production fecundity.](image)

- GtH stimulates卵泡卵 (GtH stimulates ovary function)
- Estrogen functions in liver ER function
- vitellogenin is involved in egg production

**Key Points**
- Androgens (testosterone) inhibit sperm production
- Enzymes, aromatase, are involved in the conversion of androgens to estrogens in the liver.

**Ovary Function**
- GtH
- Estrogen

**Liver Function**
- ER
- Vitellogenin

**Egg Production**
- Sperm production
- Egg production
Aromatase mRNA levels in females

2007 field studies

Lab study-ovaries

Aromatase mRNA levels in females

Ovarian AROM mRNA levels in females

Hypoxic zone

Aromatase activity

Aromatase, decreased expression at hypoxic sites- could be related to masculinization
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, ~ 3-4000km²

- 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

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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
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.