Toxic Chemicals and Fish Health in Chesapeake Bay

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USGS

Chesapeake Bay Executive Order

Strategy for Protecting and Restoring the Chesapeake Bay Watershed

- **Address the significant problem of toxic pollutants in the Bay and its watershed to protect the health of fish, wildlife and people**
- **Substantial less information on what to base specific goals and strategy for toxic reduction**
- **Legacy contaminants as well as contaminants of emerging concern**

Chemicals of "Emerging Concern"

- Defined as synthetic or naturally occurring chemicals that are not commonly monitored in the environment, are generally not regulated, but have the potential to enter the environment and cause adverse effects
- Newly recognized effects such as endocrine disruption of exposure to low concentrations of legacy contaminants

Chemicals of Emerging Concern Sources

- Wastewater Treatment Plants
- Industrial effluent
- Stormwater runoff
- Agriculture
- Landfill leachate
- Gas extraction/Marcellus shale

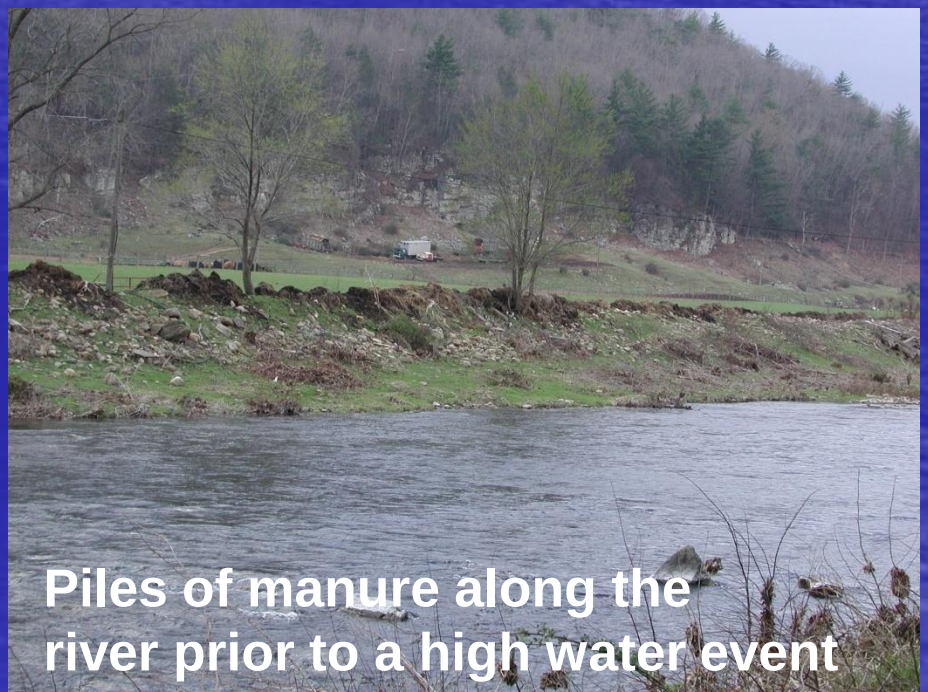
"Emerging Contaminants" WWTP-Related

- Pharmaceuticals – Human and Animal
  - Synthetic Hormones – birth control, hormone replacement therapy
  - Antibiotics
  - Viagra to Prozac
- Personal care products
  - Antimicrobials – soap, detergent, toothpaste
  - Fragrances
  - Organic UV filters
  - DEET

Agricultural Inputs

Manure, urine, litter – direct deposit and runoff
Natural and synthetic hormones
Antibiotics, feed additives
Biosolids used as fertilizer
Pesticides, herbicides and other chemicals

Cattle with free access to the river



Piles of manure along the river prior to a high water event

Classical Toxicology

- Use conventional, single chemical toxicity
  - Do not account for mixture effects – additive, synergistic, antagonistic
- Based on conventional laboratory exposures
  - Generally only one type of exposure (water, sediment, food)
  - Water quality (pH, temperature, conductivity) effects
  - Assume typical dose responses
- Based on testing of one or two species
  - Rainbow trout, fathead minnows
  - Species differences in sensitivity

Complexities Associated with Contaminants Wild Populations

- Endocrine/Immune systems - chemical communication and feedback mechanisms
- Lack of classic dose response curve – hormesis
- Multiple contaminant exposure routes - water, sediment, food (yolk sac)
- Exposures early in life may initiate effects seen in mature adults
- Complex mixtures – additive, synergistic, antagonistic effects

Benchmark Toxicity Endpoints

- Acute toxicity
  - 96 hour LC_{50}
- Chronic toxicity
  - Mortality
  - Larval fish growth
  - Reproductive - # of eggs produced

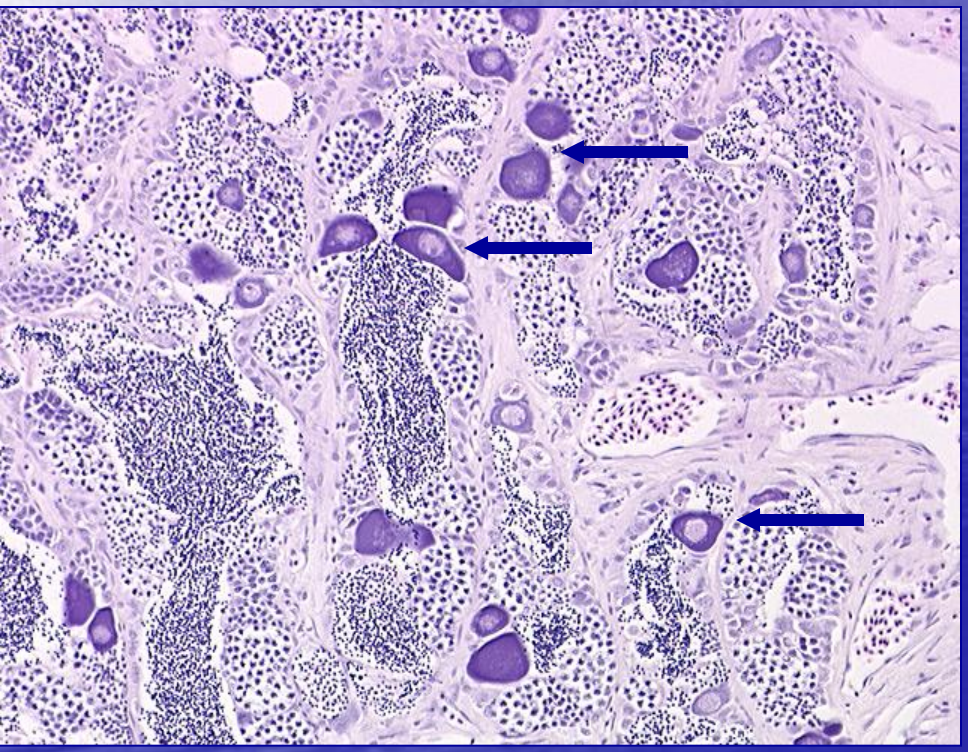
Lack of Sublethal Benchmarks

- Address
  - Endocrine disruption/modulation
  - Reproductive health
  - Immune system/disease resistance
- Population effects
  - Acute or chronic mortality
  - Reproductive effects

Fish Health Issues
Chesapeake Bay Watershed

- Indicative of environmental stress
  - Skin lesions and kills of bass, sunfish and suckers
    - Adults in the Potomac and James (spring)
    - Young-of-year in the Susquehanna (summer)
  - High prevalence of intersex in bass
  - Poor recruitment of yellow perch in certain tributaries
  - Skin and liver tumors in brown bullhead in certain tributaries

Intersex in Normally Gonochorist Fishes



- Suggested as a marker of endocrine disruption
- Most often associated with exposure to estrogenic compounds
- Probably induced early in life, but may occur due to exposure later in life

Complexities
Contaminants of Emerging Concern

- Many are produced to have a biological effect and so can influence nontarget organisms at very low levels
- May be additive in their effects
- Effects of CEC demonstrated at very low levels
  - 0.35 ng/L estradiol recently set as the aquatic "no effects level" (Europe)
  - < 1.0 ng/L induces intersex in numerous fish species
  - 0.8 or above is the minimum detection limit for many studies

Integrative Water Samplers

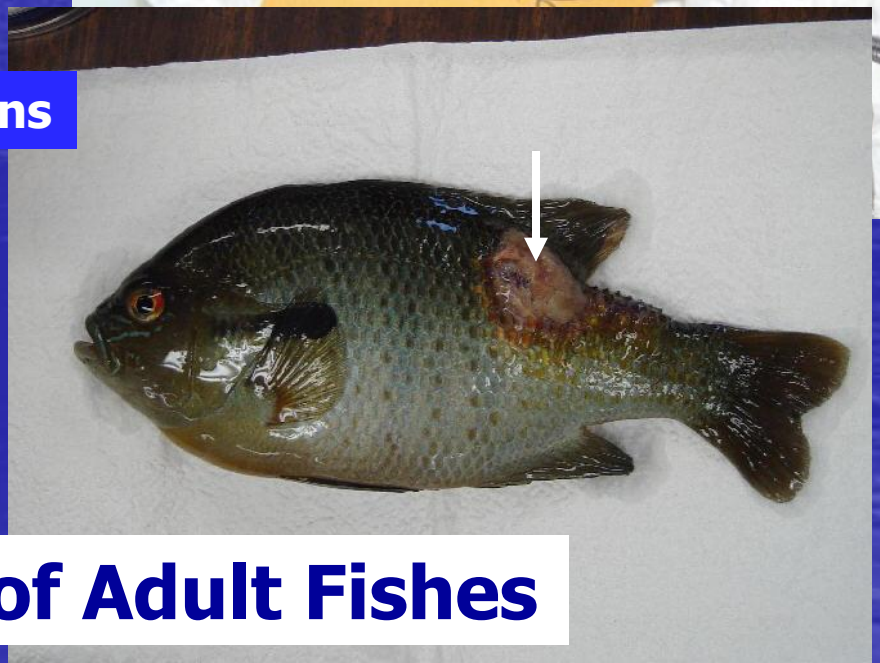
- Semi permeable Membrane Devices (SPMDs)-accumulate hydrophobic compounds
- Polar Organic Compound Integrative Samplers (POCIS)—accumulate hydrophilic compounds

Methods to Address Complex Mixtures

- Screening either grab water extracts or the extracts from the integrative samplers using in vitro cell assays
  - YES, BLYES, breast cancer cells – total estrogenicity – estrogen equivalents
  - Total androgenicity
  - Transgenic zebrafish
  - Nuclear translocation assays - glucocorticoids

- Integrative sampler hormone results – no hormones above method quantification levels (N. Fork Shen)
  - 17β estradiol, 17α-ethynylestradiol, estrone, estriol
- Estrogen equivalents ranged from 14-79 ng estradiol/sample depending on the site

Resident Fish as Integators of Environmental Stressors



Gross Lesions of Adult Fishes

Gross Lesions of YOY SMB Susquehanna River

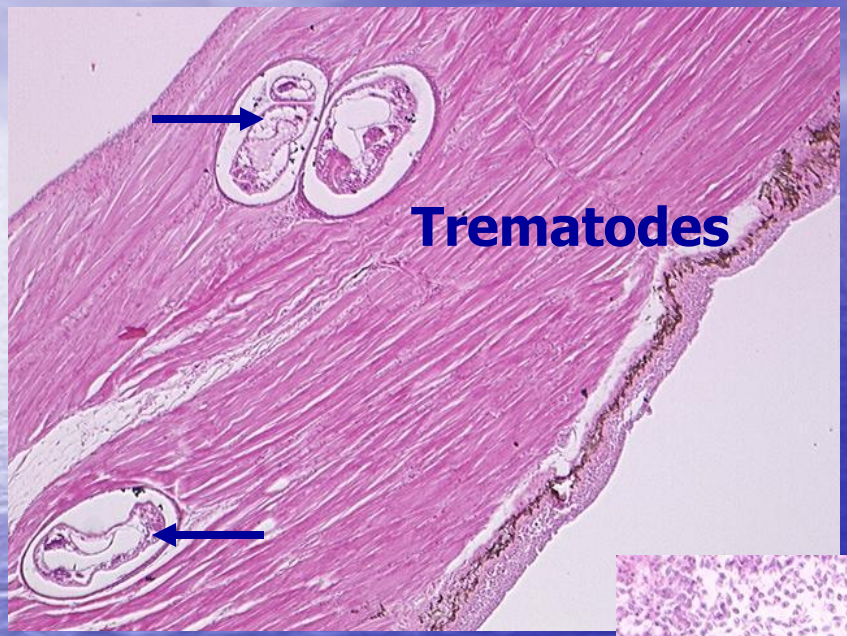
Overall Findings/Conclusions/ Fish Kills

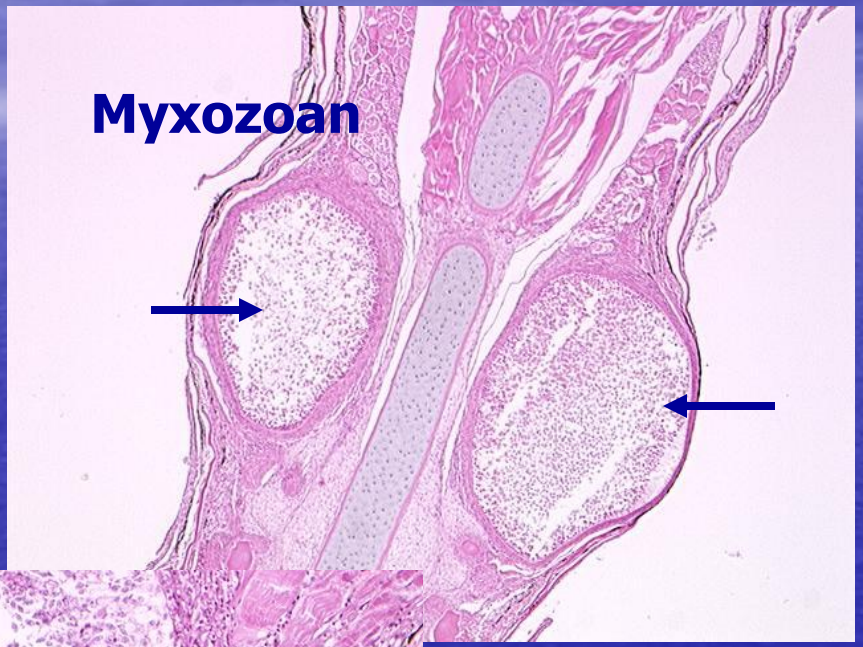
- Numerous pathogens contributing to the skin lesions and eventual death – no consistent findings
  - Bacteria – *Aeromonas hydrophila, A. salmonicida, Flavobacterium columnare*
  - Virus – largemouth bass virus
  - Numerous parasites
- High prevalence/severity of intersex

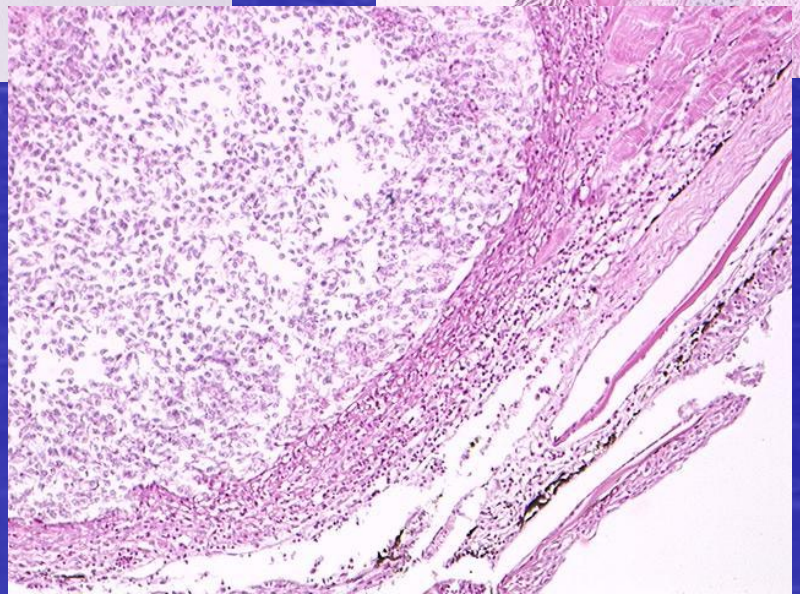
YOY Cultured 2010

Site	*Lesions Aero*	*Lesions Flavo*	*Internal Aero*	*Internal Flavo*
Juniata	5/5	5/5	1/8	1/8
Danville	12/15	15/15	8/18	2/18
Laceyville	1/1	0/1	4/16	0/16
mucus	*3/9*	*0/9*		
Liverpool	3/4	4/4	1/7	0/7
Clemson Island	6/6	4/6	1/8	0/8
Total	27/31	28/31	15/57	3/57

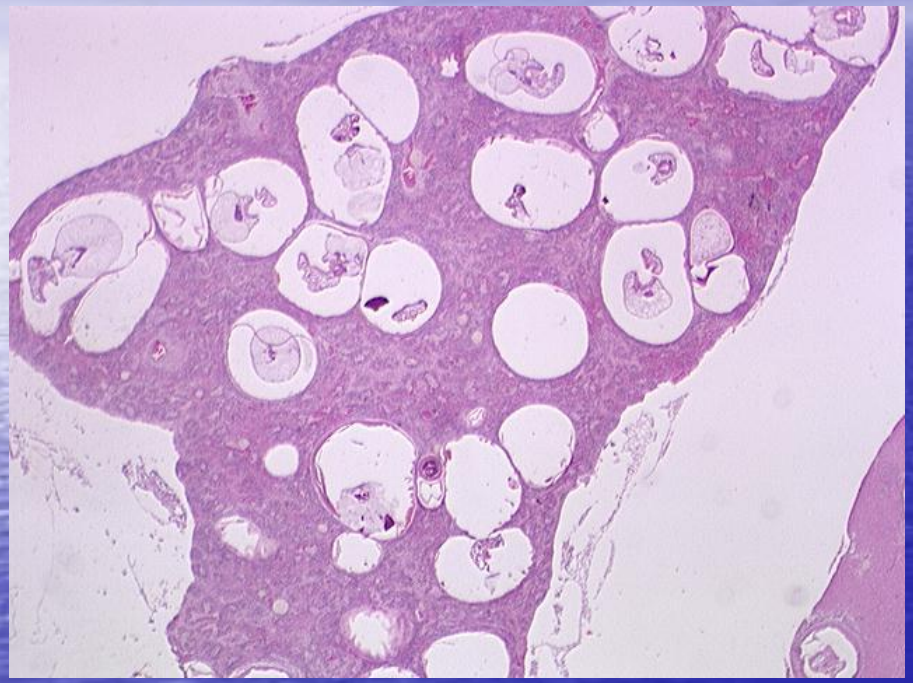
YOY SMB Parasites



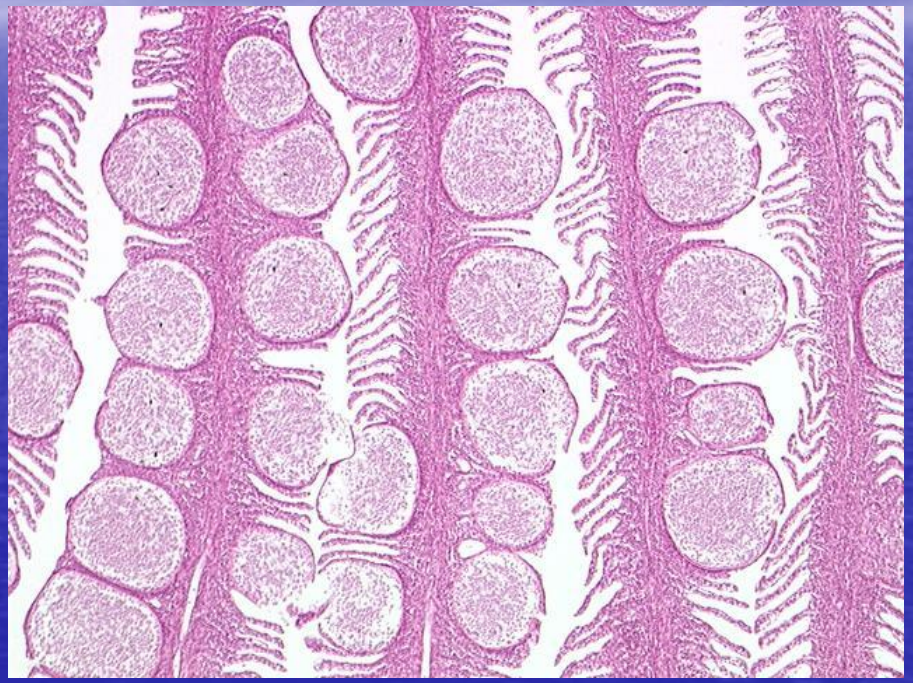




High Parasite Loads – Adult Bass



Trematodes



Myxozoans

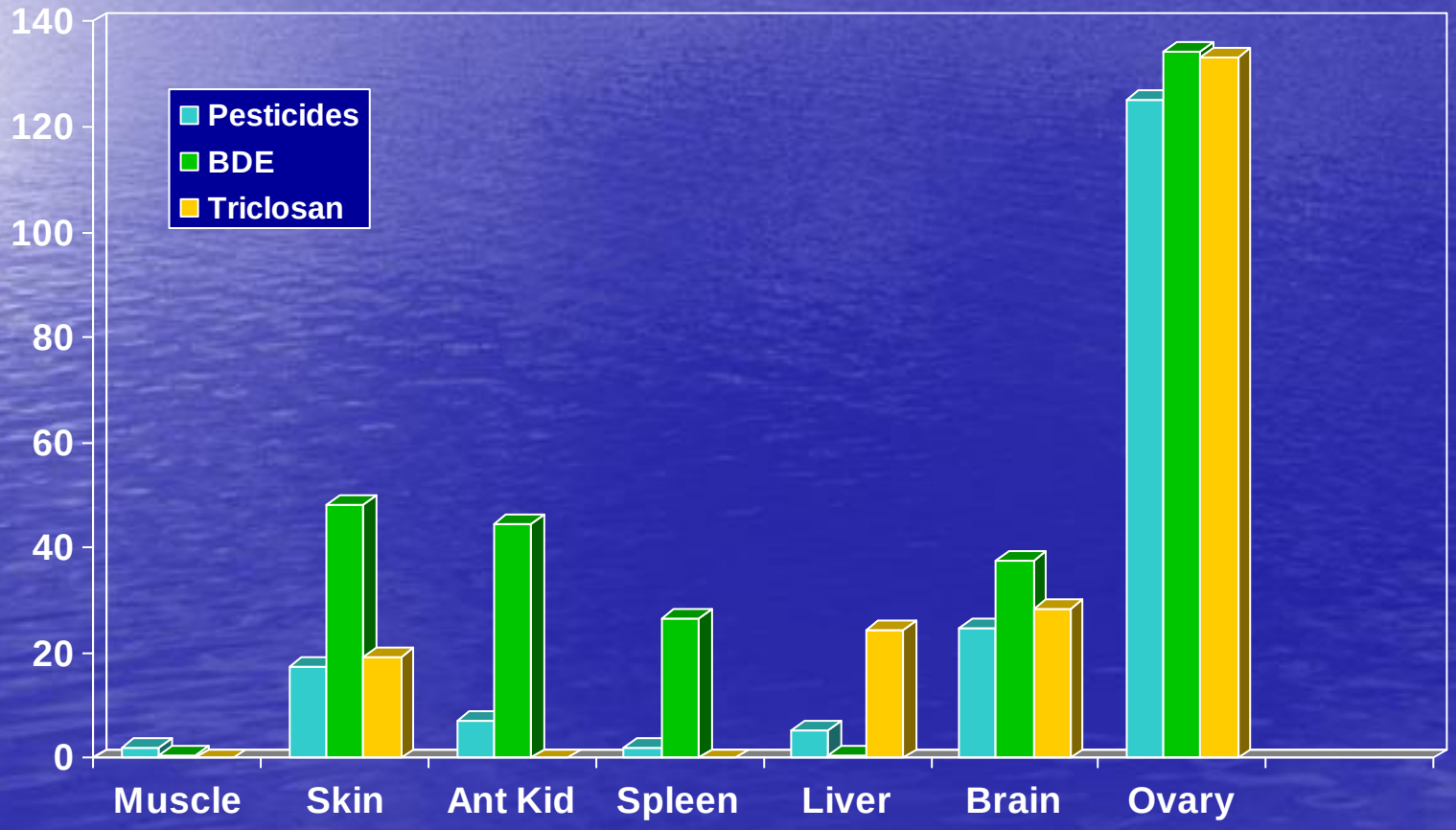
Both groups have complex life cycles that include benthic invertebrates – snails, bryozoans, worms – polycheates and oligocheates (*Tubifex*)

Fish Kill Issues Related to Intersex and Other Reproductive Findings?

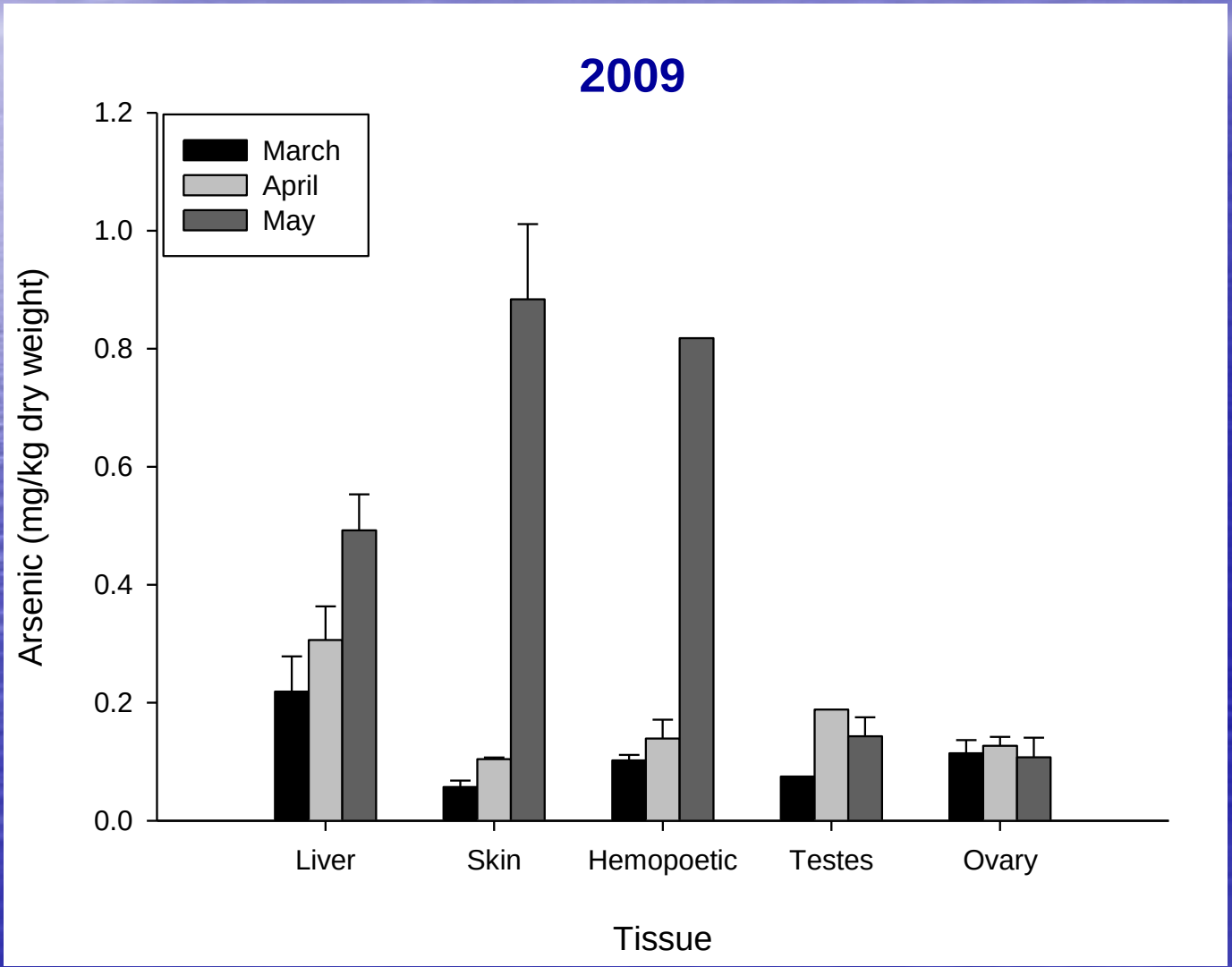
- Estrogens and estrogenic chemicals (estrogen mimics) are most often associated with intersex and vitellogenin production in male fishes
- Increasing evidence that estrogenic chemicals and other endocrine-disrupting substances modulate the immune response and disease resistance
- Also chemicals such as arsenic, atrazine, PCBs act as immunosuppressors by other mechanisms

Contaminant Body Burdens

- Generally whole body or fillet
  - Fillet analysis is reasonable when the concern is human health



Arsenic Tissue Contaminants Adult Smallmouth Bass



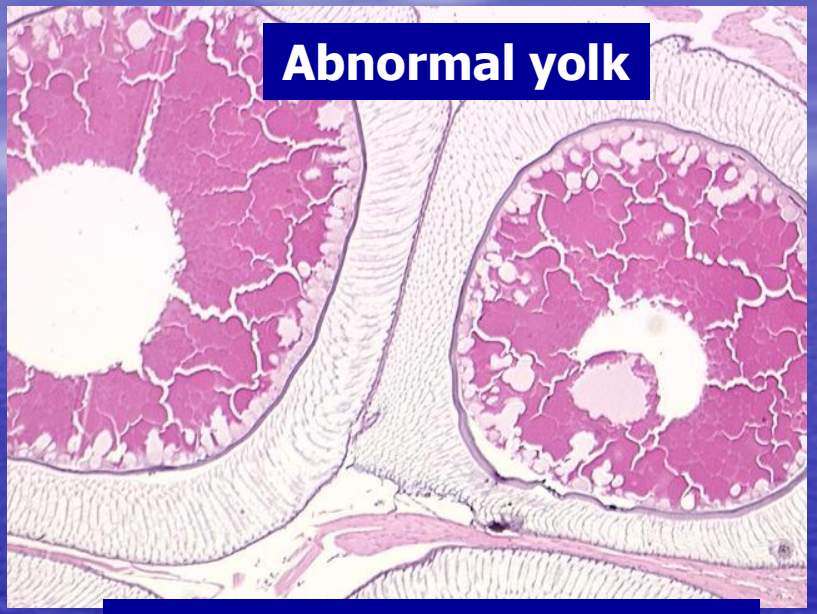
Yellow Perch

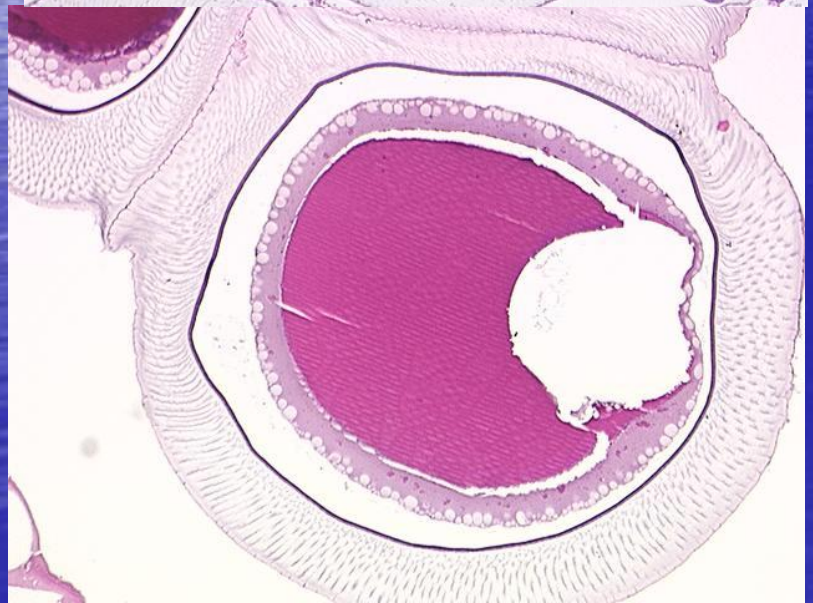
- Lack of reproductive success in urban watersheds such as Severn and South
- Compared variety of biological endpoints during spawning runs (2007-2009) in perch from Choptank, Mattawoman, Allen's Fresh, South, Severn
  - Gonad histology
  - Plasma hormones, vitellogenin
  - Sperm characteristics

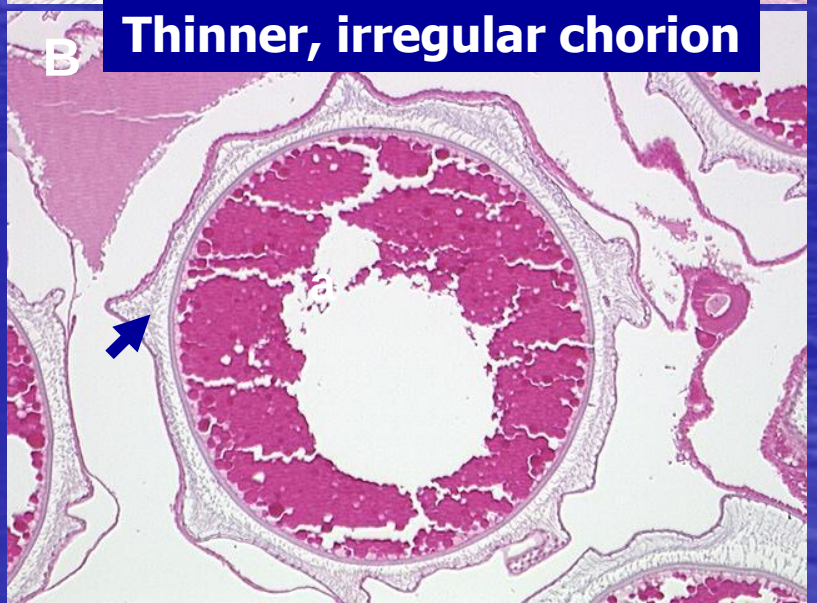
Egg Abnormalities Observed

Choptank

Severn







Contaminants Measured in Tissues Yellow Perch

Chemical (µg/kg)	Brain	Ovary	Liver	Muscle
HCB	ND	ND	2.47	5.90
PCA	ND	ND	1.31	4.04
DCPA	0.22	0.25	ND	ND
Fipronil compounds	0.21	0.09	ND	ND
Chlordane compounds	4.30	5.41	3.28	0.49
Nonachlor compounds	3.36	3.51	3.18	0.20
Dieldrin	0.64	0.82	0.60	0.10
DD_x	20.50	19.30	4.95	1.30
$\sum$ PCBs	61.34	39.30	41.37	2.81
$\sum$BDEs	7.41	0.75	1.03	0.59

Toxic Tissue Levels

- Understanding what effects the individual compounds and complex mixtures have in the individual tissues in which they accumulate
  - Spleen, anterior kidney – influence disease resistance
  - Brain – effects on reproduction, behavior etc.
    - Oocyte maturation depends the pituitary gonadotropin, luteinizing hormone stimulating the production of maturation-inducing hormone.
  - Egg
    - Effect vitellogenin incorporation, final maturation etc.
    - Fish hatch as sac fry – for the first 2-3 weeks of life live by absorbing the yolk.
    - How do chemicals present in the egg (and water and sediment) affect the fish during this critical stage of sexual differentiation, immune system development etc.

Conclusions
Toxics Monitoring

- Chemical Monitoring
  - Multiple matrixes (water, sediment, tissue)
  - Appropriate sampling regimes (temporal, spatial)
  - Methods to measure biological relevant concentrations
- Biological Effects Monitoring
  - Sensitive species
  - Sensitive life stages
  - Variety of methods to detect effects – gross observations to molecular mechanistic indicators
  - Methods to evaluate biological effects of complex mixtures

Conclusions

- We need a better understanding of the complex interactions of contaminants of emerging concern, legacy contaminants and water quality parameters such as nutrients, pH, temperature
- We need a better understanding of the temporal changes (flow, season, activities on the land) that may help target management actions, particularly during sensitive life-stages
- Management will depend on the individual area/watershed – point and nonpoint sources within the catchment

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