Zebra Mussels in Texas: Implications For Southern States

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South Shore, Lake Texoma

Outline

- Invasive Biology and Impacts of Zebra and Quagga Mussels
- Overview of Past Texas Dreissenid Research
- Recent Texas Dreissenid Research
- Zebra Mussels in Texas Water Bodies?
- Threat to Gulf States
- Conclusions

Invasive Biology and Impacts of Dreissenid Mussels

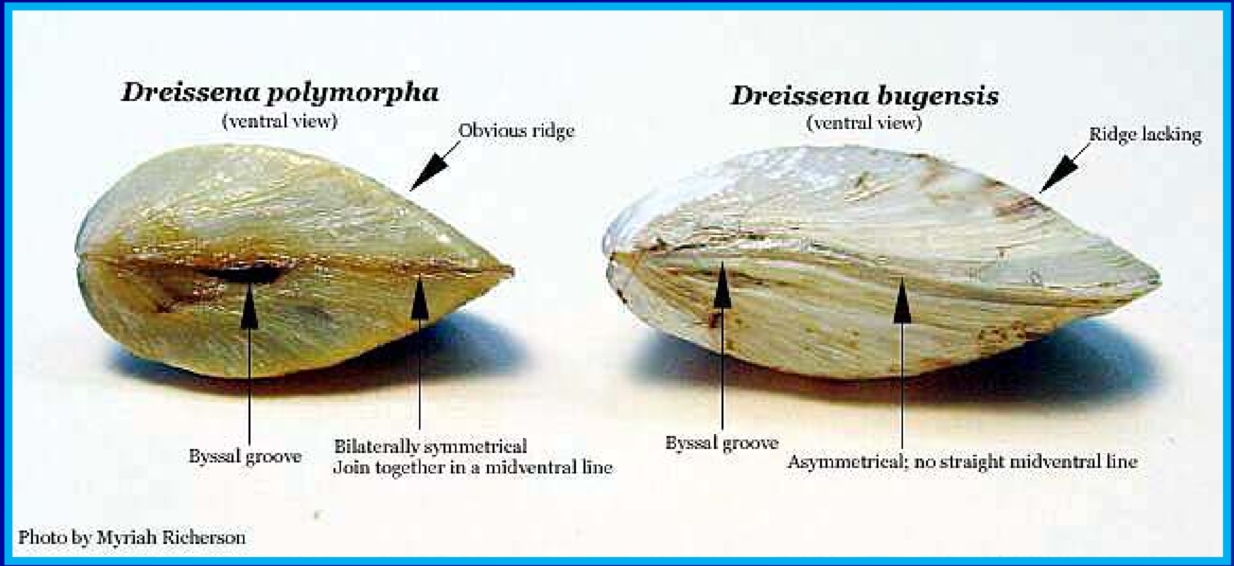
Zebra and Quagga Mussels

- Originally endemic to Europe
- Introduced to North America in ~ 1986
- Found in Lake St. Clair and eastern basin of Lake Erie in 1989
- Rapidly spread throughout major US and Canadian drainage systems east of the Rocky mountains
  - Great Lakes drainage, the Mississippi River, and its eastern tributaries, lower Missouri River, Arkansas River and isolated lakes and rivers
  - Rapid dispersal through navigable waterways on commercial vessels
  - Dispersed more slowly to isolated water bodies (i.e., overland transport)
  - Quagga mussels recently found in Lake Mead, lower Colorado River, and lakes in southern California
  - Zebra Mussel recently found in San Justo Reservoir Central California
- Most costly macrofouling and ecological pests ever introduced to North American freshwaters

Dreissenid Shell Morphology

Zebra Mussel
Dreissena polymorpha

Quaaga Mussel
Dreissena rostriformis bugensis



Zebra Mussel Invasion of the US

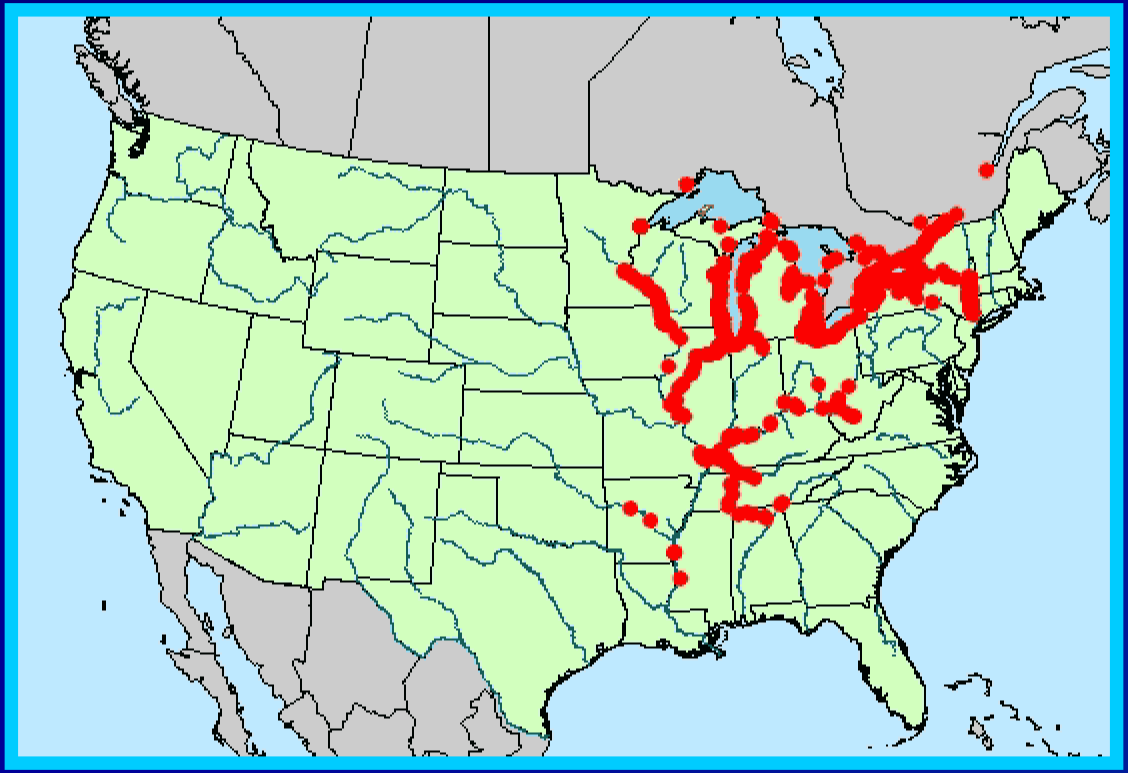
1988

Zebra Mussel Invasion of the US

1990

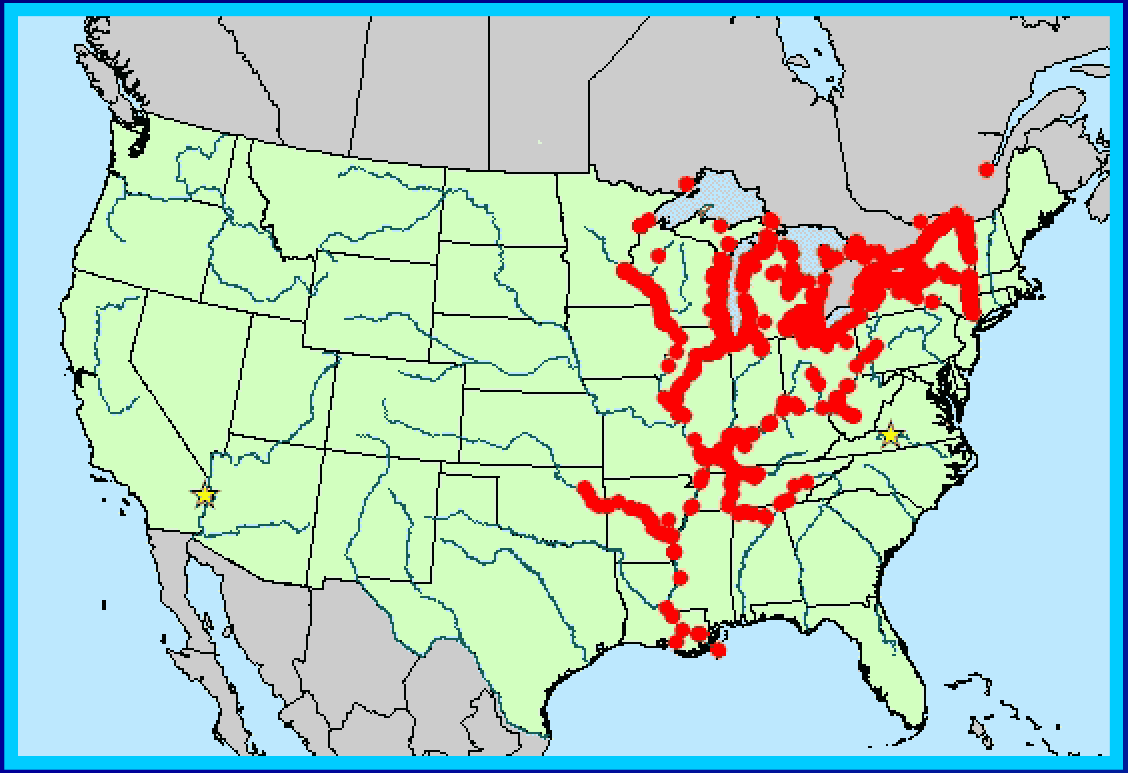
Zebra Mussel Invasion of the US

1992



Zebra Mussel Invasion of the US

1994

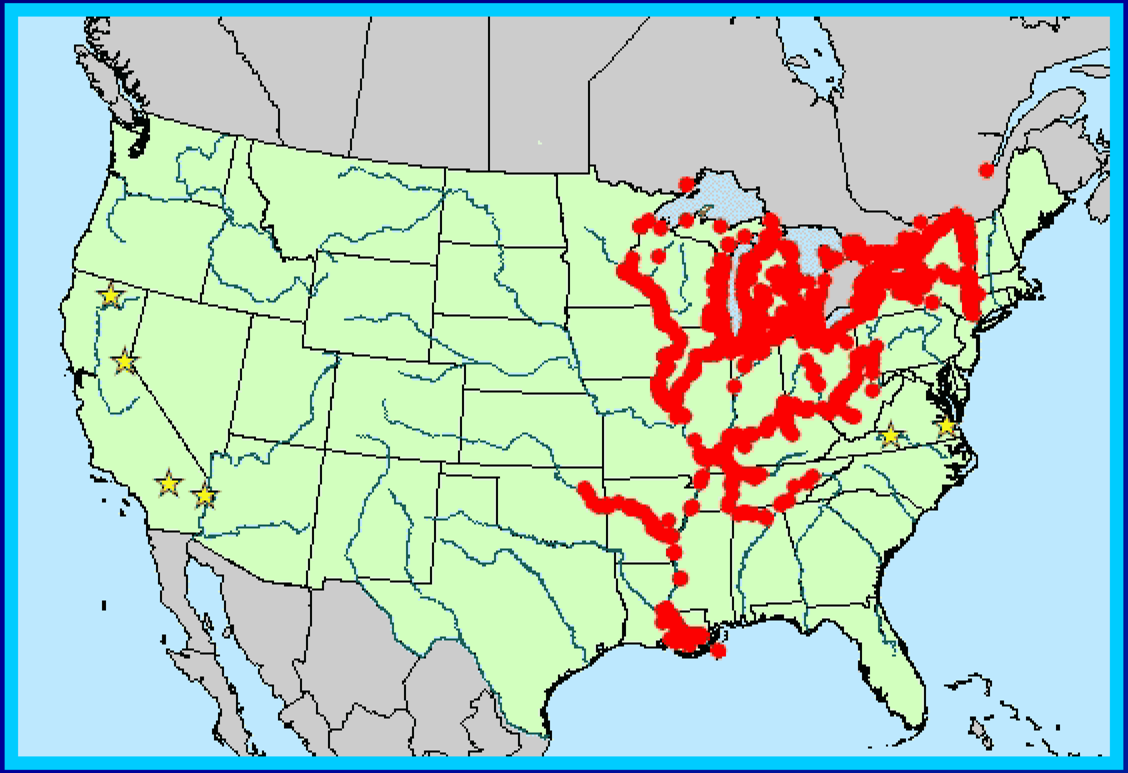


Zebra Mussel Invasion of the US

1996

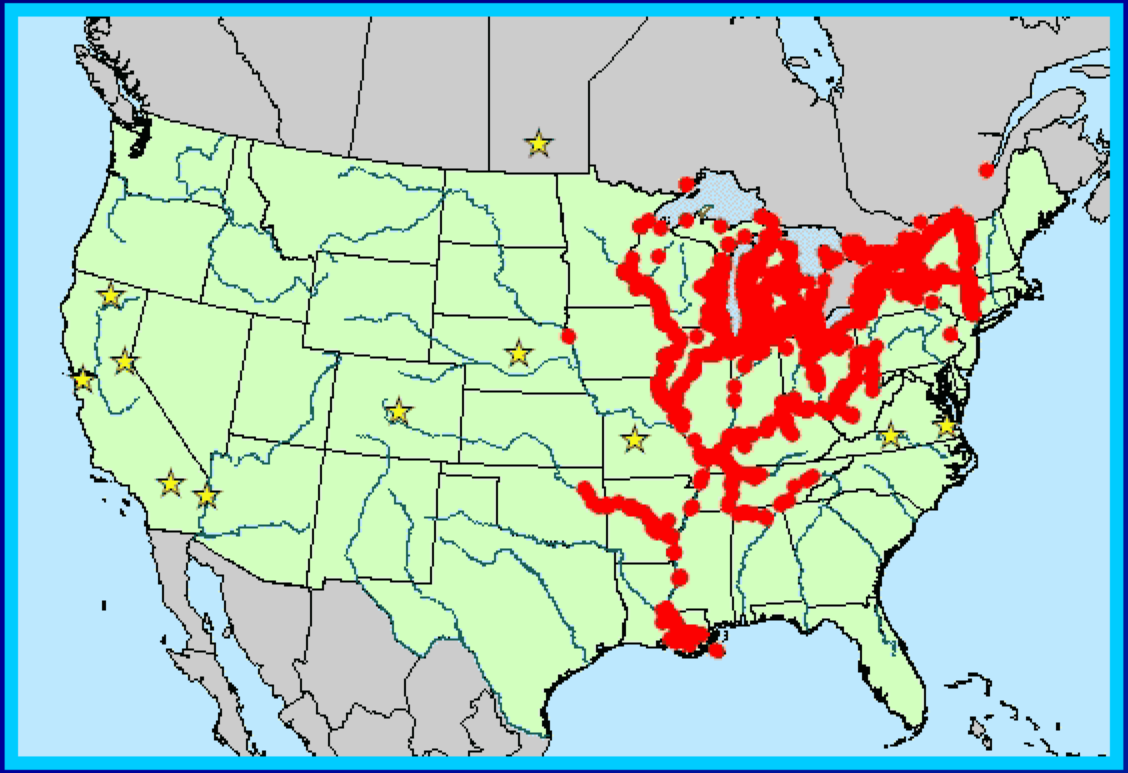
Zebra Mussel Invasion of the US

1998



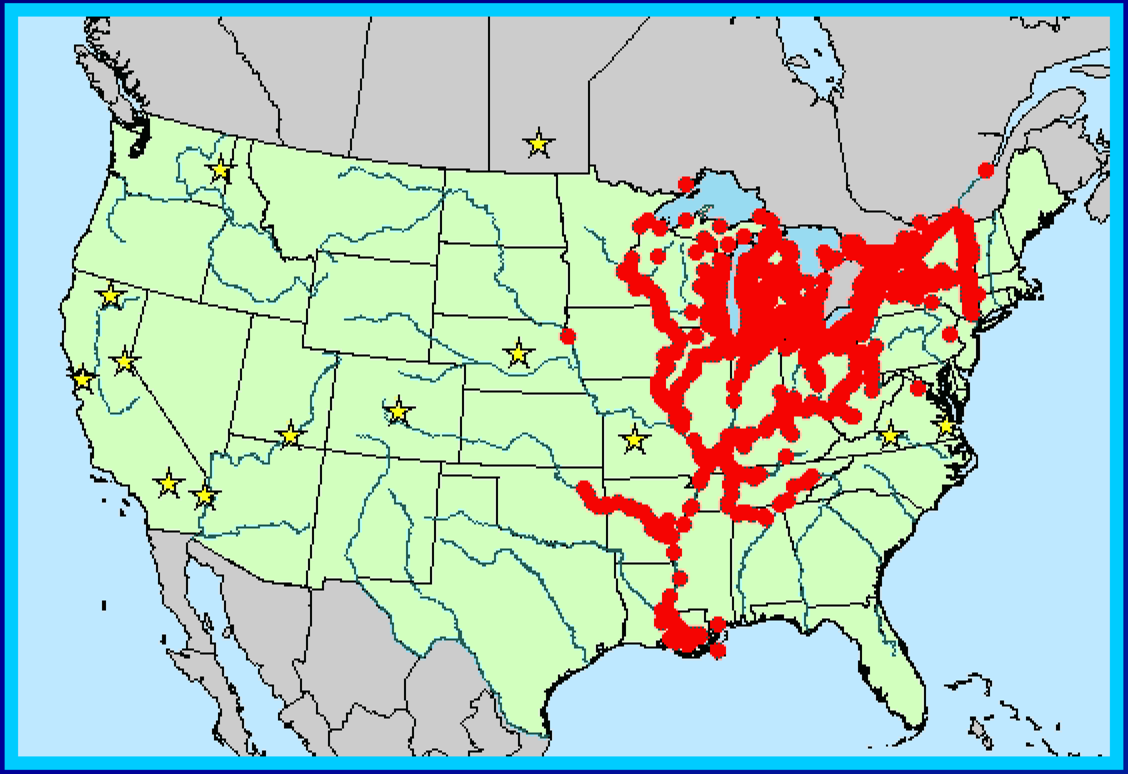
Zebra Mussel Invasion of the US

2000



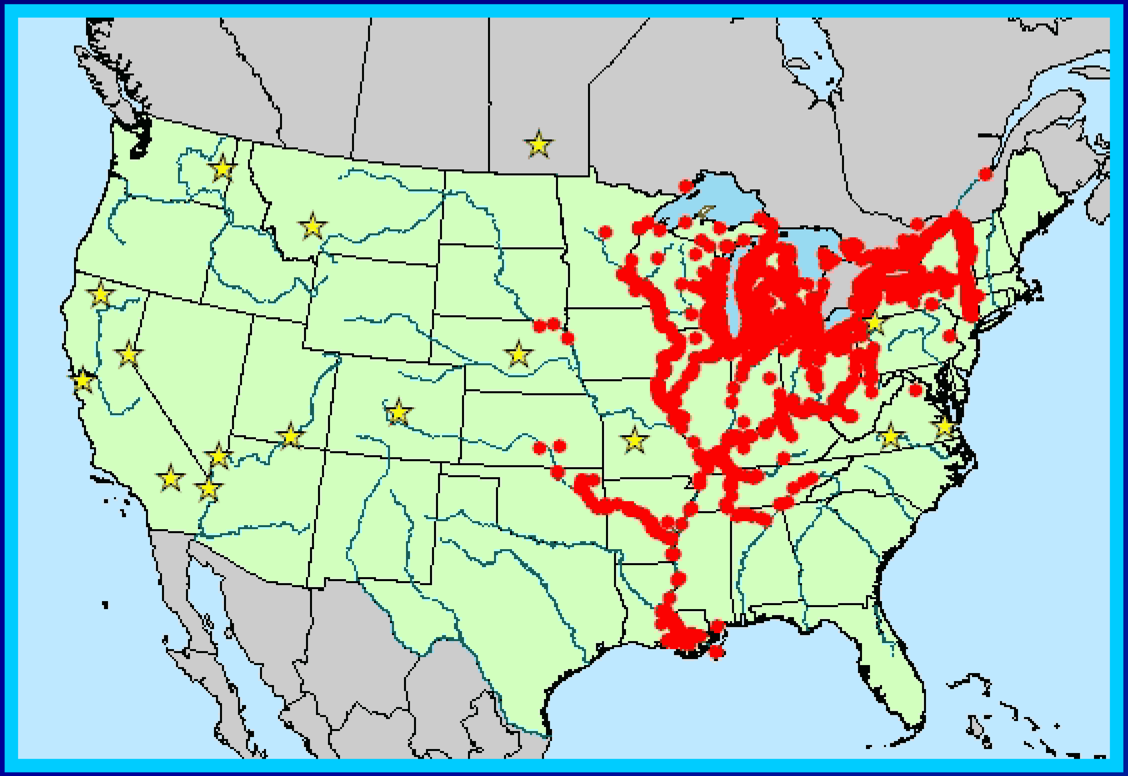
Zebra Mussel Invasion of the US

2002



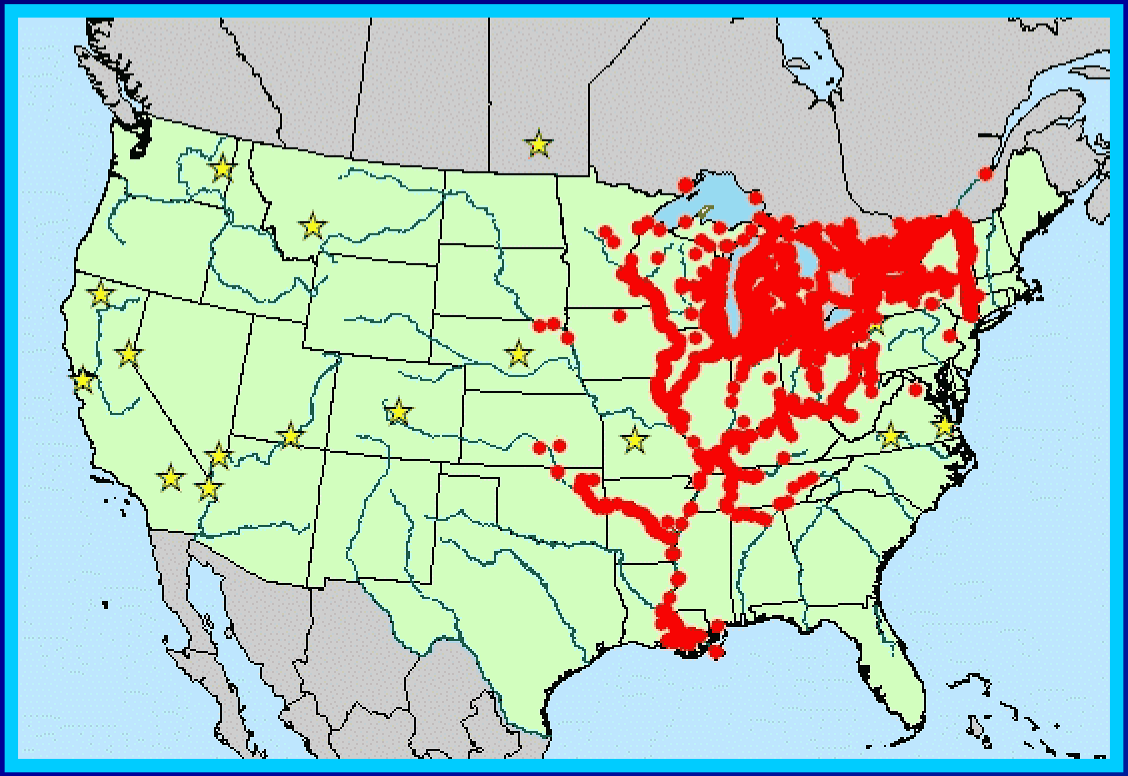
Zebra Mussel Invasion of the US

2004



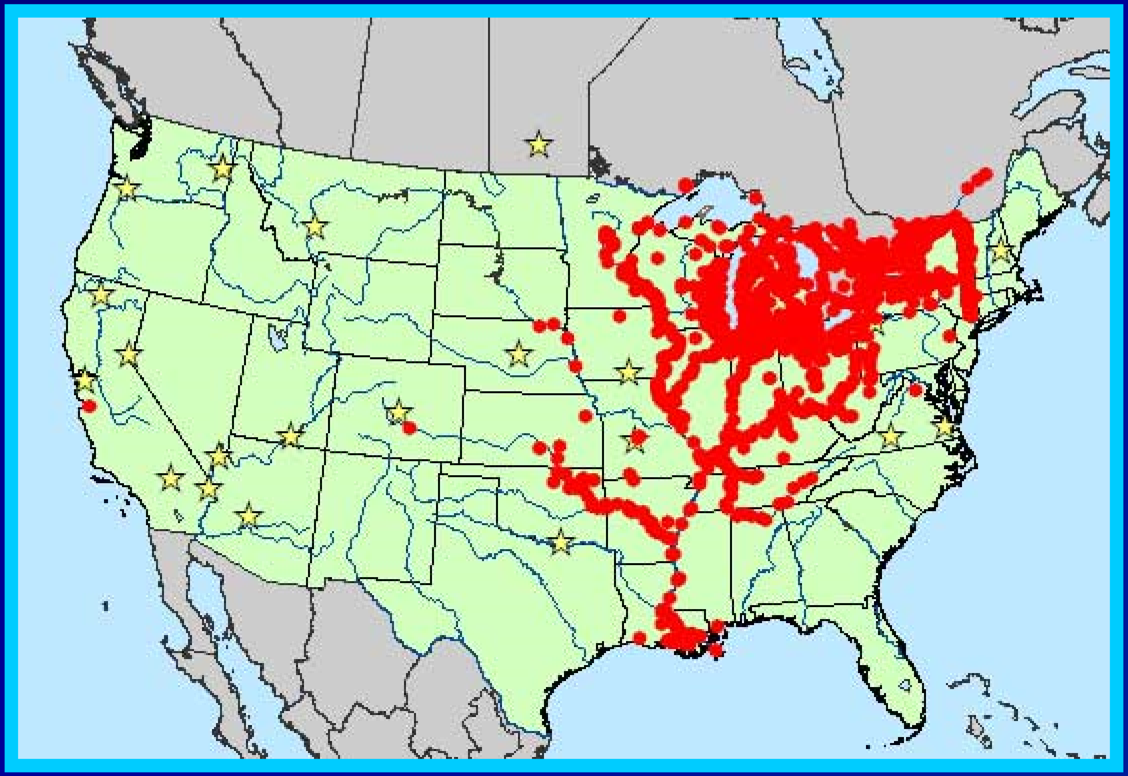
Zebra Mussel Invasion of the US

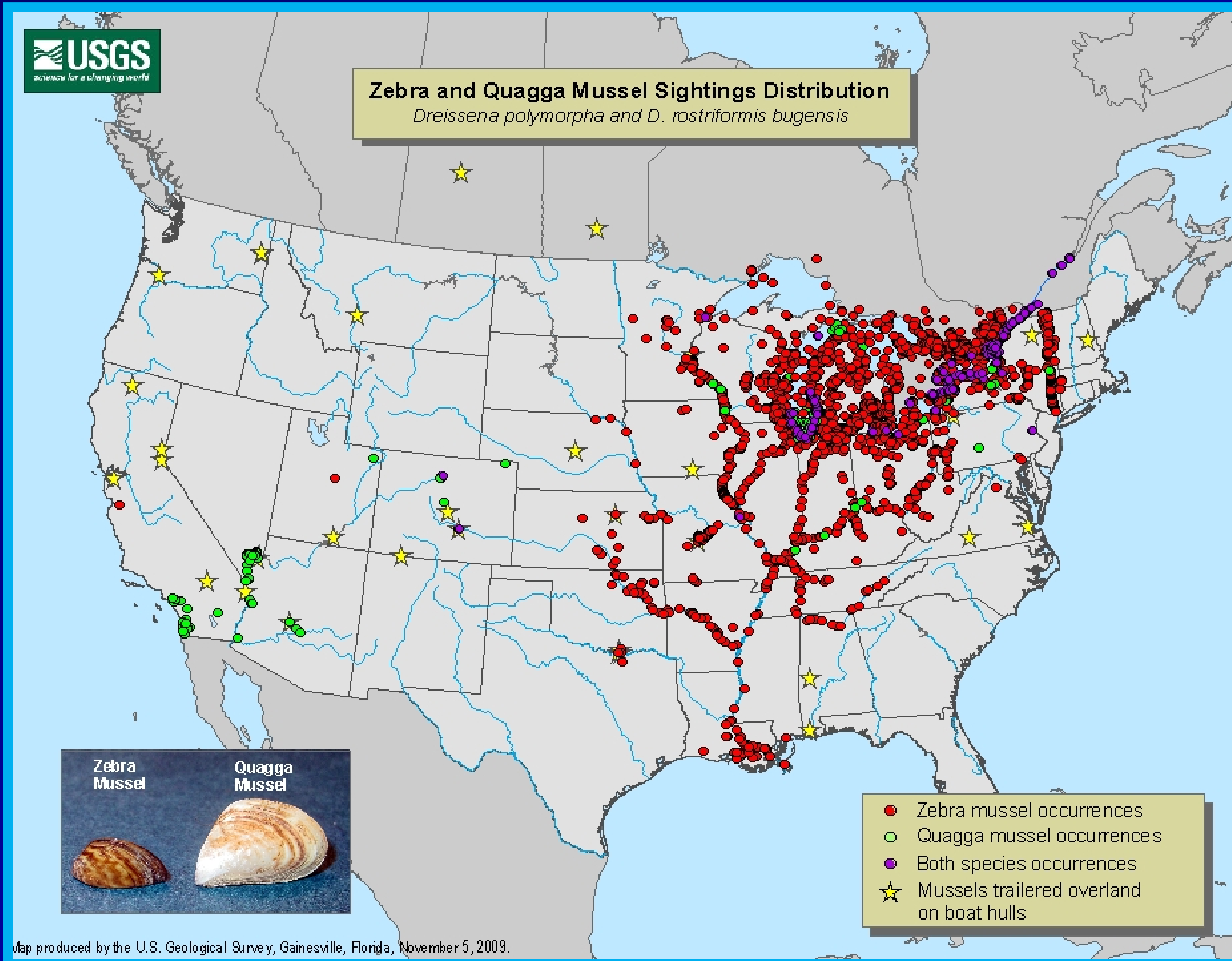
2005



Zebra Mussel Invasion of the US

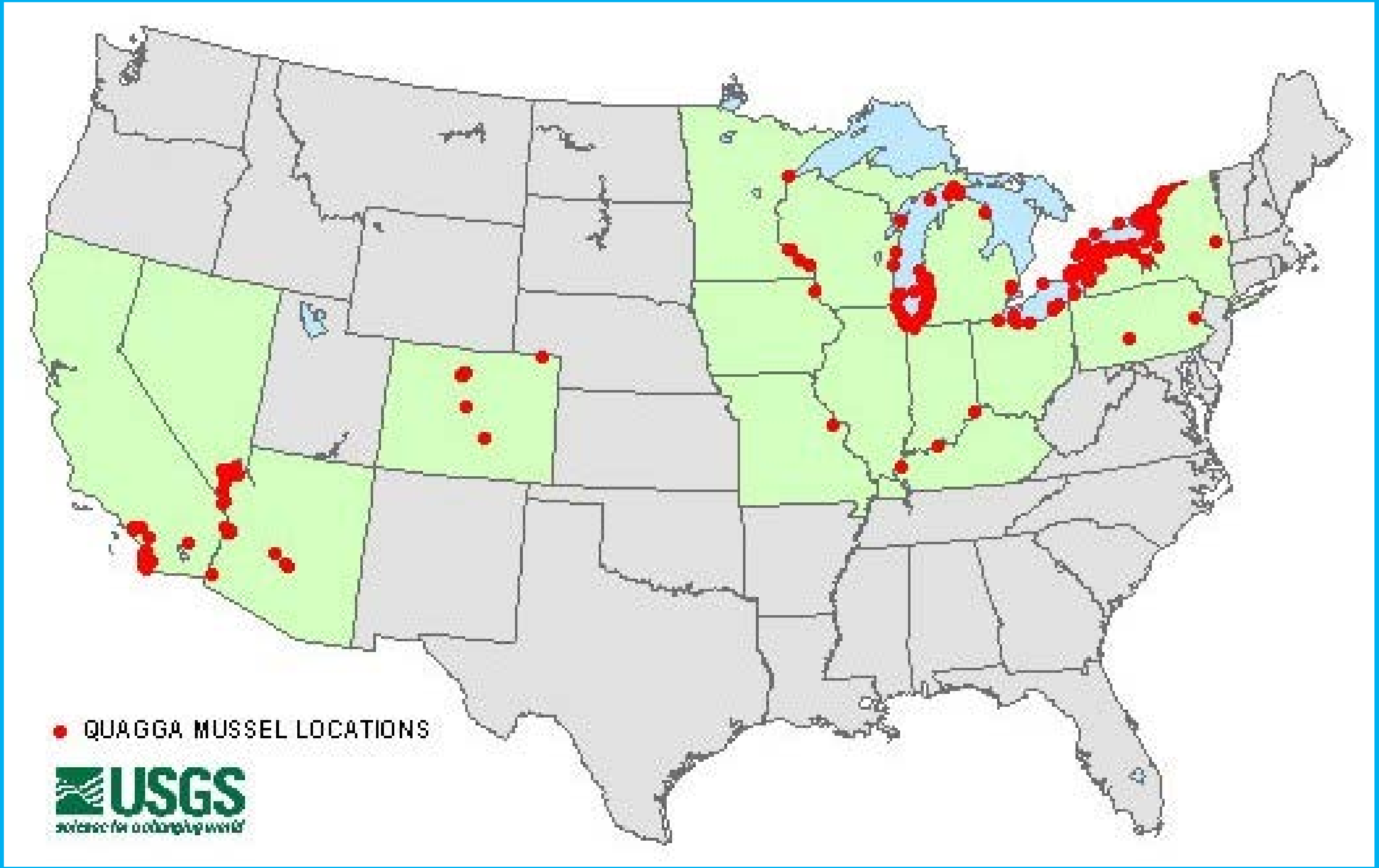
2008

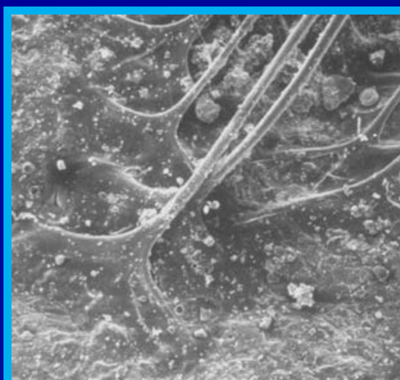




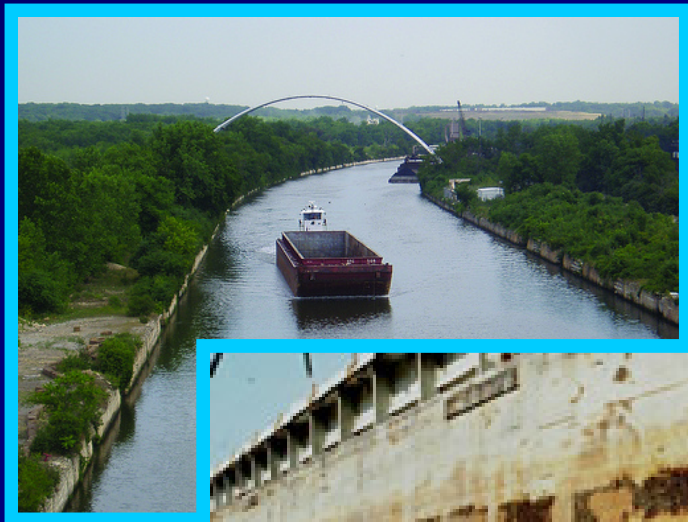
USGS
science for a changing world
Zebra and Quagga Mussel Sightings Distribution
Dreissena polymorpha and D. rostriformis bugensis
Zebra Mussel
Quagga Mussel
Zebra mussel occurrences
Quagga mussel occurrences
Both species occurrences
Mussels trailered overland on boat hulls
Map produced by the U.S. Geological Survey, Gainesville, Florida, November 5, 2009.

Present Quagga Mussel Distribution in the United States






Wisconsin

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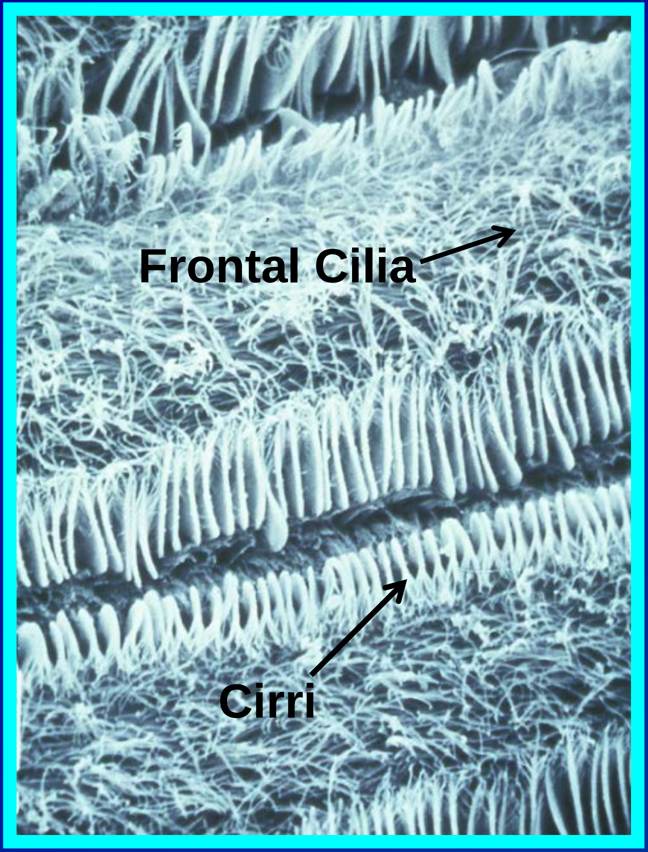
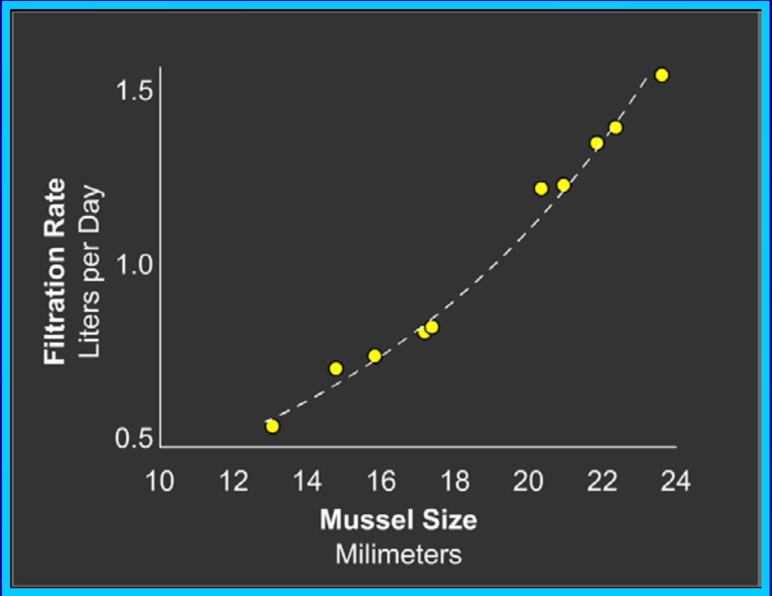
Zebra Mussel Filter Feeding

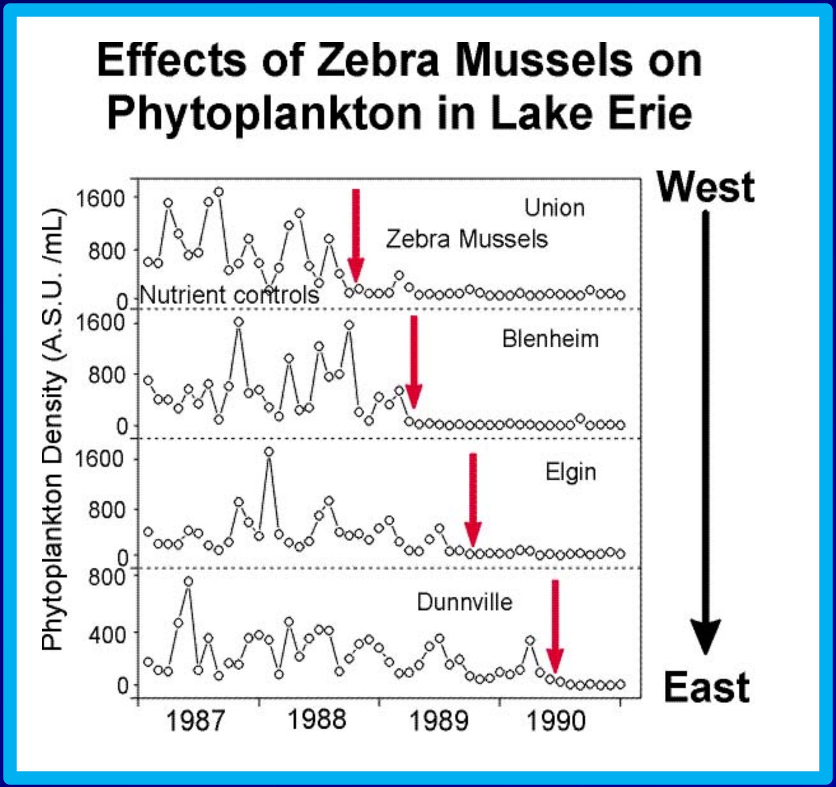


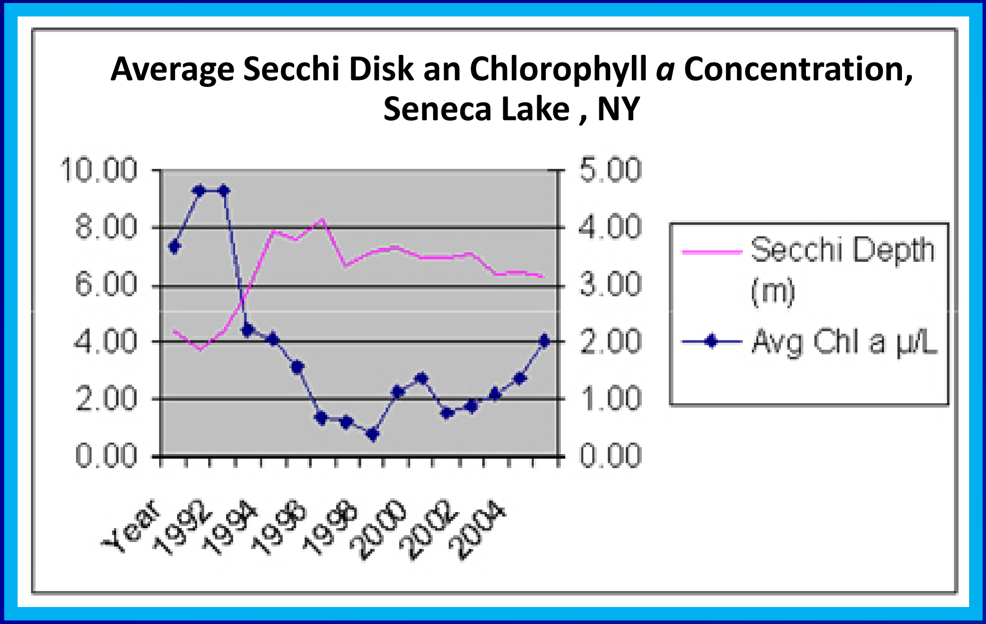
Filter Feeding

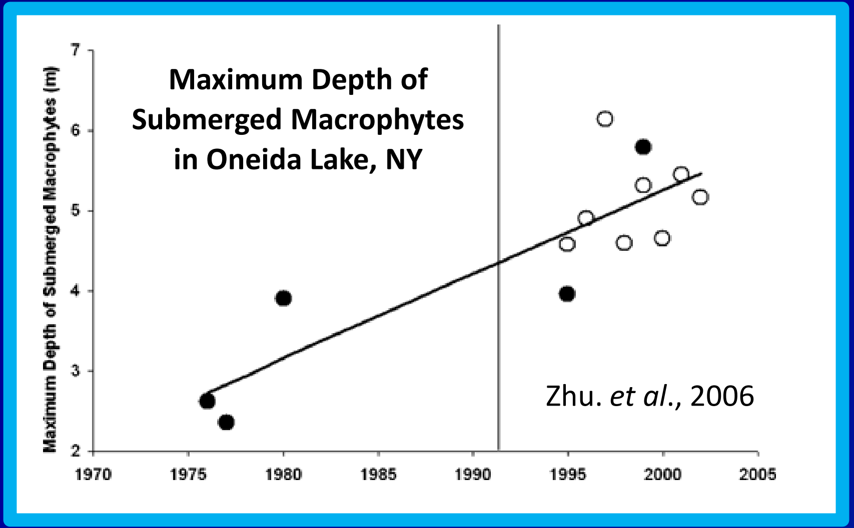
- Zebra and quagga mussels both efficiently filter bacterioplankton (< 1 µm)
- Large adults may filter up to 1 L / hr
- Average ≈ 1.5 L / Day
- 150,000 L / Day at a density of 100,000 mussels / m^2
- Results in rapid clarification of infested waters
- Removes phytoplankton impacting energy flow through food webs
- Quagga mussels are more efficient at filtering bacteria
- Leads to eventual replacement of zebra mussels by quagga mussels

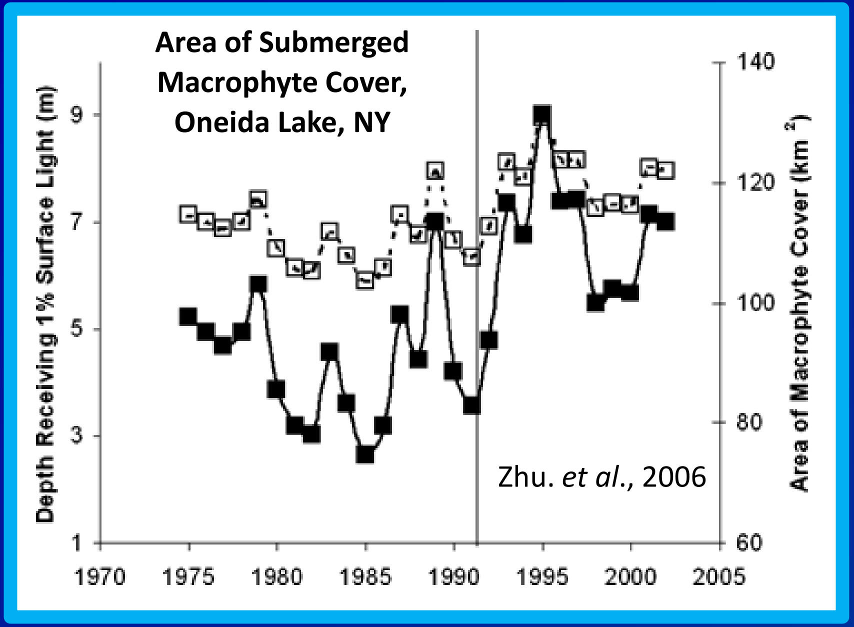


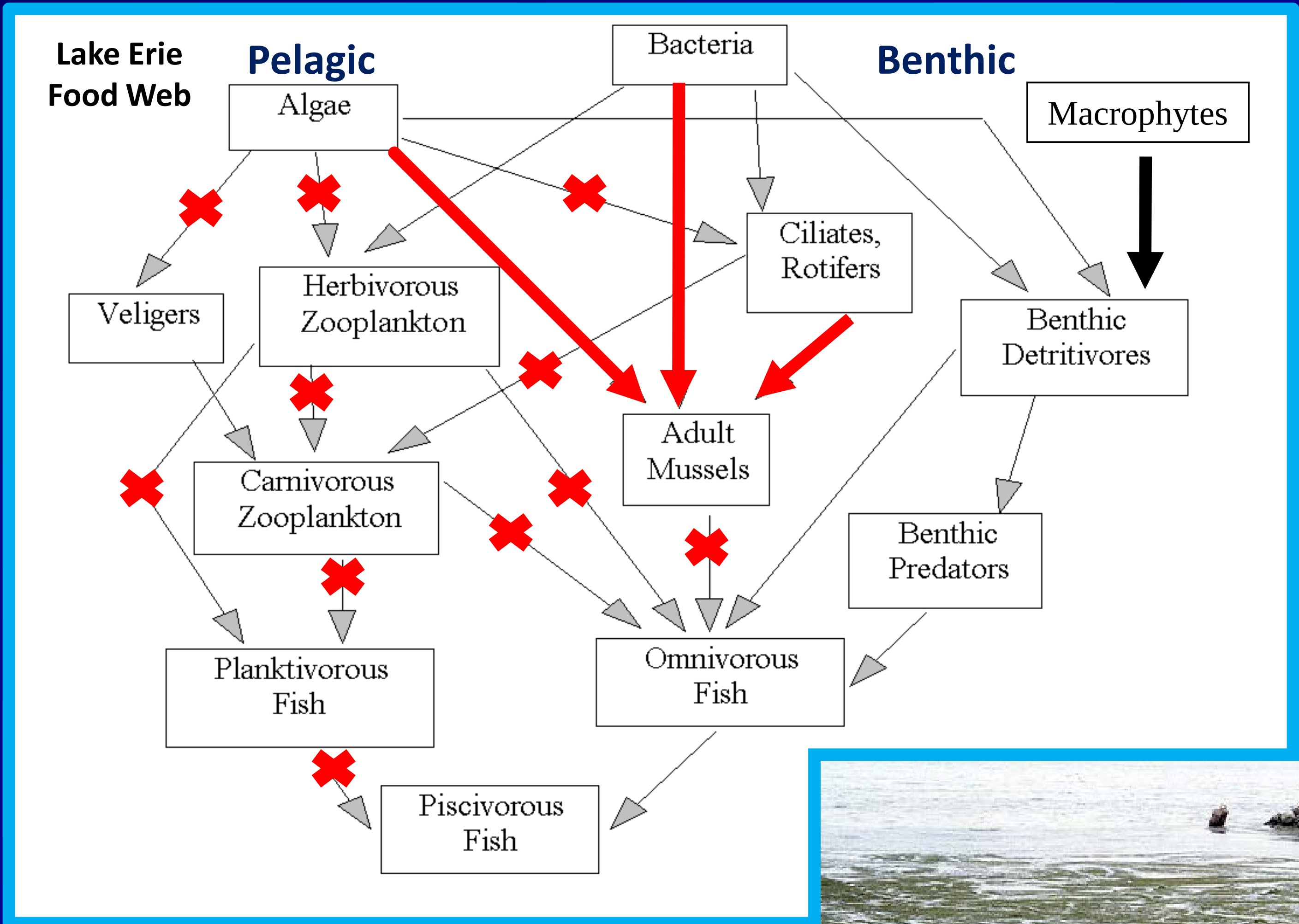
Filter feeding Impacts







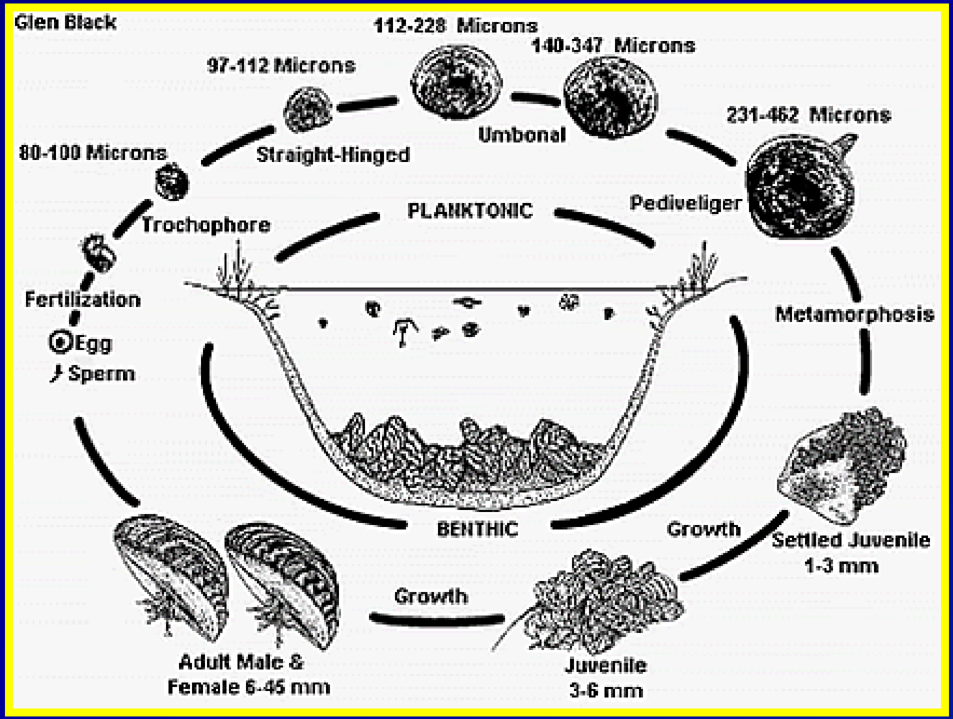


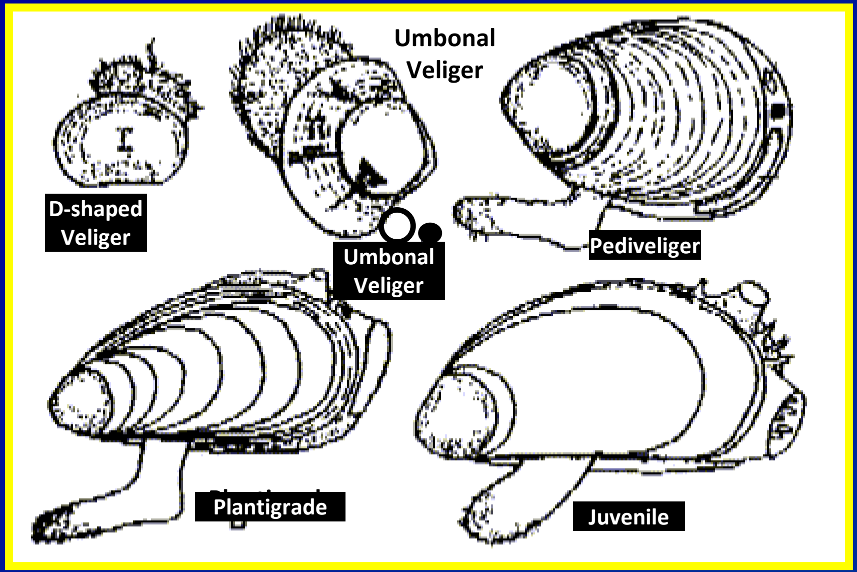


Dreissenid Mussel Impacts on Aquatic Ecosystems

Dreissenid Life Cycle

- Gonochoristic - External Fertilization
- Fecundity as high as 1,000,000 eggs per adult female per year
- Trochophore (6-20 Hours)
  - No shell (≥ 40 µm)
- Early Veliger (3-4 Days
  - D-shaped shell (80-100 µm)
- Late veliger (1-2 weeks)
  - Umbonal shell (100-250 µm)
- Pediveliger (2-3 weeks)
  - Develops foot – settles, crawls to attachment site (200-400 µm)
- Plantigrade (3-4 weeks)
  - Byssal attachment – transforms to mussel shape (250-500 µm)
- Juvenile (3-5 Weeks)
  - Mussel-shaped shell (>400 µm)
- Spawning occurs at low levels > 10°C
- Spawning maximized at > 18-24°C
- Settle in three to five weeks





Dreissenid Population Dynamics

- Maximum age = 3-5 years depending on population
- Maximum adult size = 2.5 – 4.0 cm dependent on population
- Growth rate declines with increasing adult size
- Survival rate is low across year classes
- Adult growth rates and population density dependent on temperature and phytoplankton and bacterioplankton productivity
- High fecundity leads to development of massive populations within 3-5 years of initial introduction

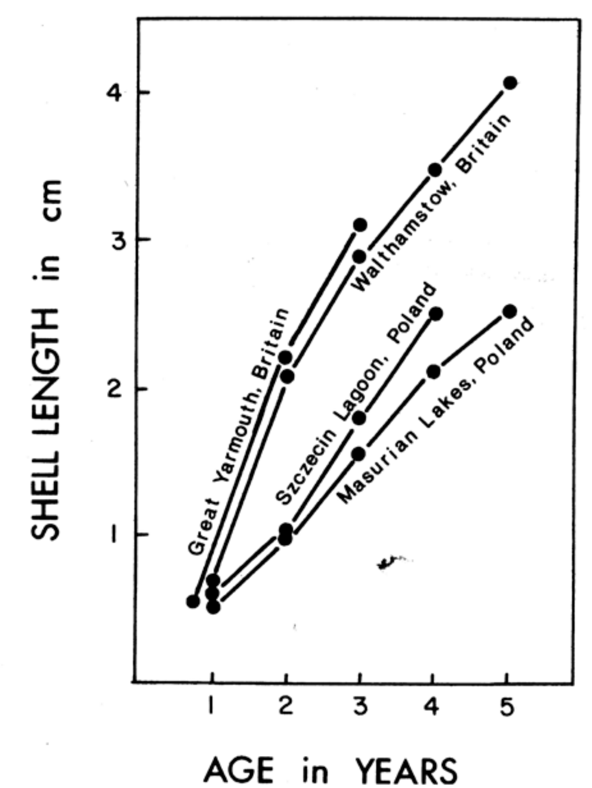


FIGURE 19 Shell-growth rates in European populations of the zebra mussel, *Dreissena polymorpha*. Growth rates for North American populations in Lake Erie are similar to or greater than faster growing British populations depicted in this figure.

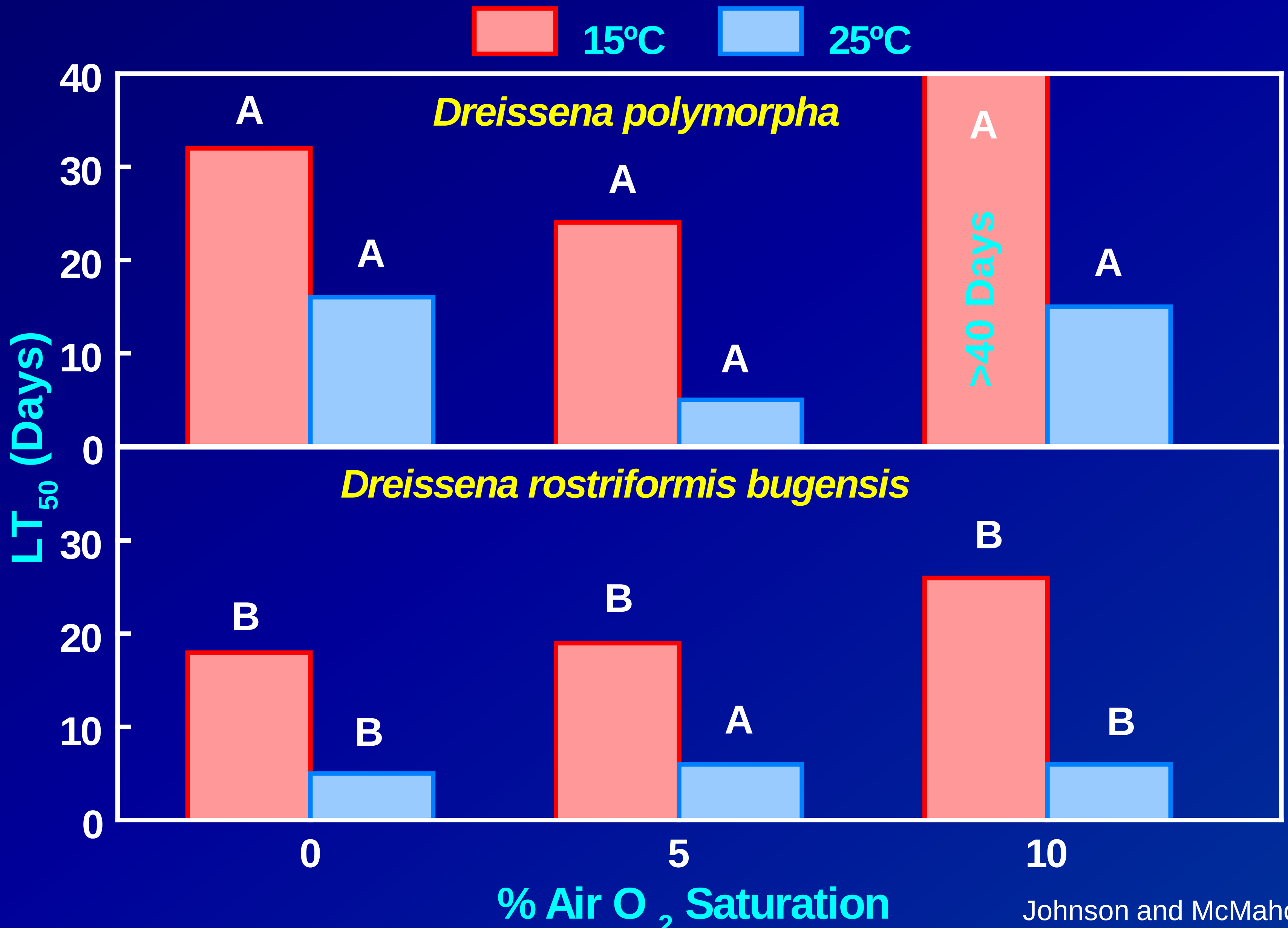
Water Quality Factors Affecting Dreissenid Mussel Distribution and Invasion

- **pH:** Inhabit waters with pH < 7.4
  - Attain highest densities at pH > 8.0
- **Salinity:**
  - Do not spawn or successfully fertilize above 7 ppt
  - larvae do not develop at > 8 ppt
  - juveniles and adults do not survive > 5 ppt (14% SW)
- **Turbidity and Suspended Solids:**
  - Thrive in lower Ohio and Lower Mississippi Rivers at > 80 NTU units
  - Turbidity unlikely to be a factor in limiting distribution
- **Organic Enrichment:** Does not generally limit distribution except when associated with hypoxic conditions - will accelerate growth
- **Phosphate Concentration:** Found as low as 0.001 mg/L
- **Nitrate Concentration:** Not found below 0.009 mg/L
- **Calcium Ion Concentration:** Not found below 12-15 mg/L Ca
- **Total Hardness:** Not found below 25 mg/L Ca
- **Alkalinity:** Not found below 20 mg/L Ca

Water Quality Factors Affecting Dreissenid Mussel Distribution and Invasion (Continued)

- **Potassium Ion:**
  - **Intolerant of waters with natural potassium concentrations > 30 mg/L K**
- **Flooding and Water Level Variation:**
  - **Limited success in rivers prone to extensive flooding and lakes with large annual level fluctuations**
  - **Large stable rivers and lakes with reduced level fluctuations are most prone to invasion**
  - **River populations sustained by mussel populations in upstream impoundments**
- **Pollution:**
  - **Generally as tolerant of industrial and municipal water pollution as are native unionid and Asian clams**
  - **Will not invade waters made chronically hypoxic by receipt of organic pollutants**

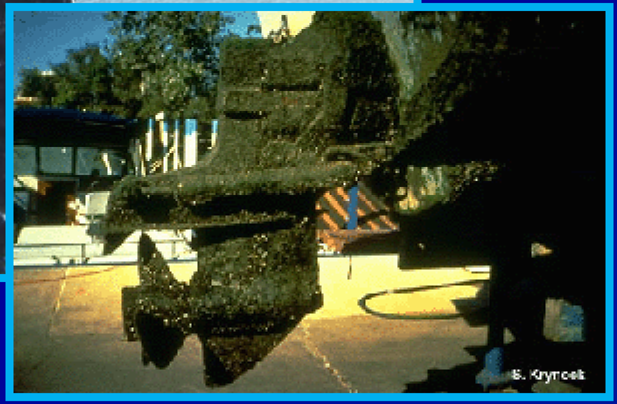
Chronic Hypoxia Tolerance



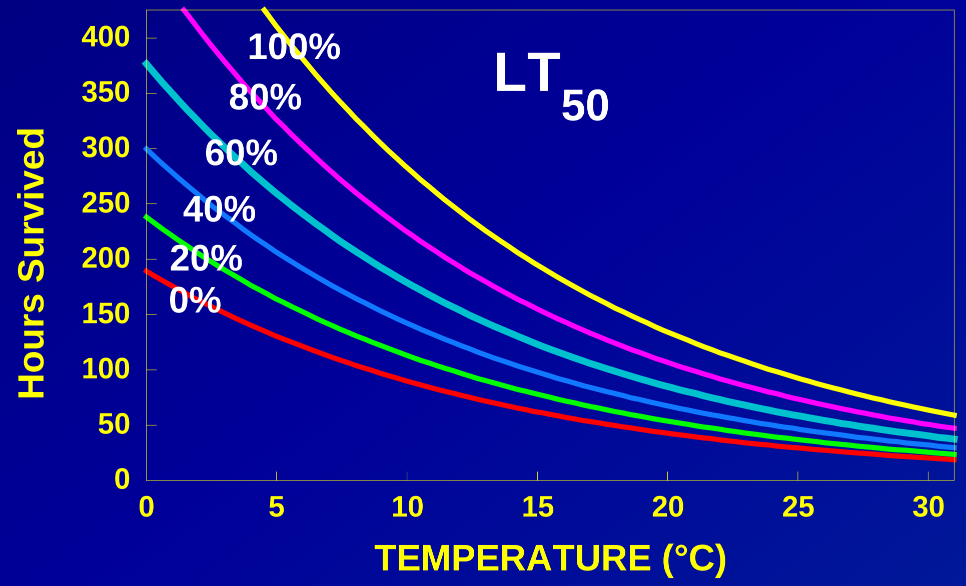
Johnson and McMahon

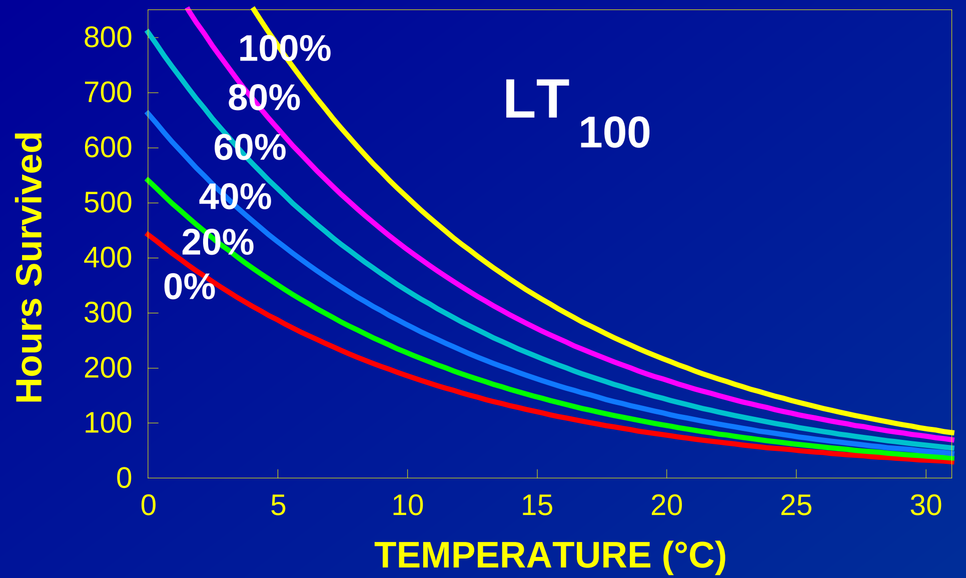
Emersion Tolerance

- Summer emersion and desiccation (<10-20 Days)
- Temperature and humidity dependent responses



Desiccation Tolerance in Zebra Mussels at Different Temperatures and Relative Humidities

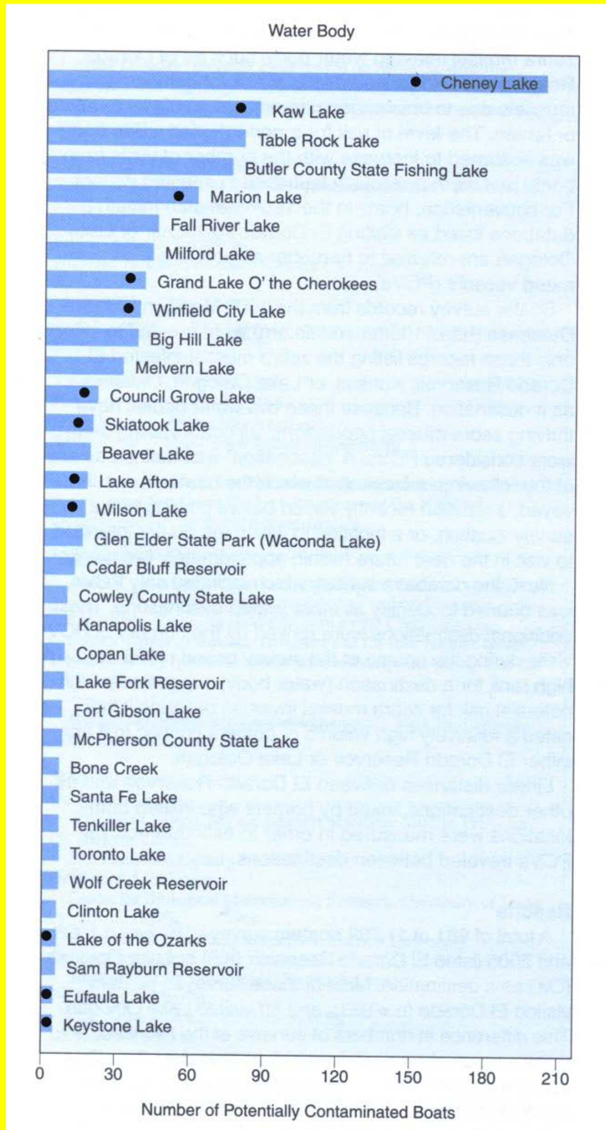


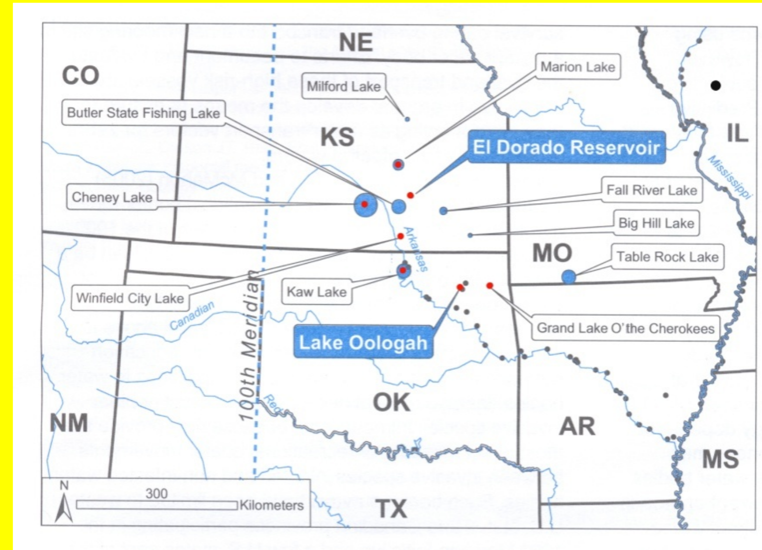


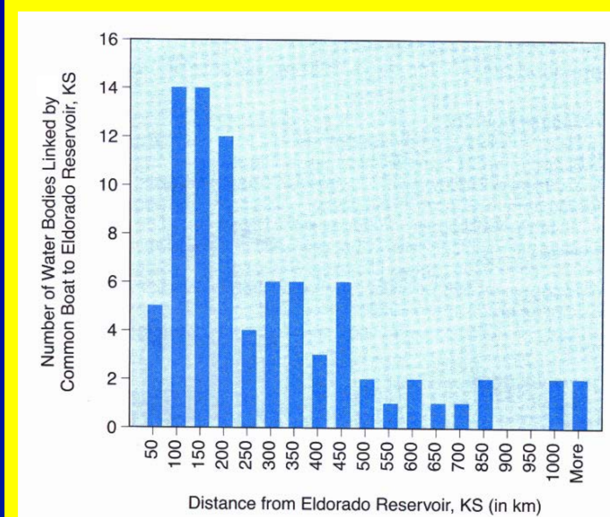
McMahon and Ussery

Trailered Boats as Zebra Mussel Dispersal Vectors in Southwest US

100th Meridian Boater Movement in Western States Database

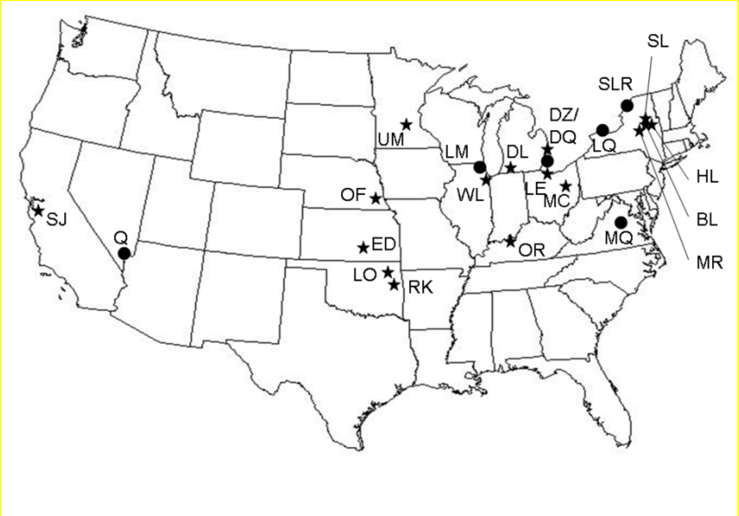


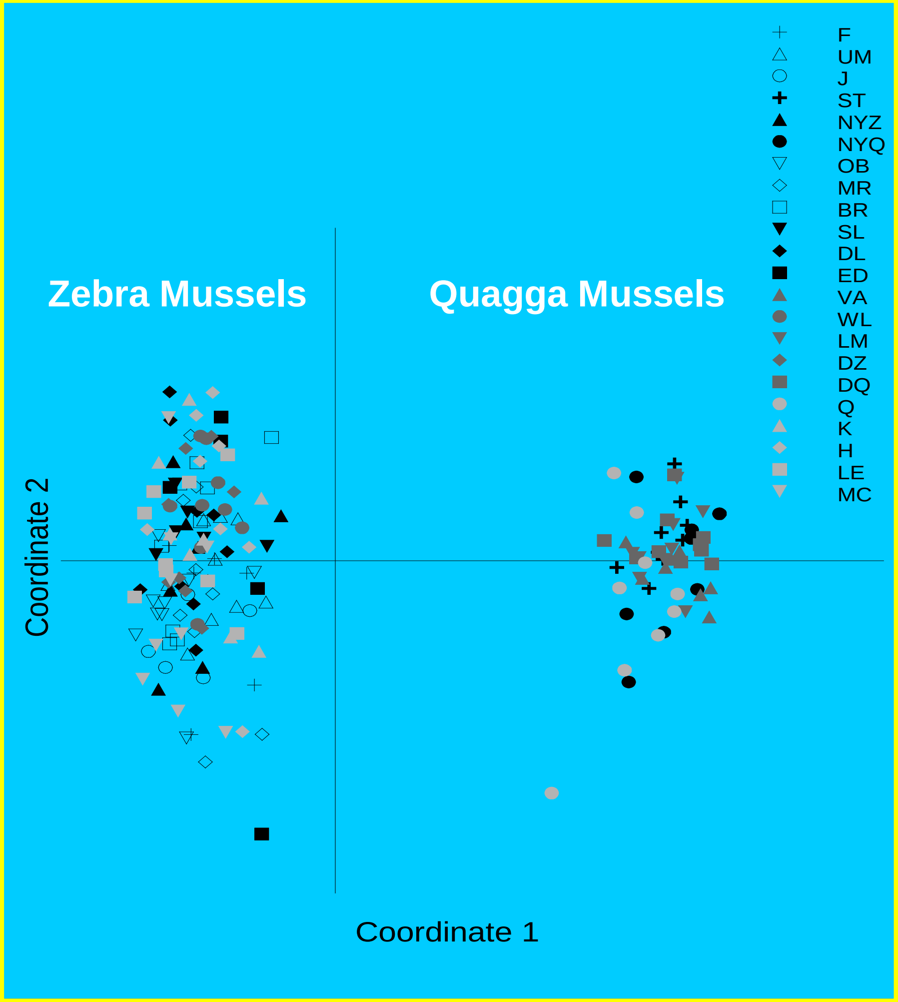




Britton and McMahon

AFLP Analysis of Dreissenid Mussel Genetic Diversity

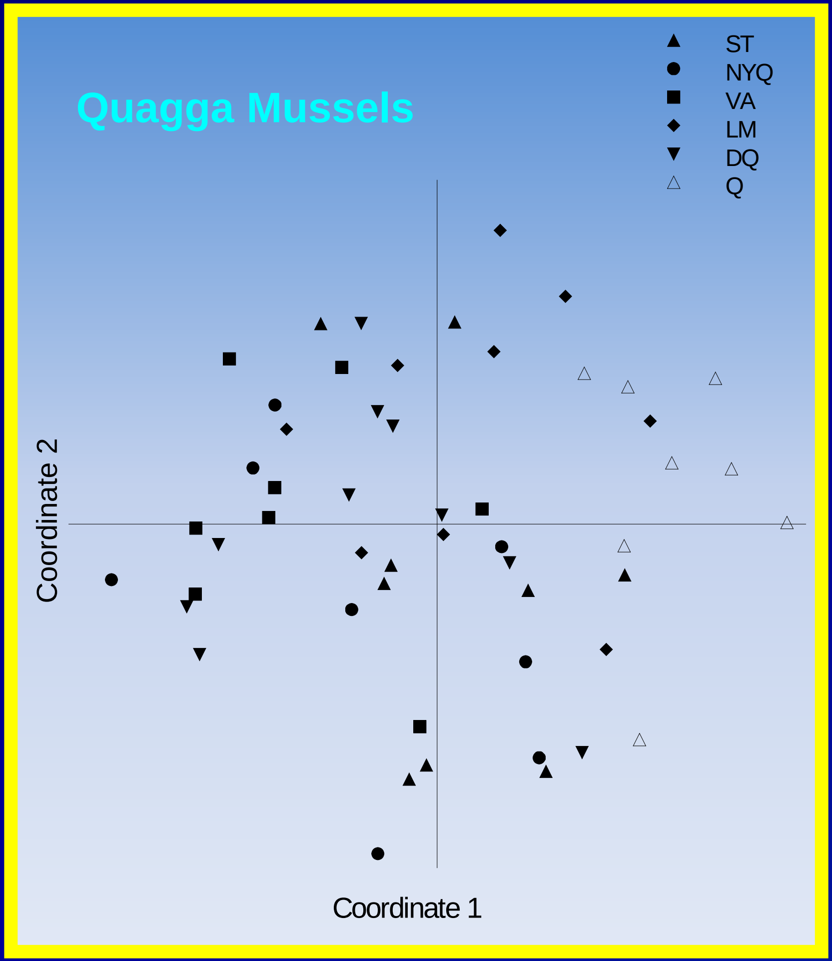


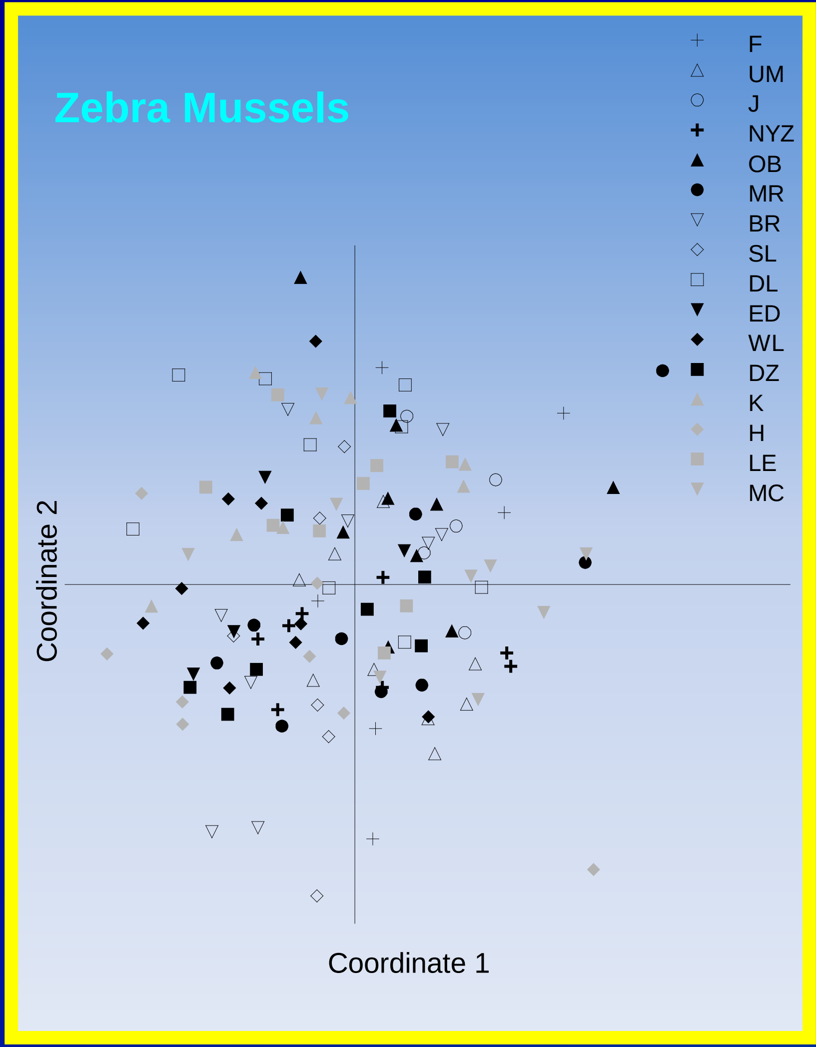


- **Analyzed genetic diversity for 16 zebra mussel and 6 quagga mussel populations**
- **Of various ages of establishment (<3->25 yrs)**
- **Compared for genetic differences with AFLP**
  (Amplified Fragment Length Polymorphisms)

Morse and McMahon

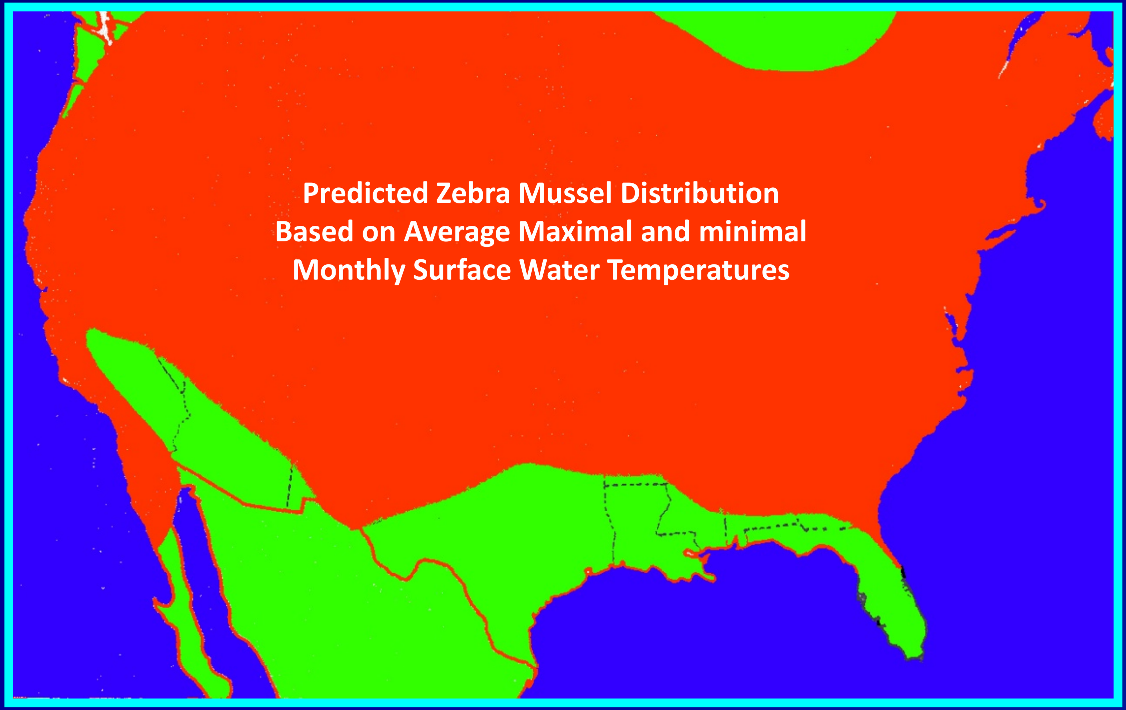
- Could not distinguish populations of either species based on AFLP
- All showed high levels of genetic diversity
- Suggested that there were no genetic bottlenecks or founder effects in recently established populations
- A large number of individuals are required to establish a population





Morse and McMahon

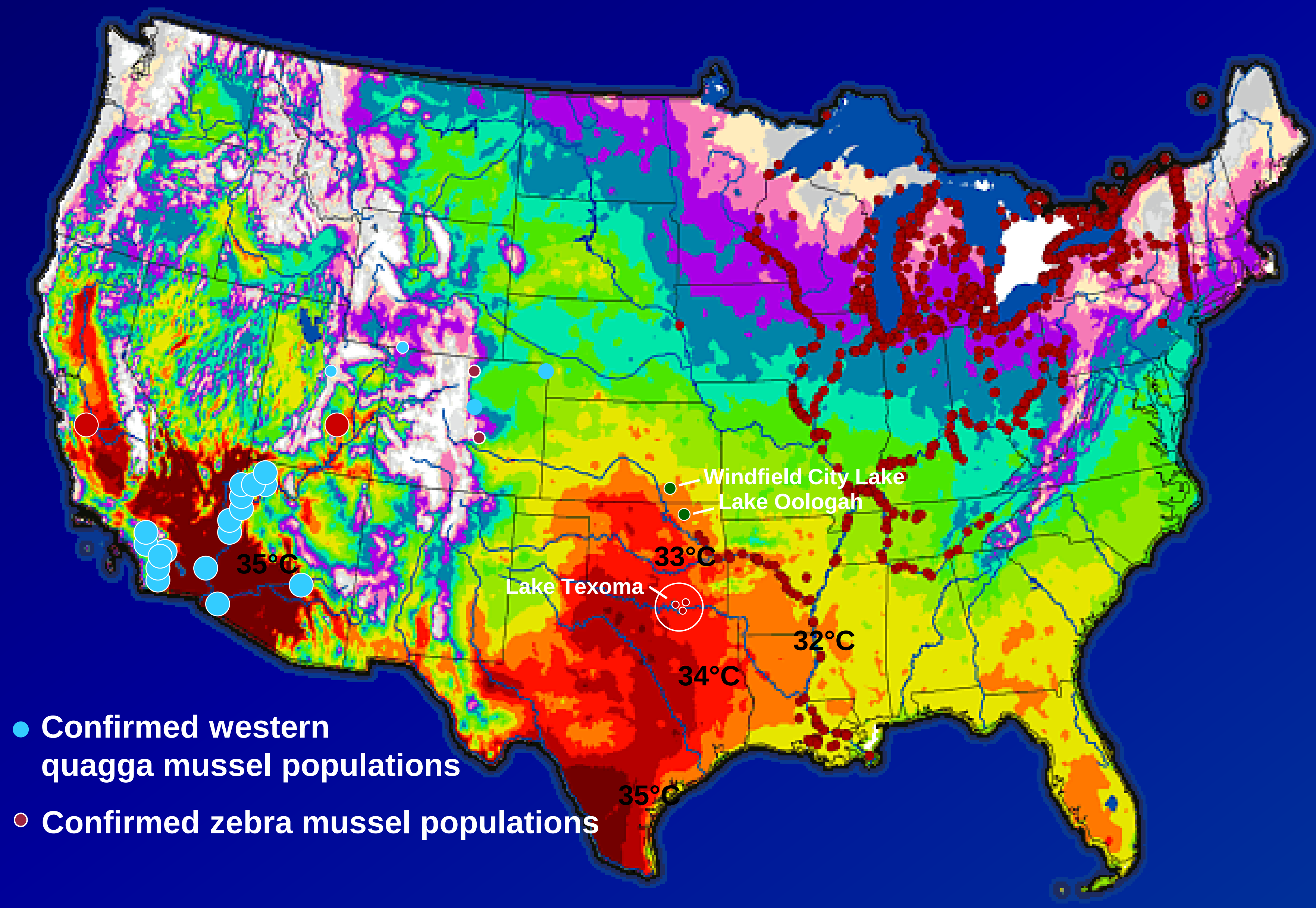
Invasion of Southern Water Bodies by Zebra Mussels



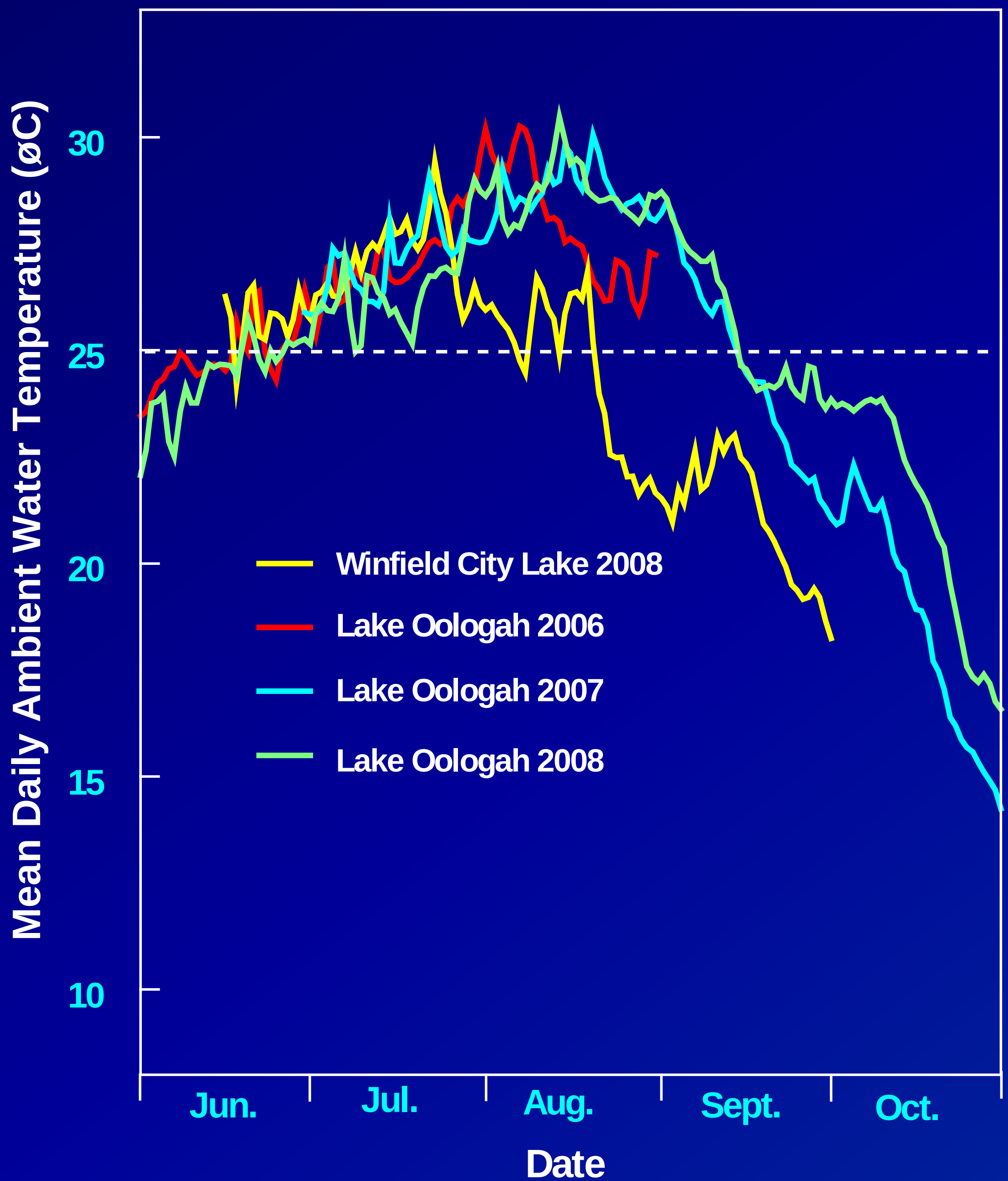
- Generally agreed long-term incipient upper thermal limit of zebra mussels was 28-30°C
- Generally agreed temperature for initiation of spawning was 16-18°C
- These temperature limits were used predict potential zebra mussel distribution in North America based on maximum summer surface water temperatures
- Recent successful establishment of zebra mussels Texas requires a re-examination of these assumptions

McMahon

1°C Mean Maximum Air Temperature Isotherms (1961-1990)
Source: Spatial Climate Analysis Service, Oregon State University



Chronic Thermal Tolerance of Zebra Mussels in the Southwest

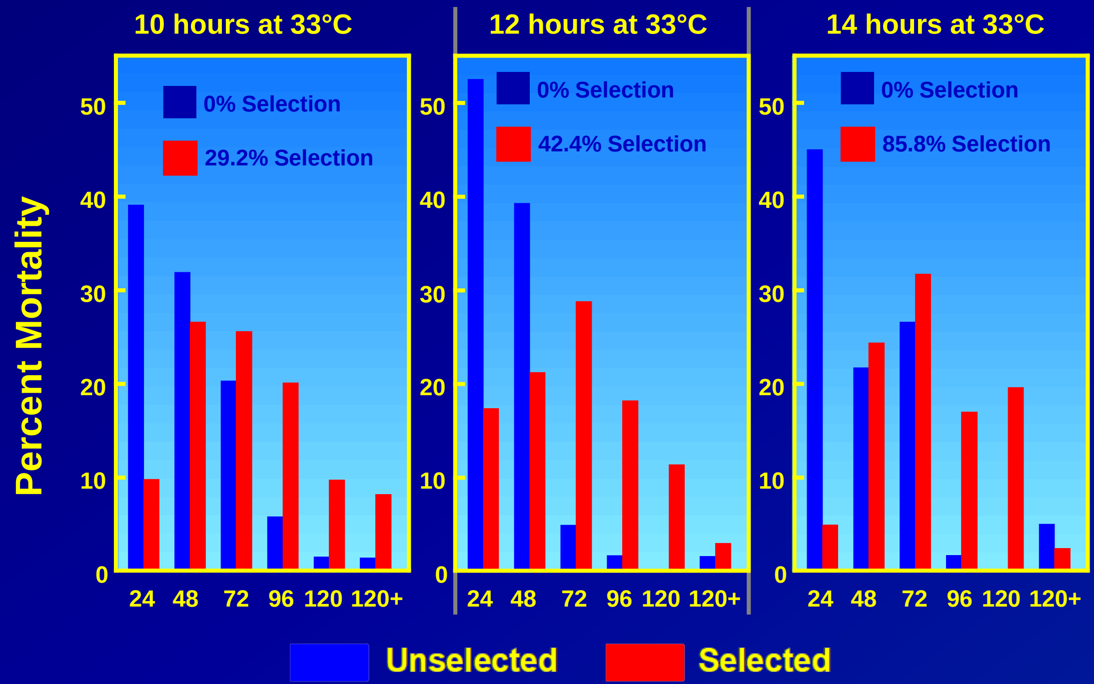


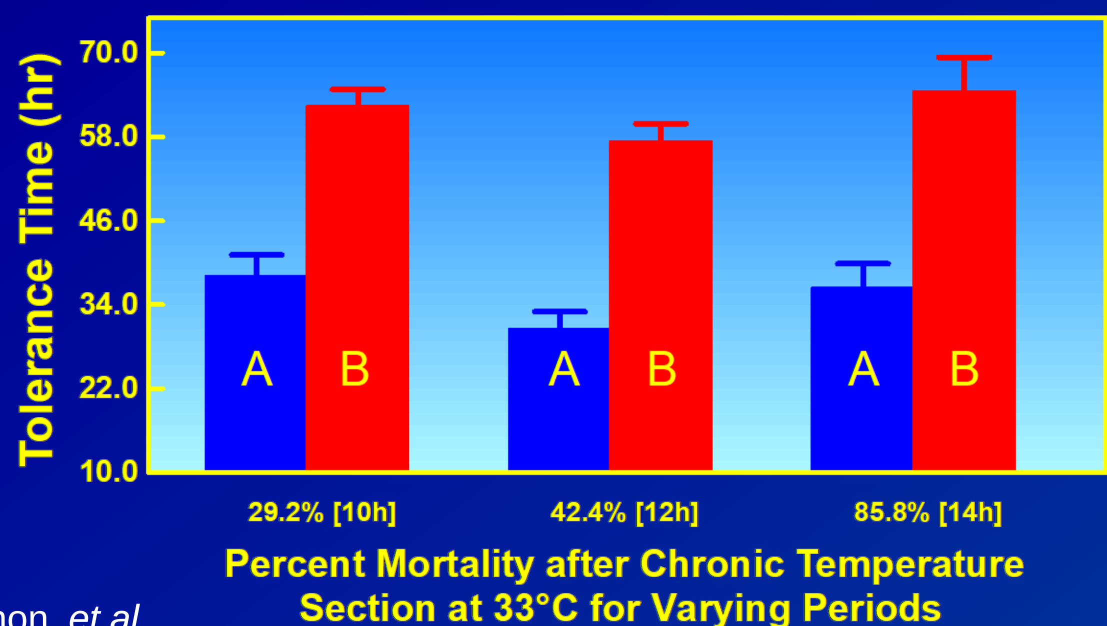
Ambient Water Temperatures of Lake Oologah (OK) and Winfield City Lake (KS)

McMahon, Leung and Morse

Selection for Chronic Temperature Tolerance in Zebra Mussels

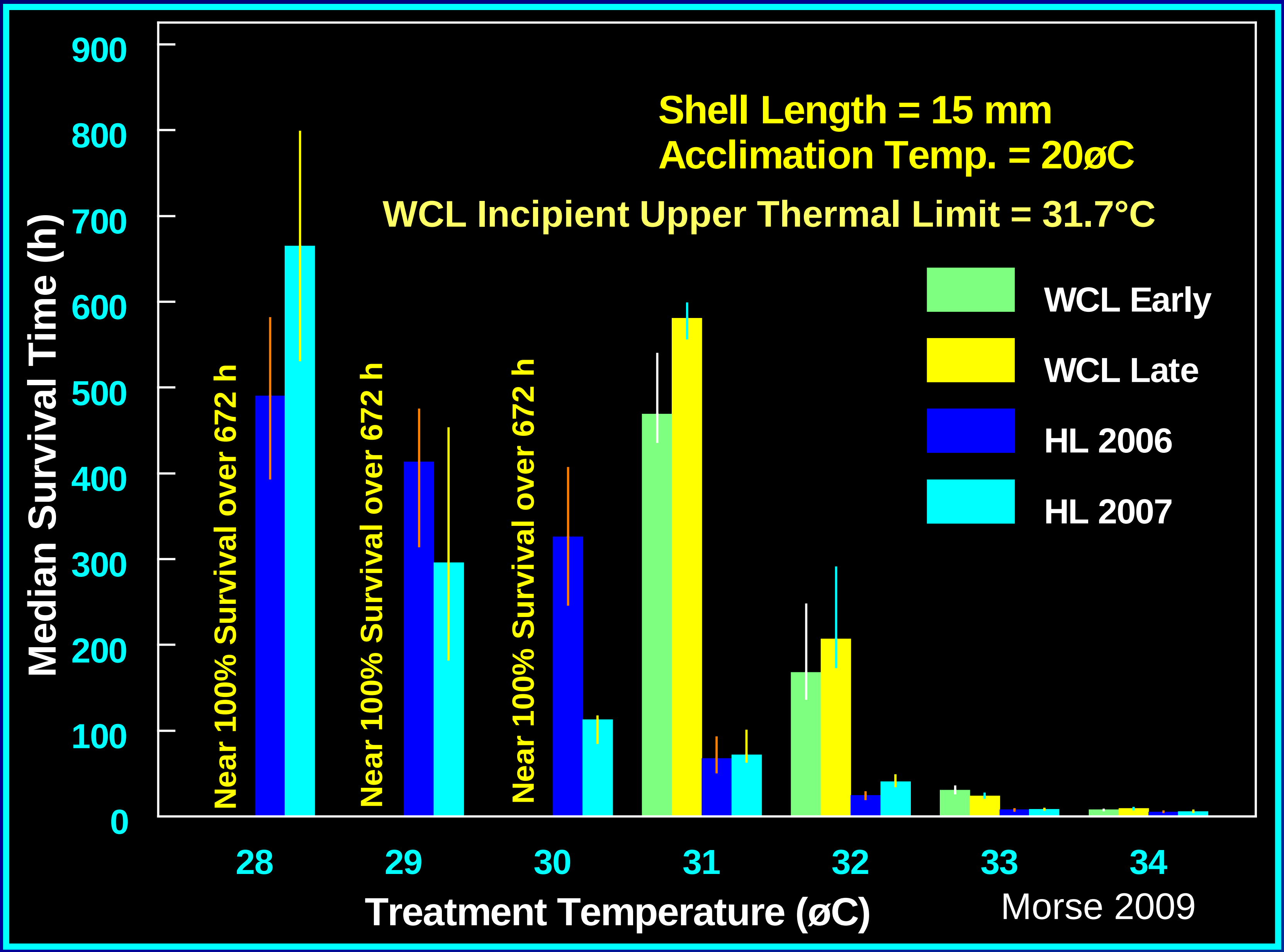
- 25°C acclimated mussels exposed to a lethal temperature of 33°C
- Control sample held at 33°C until 100% mortality ensued
- Second sample to 33°C long enough to induce partial sample mortality
- Surviving individuals allowed to recover at 25°C
- Chronic thermal tolerance at 33°C of surviving individuals retested
- Experiment repeated three times





McMahon, *et al.*

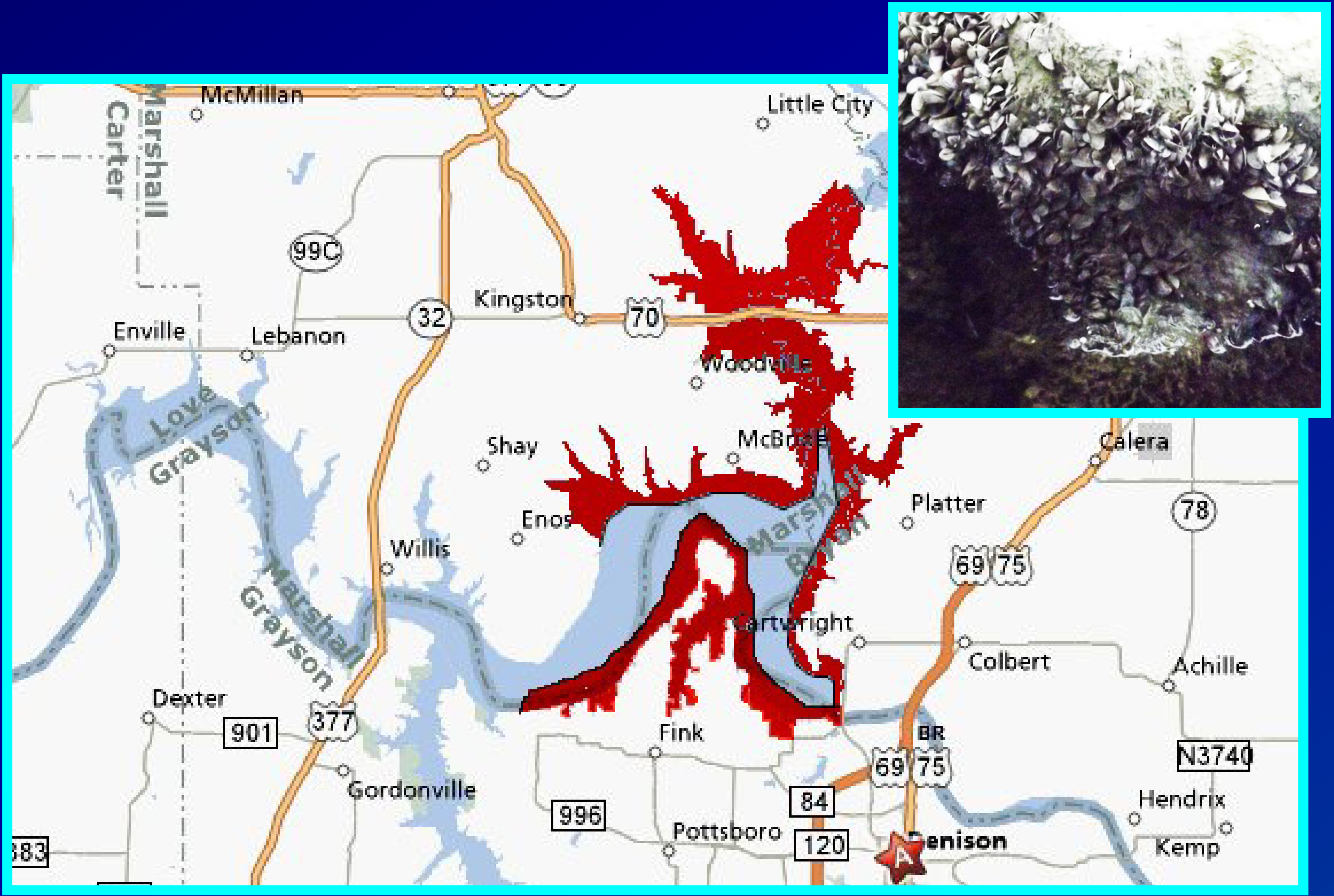
Comparison of Median Survival Times Between Zebra Mussels from Winfield City Lake (KS) and Hedges Lake (NY)



Zebra Mussels Invasion of Lake Texoma (TX/OK)

- Lake Texoma was considered thermally resistant to zebra mussel invasion
  - Surface water temperatures reach or exceed 30°C in mid-summer
  - Much recreational boat traffic from infested water bodies in Oklahoma
  - Establishing individuals likely to have evolved increased thermal tolerance in nearby southwestern water bodies (KS and OK)
- An adult zebra mussel was discovered in the lower end of Lake Texoma, on the Red River on April 3 2009
- Now recorded at numerous sites in the lower end of the lake
- Populations are rapidly expanding and increasing in density

Zebra Mussel Distribution in Lake Texoma (TK/OK)



The Question

- If zebra mussels can thrive in the warm waters of Lake Texoma can they invade other Texas Lakes with similar annual temperature profiles?
- Through the Quagga-Zebra Mussel Action Plan (Q-ZAP) , the USFWS funded an effort to develop and test a zebra mussel monitoring and risk assessment system for 13 lakes in northeastern Texas receiving recreational boat traffic from Lake Texoma

Methodology

- Monitoring/risk assessment system design requirements
  - Must be simple, accurate, cost effective, easily applied
  - Must provide rapid risk assessment and detection
  - Must be readily applied by Texas Parks and Wildlife personnel
- 14 lakes sampled spring and fall 2011 when larvae were present (18-28°C)
  - Physical data recorded for risk assessment
    - Temperature data loggers in surface waters (≈1 m) for a year's period
      - Recorded ambient water temperature hourly
    - Ca^{2+} concentration
    - pH
    - O_2 Concentration
  - Plankton net sampling for mussel veliger larvae (60 µm mesh)
    - Microscopic examination of live samples immediately after collection
    - Cross-polarized light examination of fixed samples in the laboratory
    - Molecular qPCR testing (real-time, quantitative PCR) for larval DNA
      - 197 bp fragment of the rDNA ITS 2 region
      - John Wood, Pisces Molecular LLC, Boulder, Colorado
  - Scouring pad pediveliger settlement monitors
    - Allow rapid detection of settling pediveligers and juvenile mussels
    - Deployed for 3-4 weeks
    - Pads examined immediately in the field
    - Preserved for later, more detailed examination in the laboratory
  - Use of multiple tests increases likelihood of detection
    - Allows multiple confirmation of a positive result

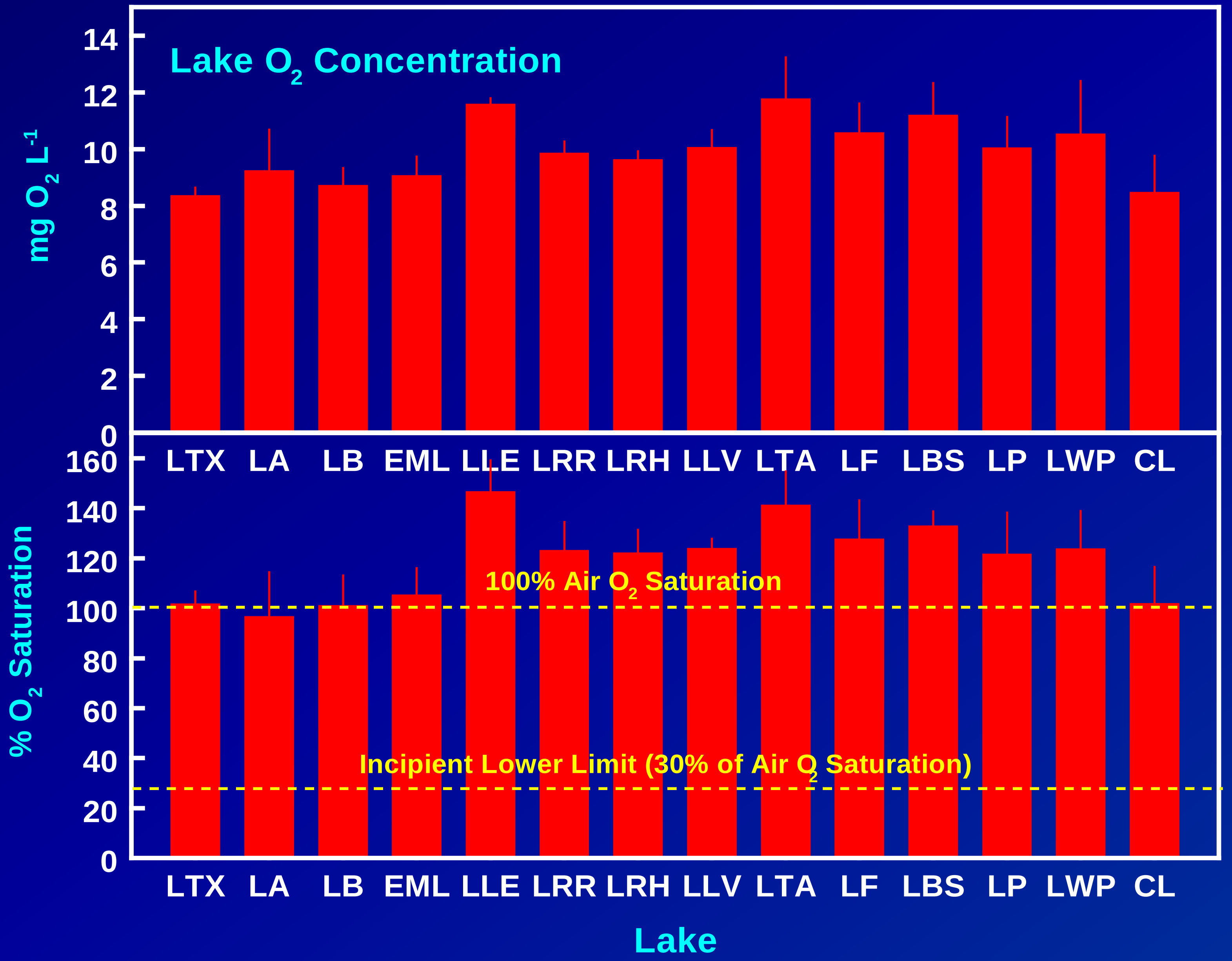



2011 Spring & Fall Settlement Sampling

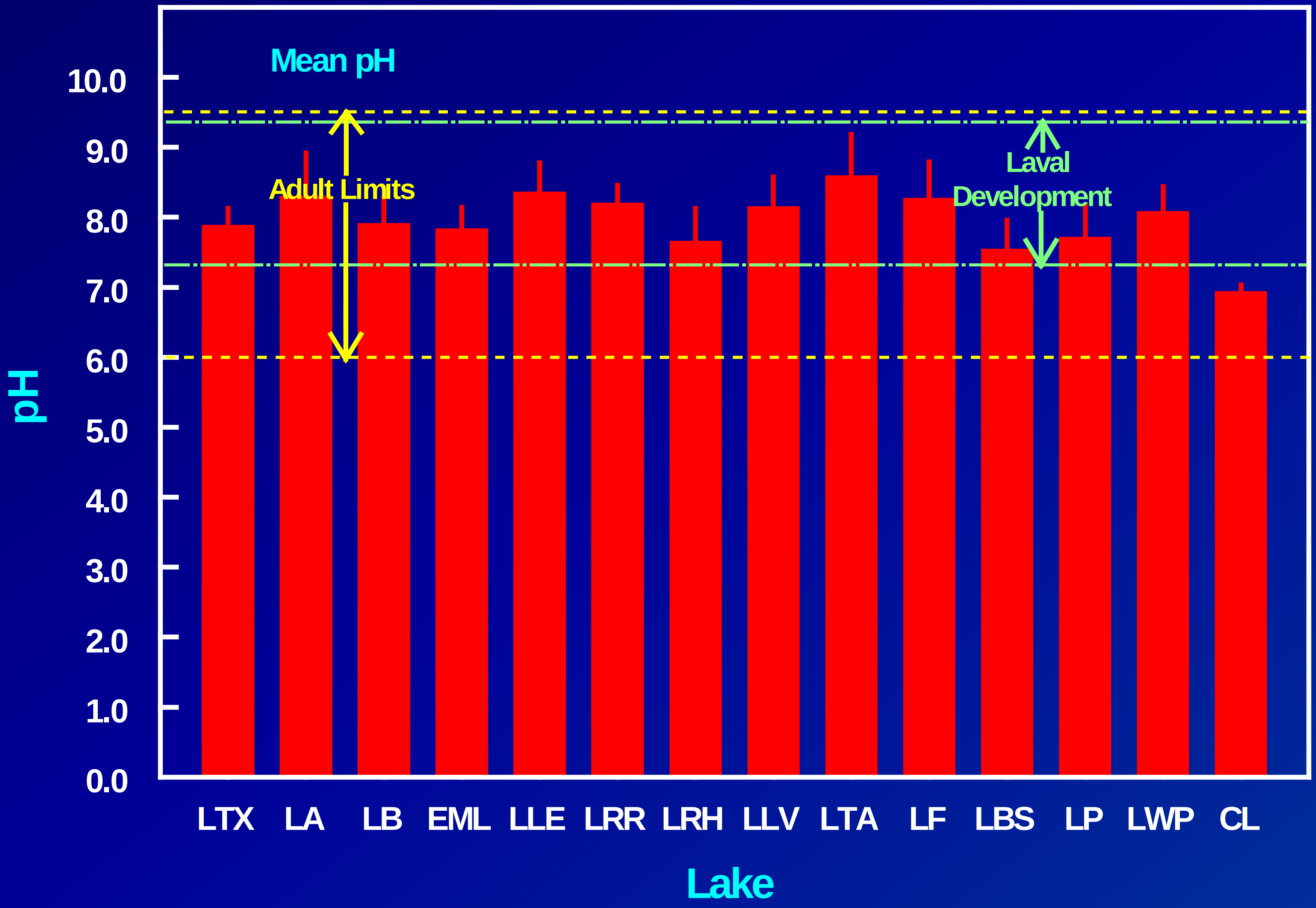
Lake	Monitor Deployment	Monitor Recovery	Days Deployed	Monitor Deployment	Monitor Recovery	Days Deployed
Arrowhead Lake	6/1/2011	6/30/2011	29	10/21/2011	11/21/2011	33
Lake Bridgeport	6/1 2011	6/30/2011	29	10/21/2011	11/21/2011	33
Eagle Mountain Lake	6/1/2011	6/30/2011	29	10/21/2011	11/21/2011	33
Lake Lewisville	8/8/2011	7/1/2011	23	10/22/2011	11/19/2011	29
Lake Ray Hubbard	6/8/2011	7/1/2011	23	10/22/2011	11/19/2011	29
Lake Ray Roberts	6/2/2011	6/30/2011	28	10/22/2011	11/19/2011	29
Lake Lavon	6/8/2011	7/1/2011	23	10/22/2011	11/19/2011	29
Lake Texoma	6/2/2011	6/30 /2011	28	10/21/2011	11/19/2011	30
Lake Tawakoni	6/8/2011	7/1/2011	23	10/22/2011	11/19/2011	29
Lake Fork	6/8/2011	7/1/2011	23	10/23/2011	11/20/2011	29
Lake Bob Sandlin	6/7/2011	7/5/2011	28	10/24/2011	11/20/2011	27
Lake O' the Pines	6/7/2011	7/5/2011	28	10/23/2011	11/20/2011	29
Lake Wright Patman	6/7/2011	7/5/2011	28	10/23/2011	11/20/2011	29
Caddo Lake	6/7/2011	7/6/2011	29	10/23/2011	11/20/2011	29

Risk Assessment

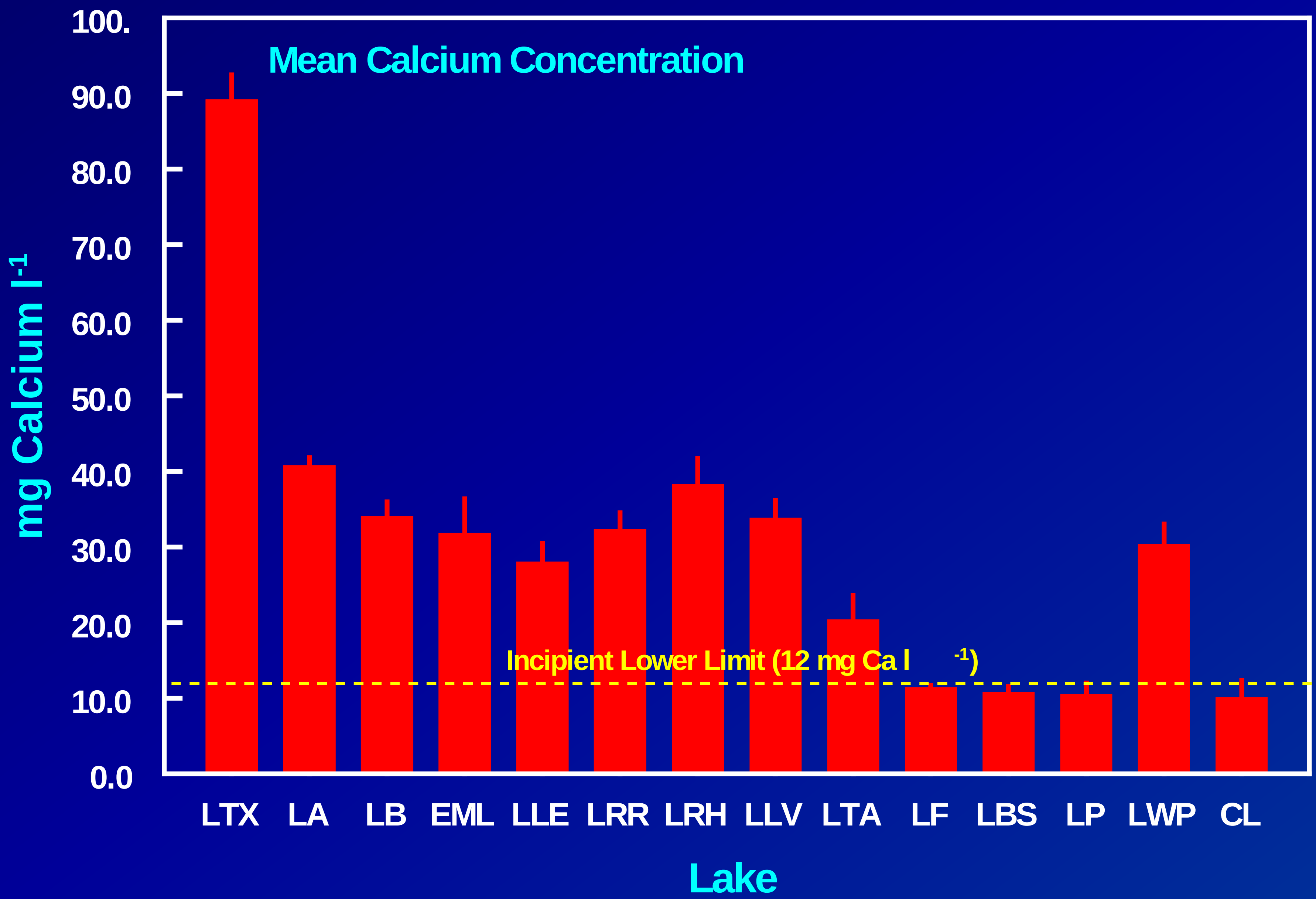
Surface Water Oxygen Concentration



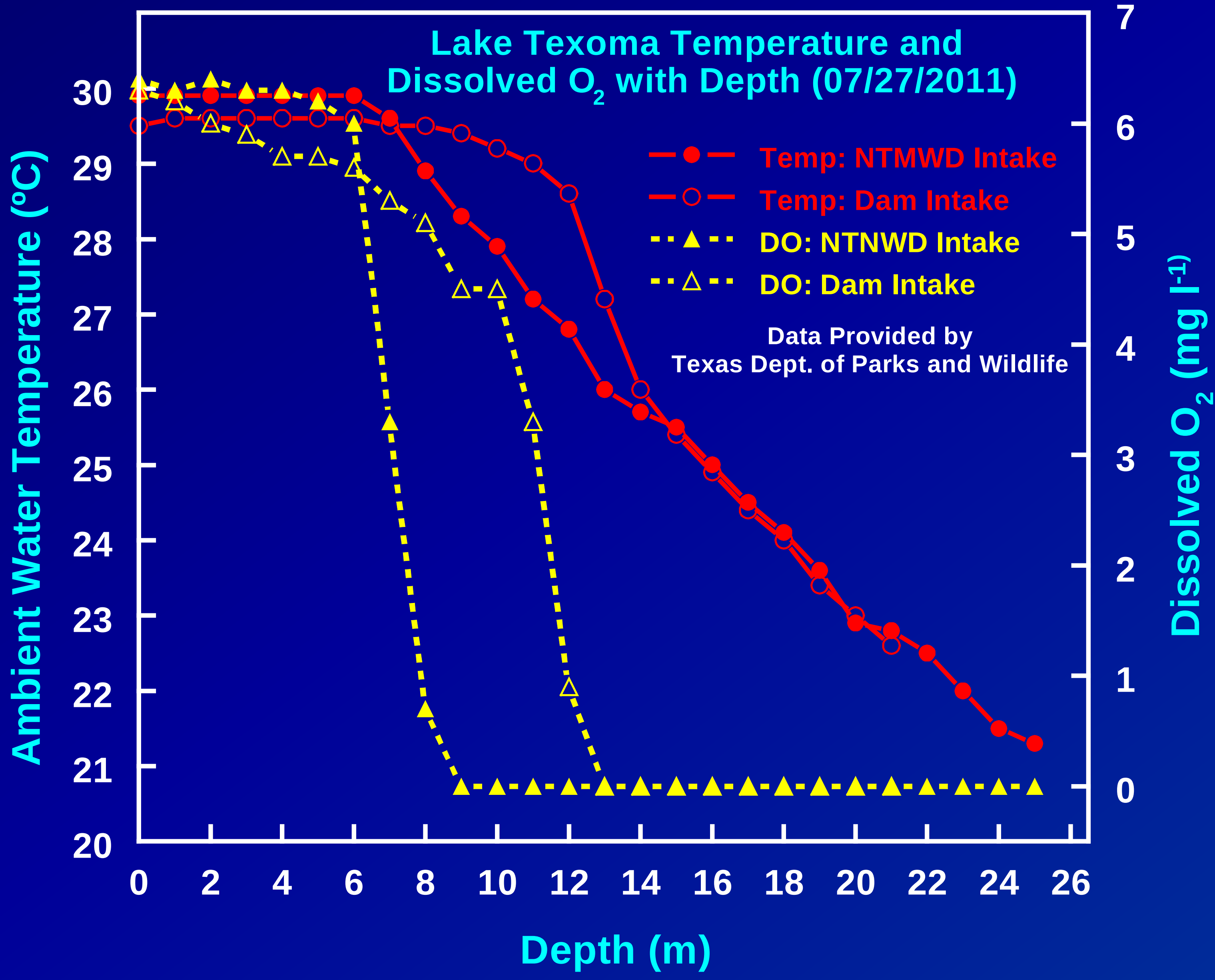
Surface Water pH



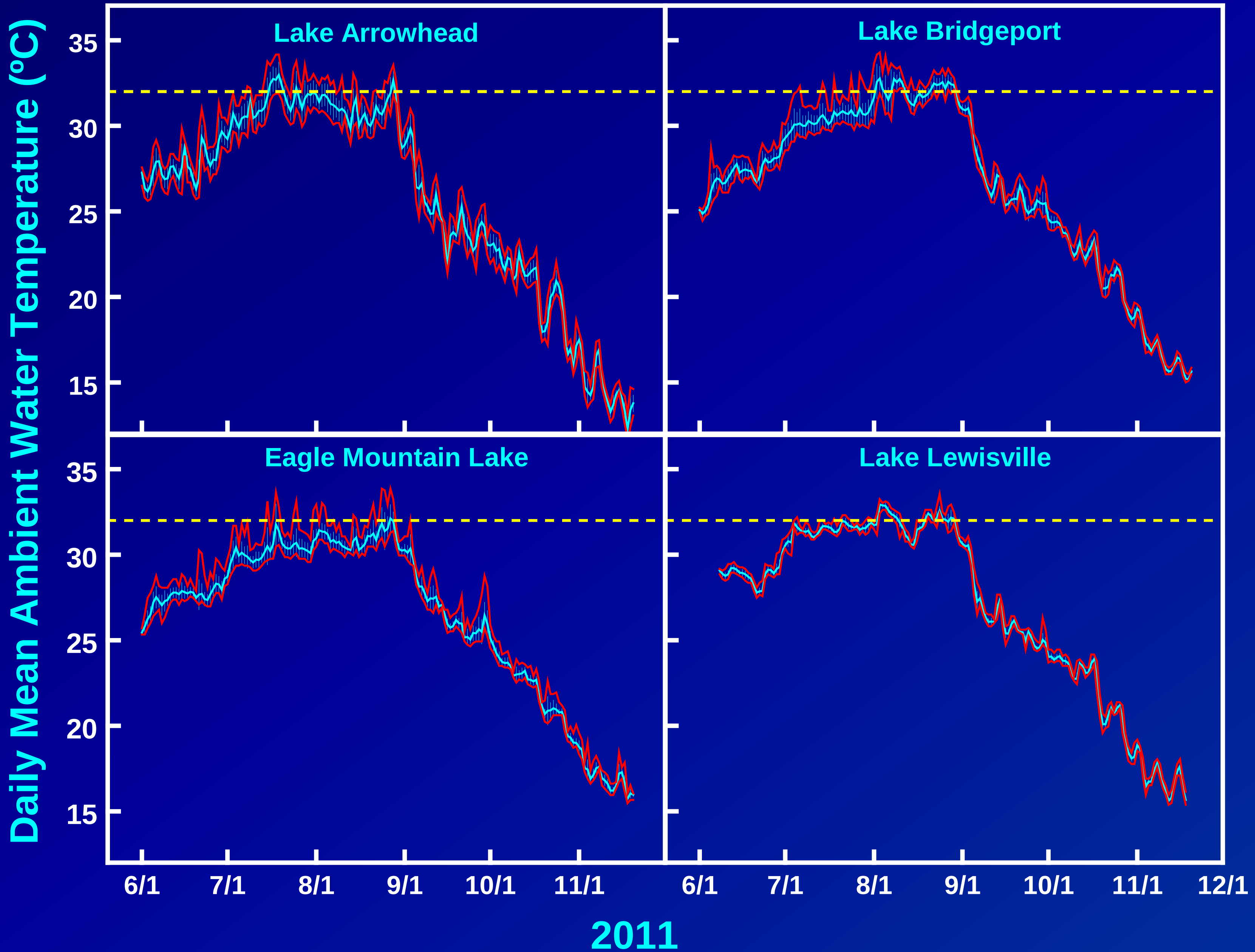
Surface Water Calcium Concentration



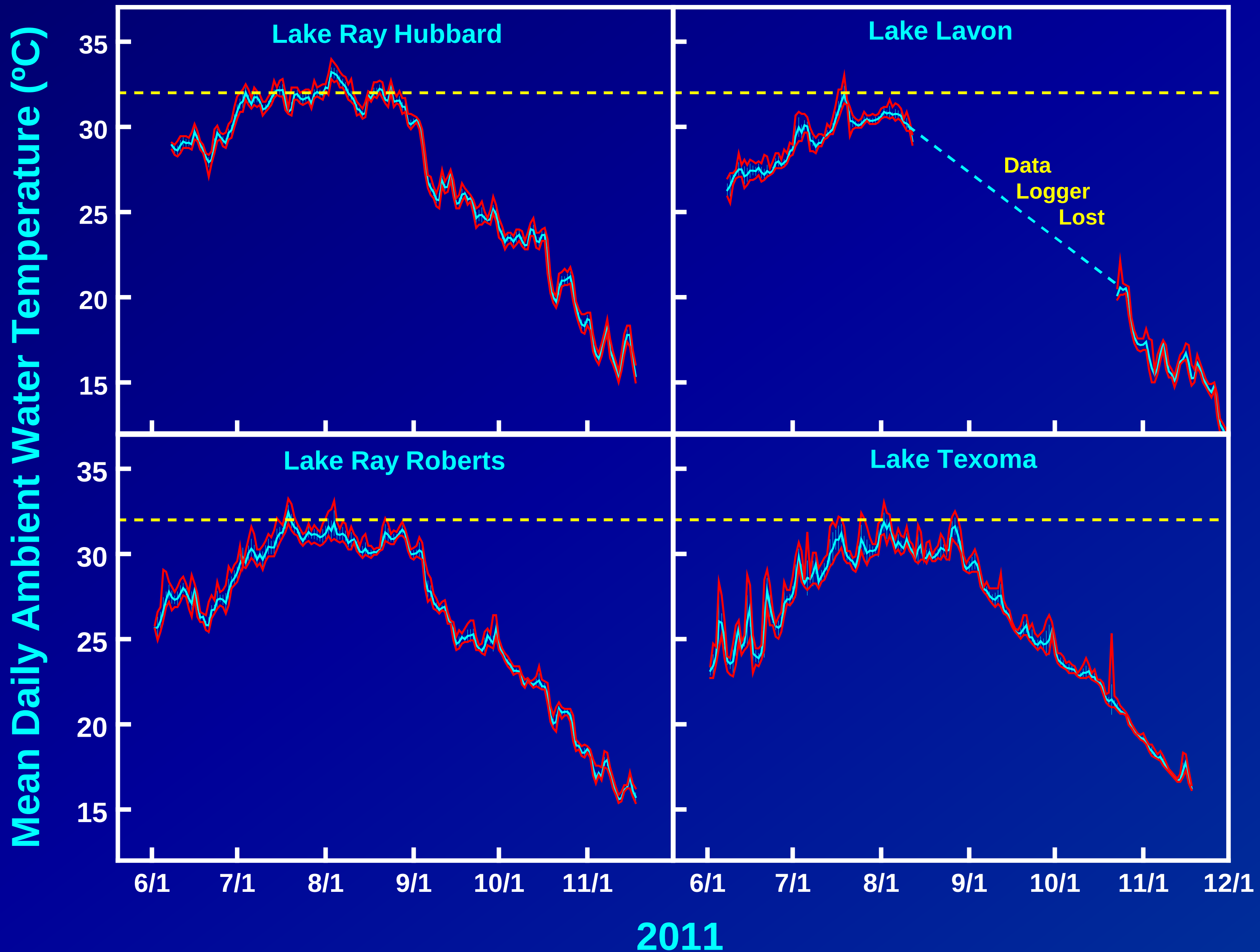
Surface Water Temperature



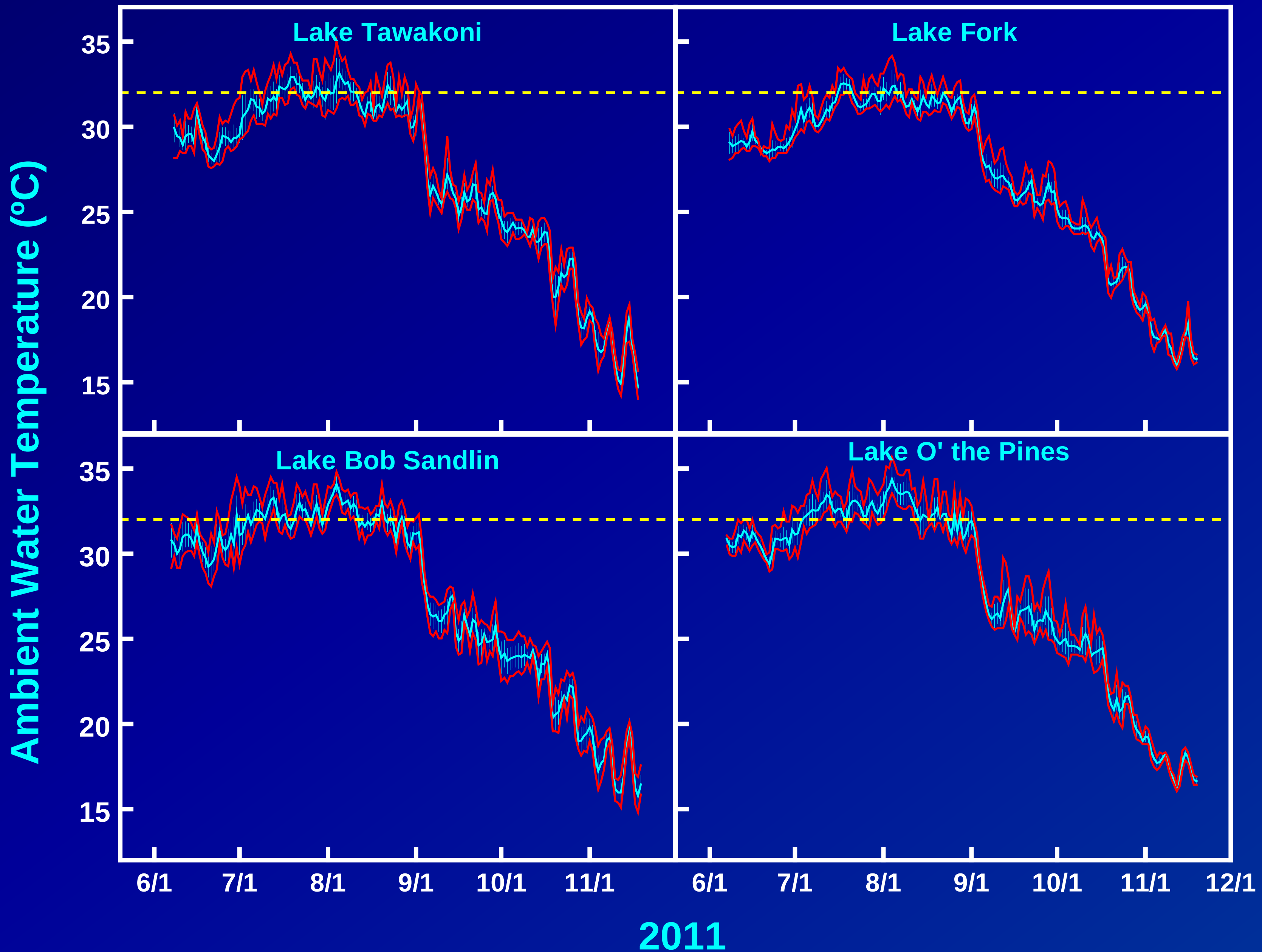
Lake Surface Water Temperature



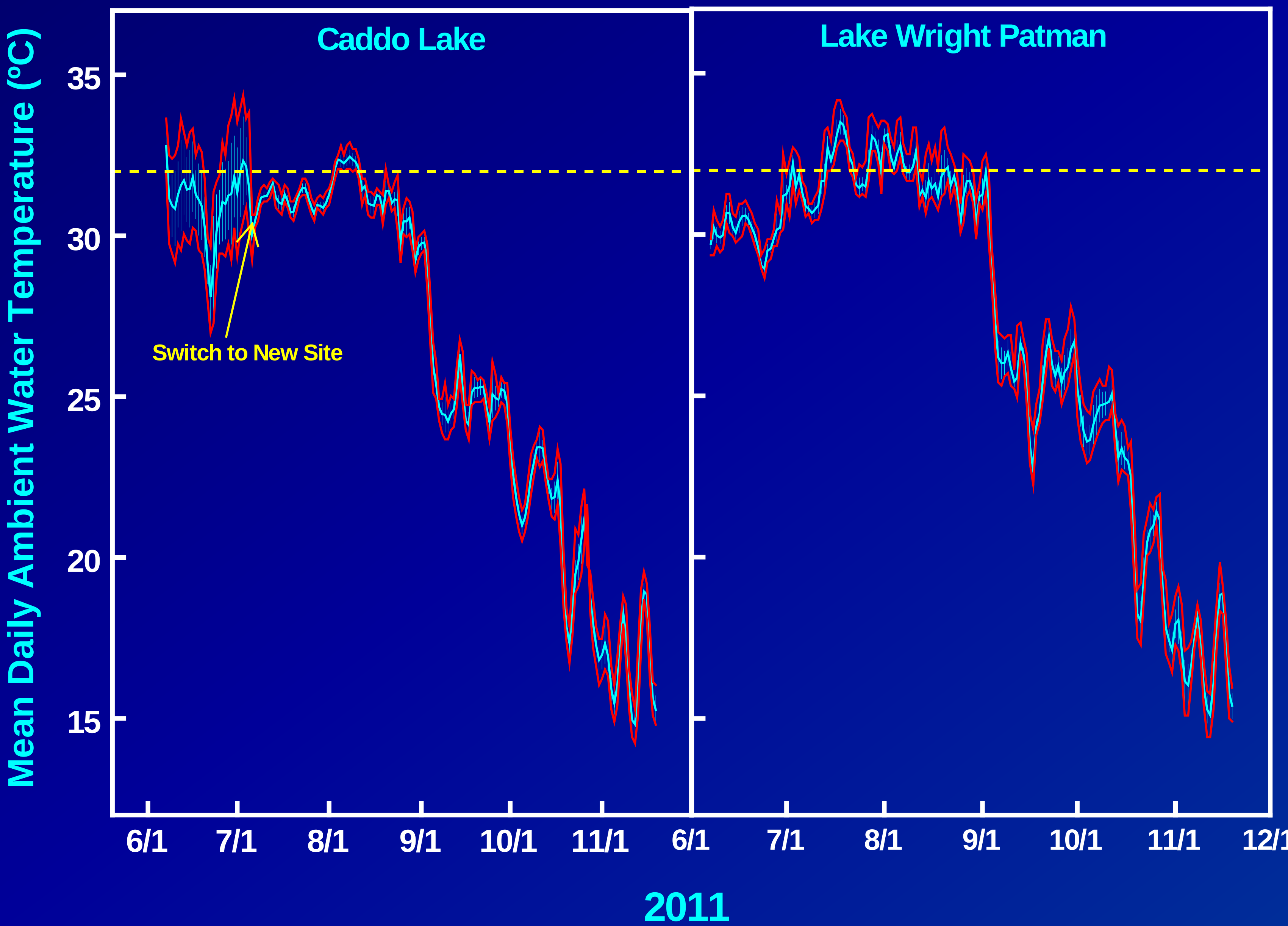
Lake Surface Water Temperature



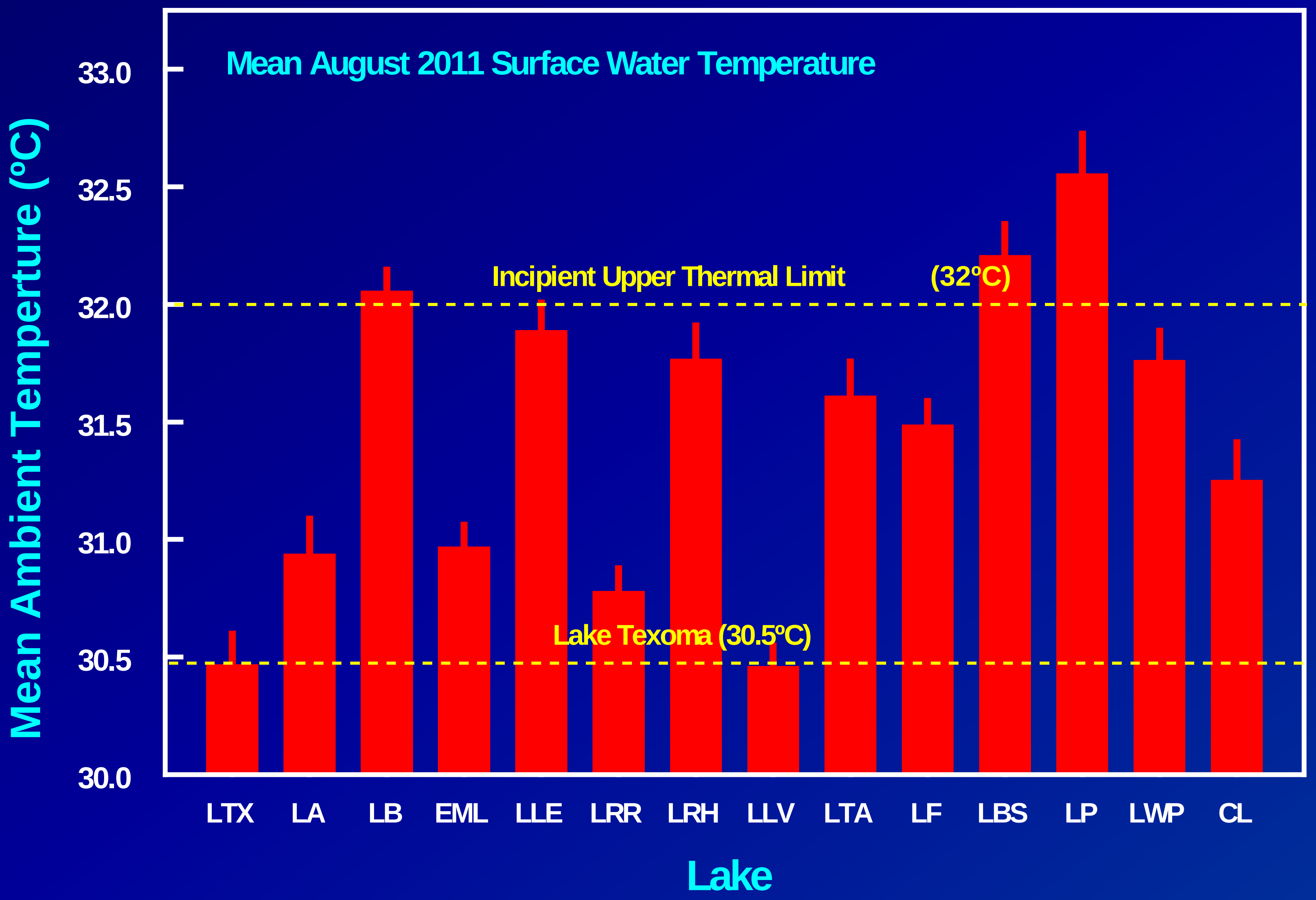
Lake Surface Water Temperature



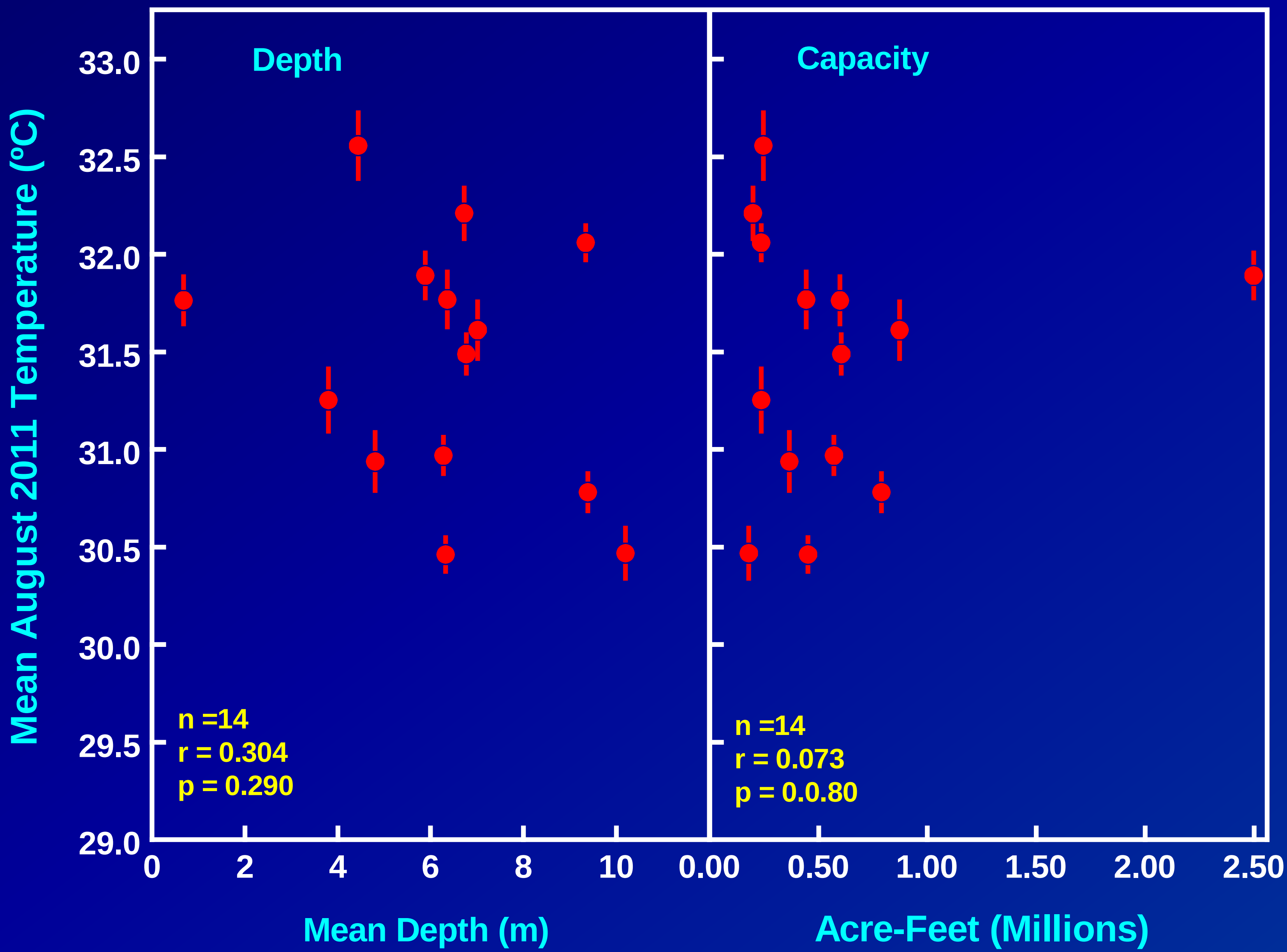
Surface Water Temperature



Mean August Surface Water Temperature



Water Temperature versus Depth & Capacity



Risk Assessment Matrix

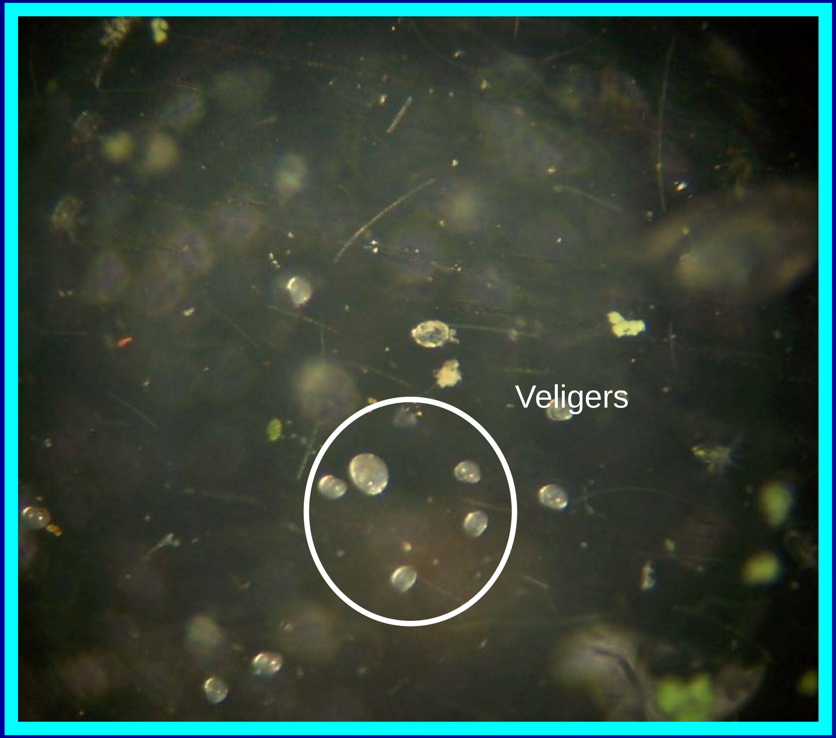
Lake	O_2	pH	Ca	Temperature*	Risk Level
Arrowhead Lake	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Bridgeport	Suitable	Suitable	Suitable	Marginal	MARGINAL
Eagle Mountain Lake	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Lewisville	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Texoma	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Ray Roberts	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Ray Hubbard	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Lavon	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Tawakoni	Suitable	Suitable	Suitable	Suitable	HIGH
Lake Fork	Suitable	Suitable	Marginal	Suitable	MARGINAL
Lake Bob Sandlin	Suitable	Suitable	Unsuitable	Unsuitable	POOR
Lake O' the Pines	Suitable	Suitable	Unsuitable	Unsuitable	POOR
Lake Wright Patman	Suitable	Suitable	Suitable	Suitable	HIGH
Caddo Lake	Suitable	Marginal	Unsuitable	Suitable	POOR

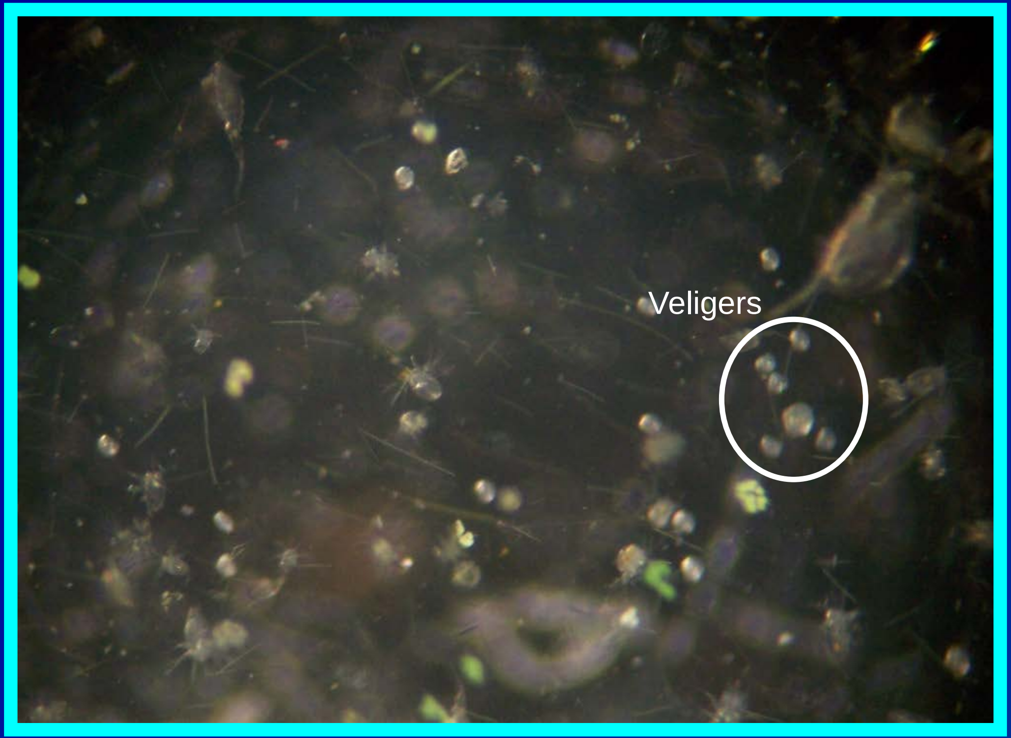
Suitable = Good to excellent for mussels
Marginal = Marginal for mussels
Unsuitable = Unlikely to support mussels

Monitoring for Veligers
and
Juvenile Settlement

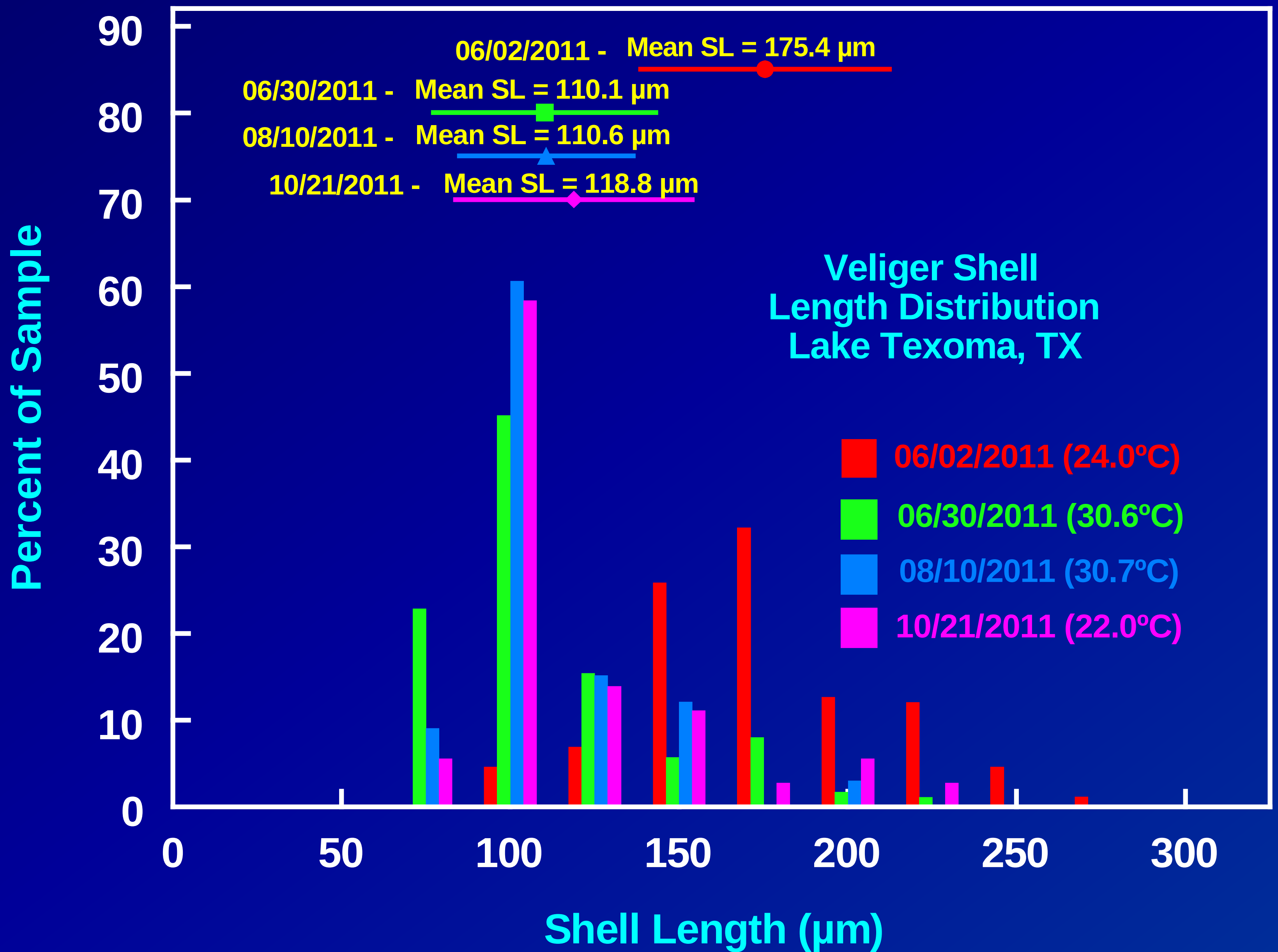
Plankton Samples

- Microscopic examination of live and preserved plankton samples revealed presence of veliger larvae June – November only at Lake Texoma
  - Dense veliger concentrations on 2 June (24.0°C) and 30 June 2011 (29.4°C)
  - Low veliger concentrations on 8/10/2011 (30.7°C), 10/21/2011 (24.5°), 11/19/2011 (16.0°C)
- No veligers observed in either spring and fall plankton samples from the 13 other examined lakes



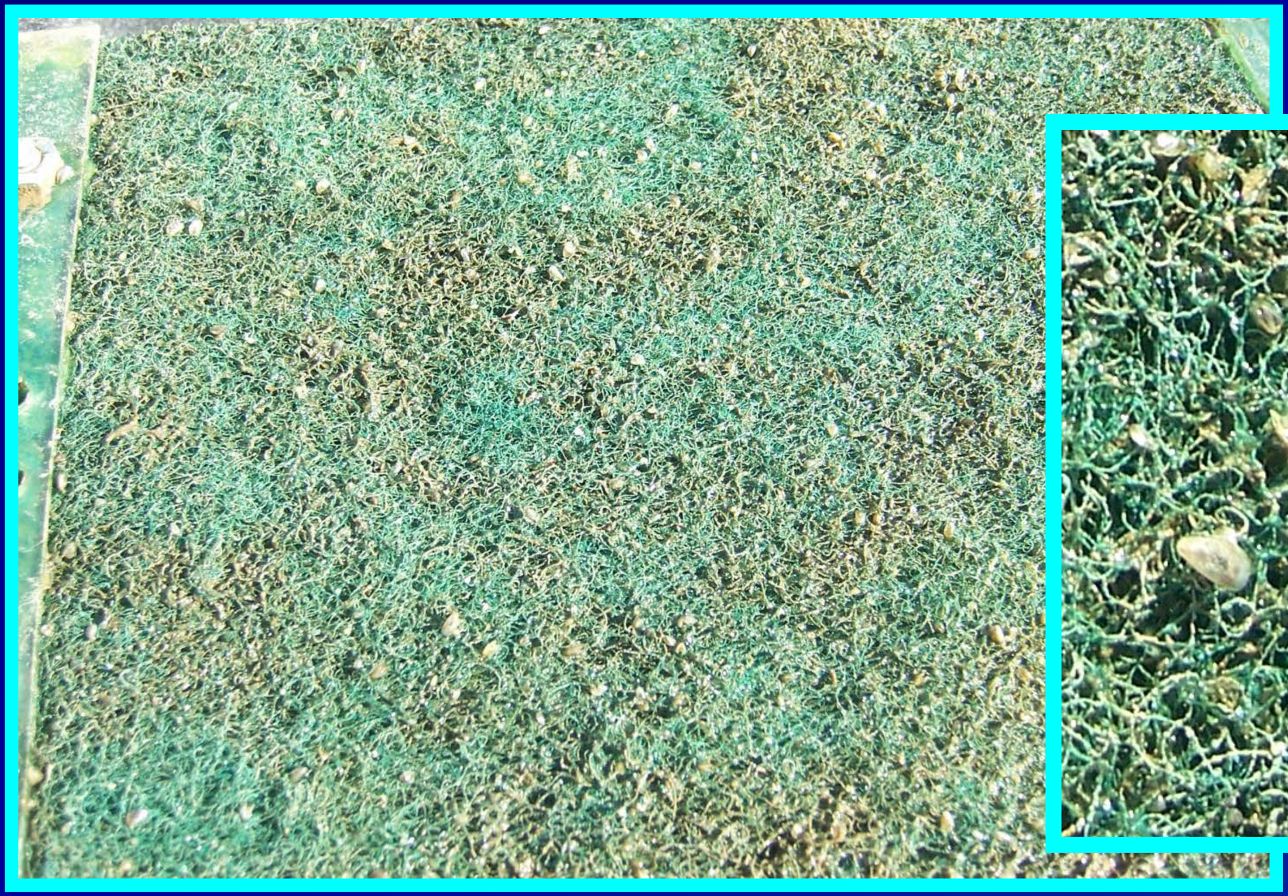


Veliger Shell Lengths

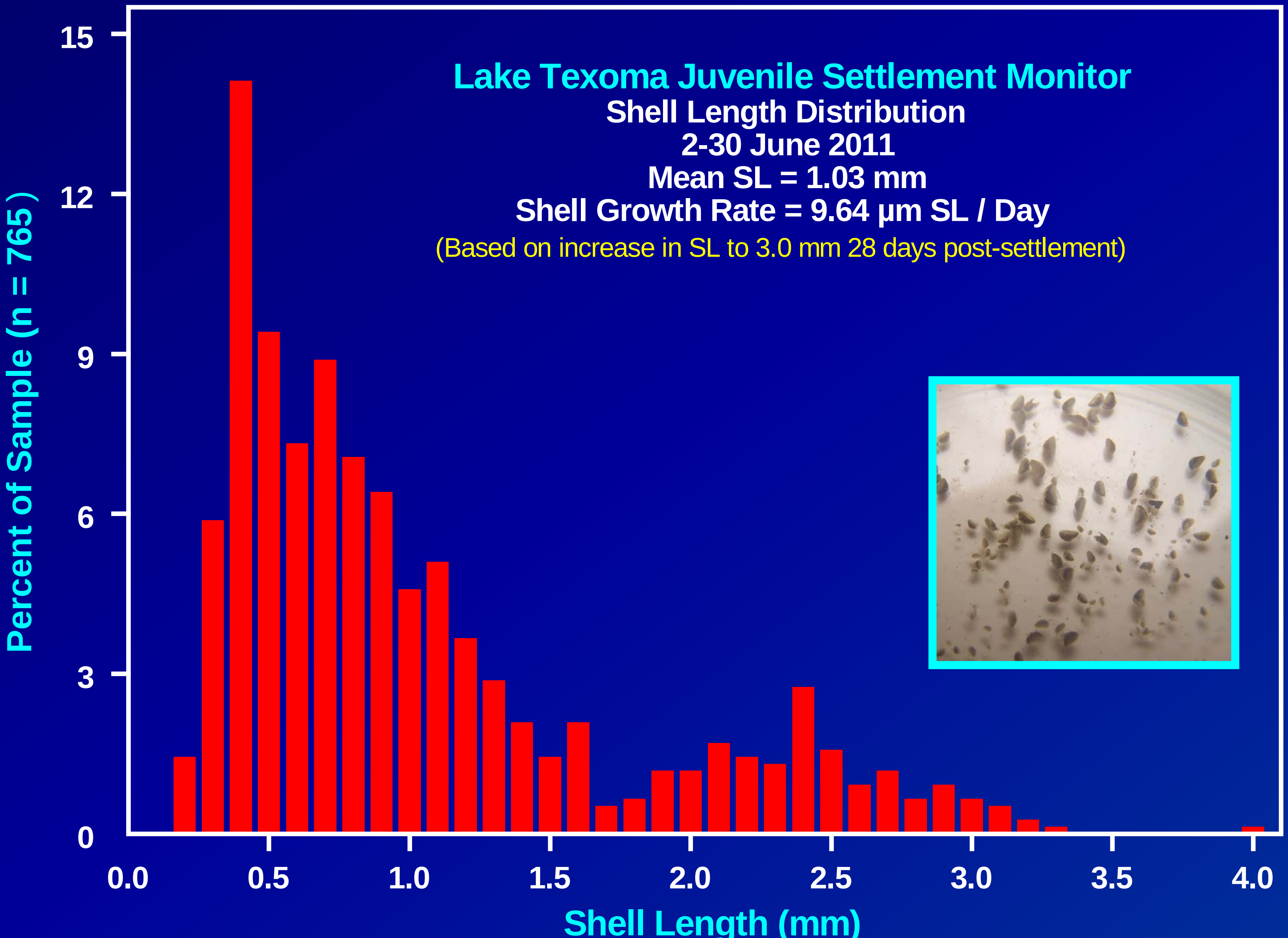


Settlement Monitoring

- Settled juvenile mussels recorded only on Lake Texoma monitors immersed from 6/2/2011 – 6/30/2011
  - Mean water temperature = 25.3°C over 28 days of immersion
  - Juveniles were relatively densely settled on the monitor

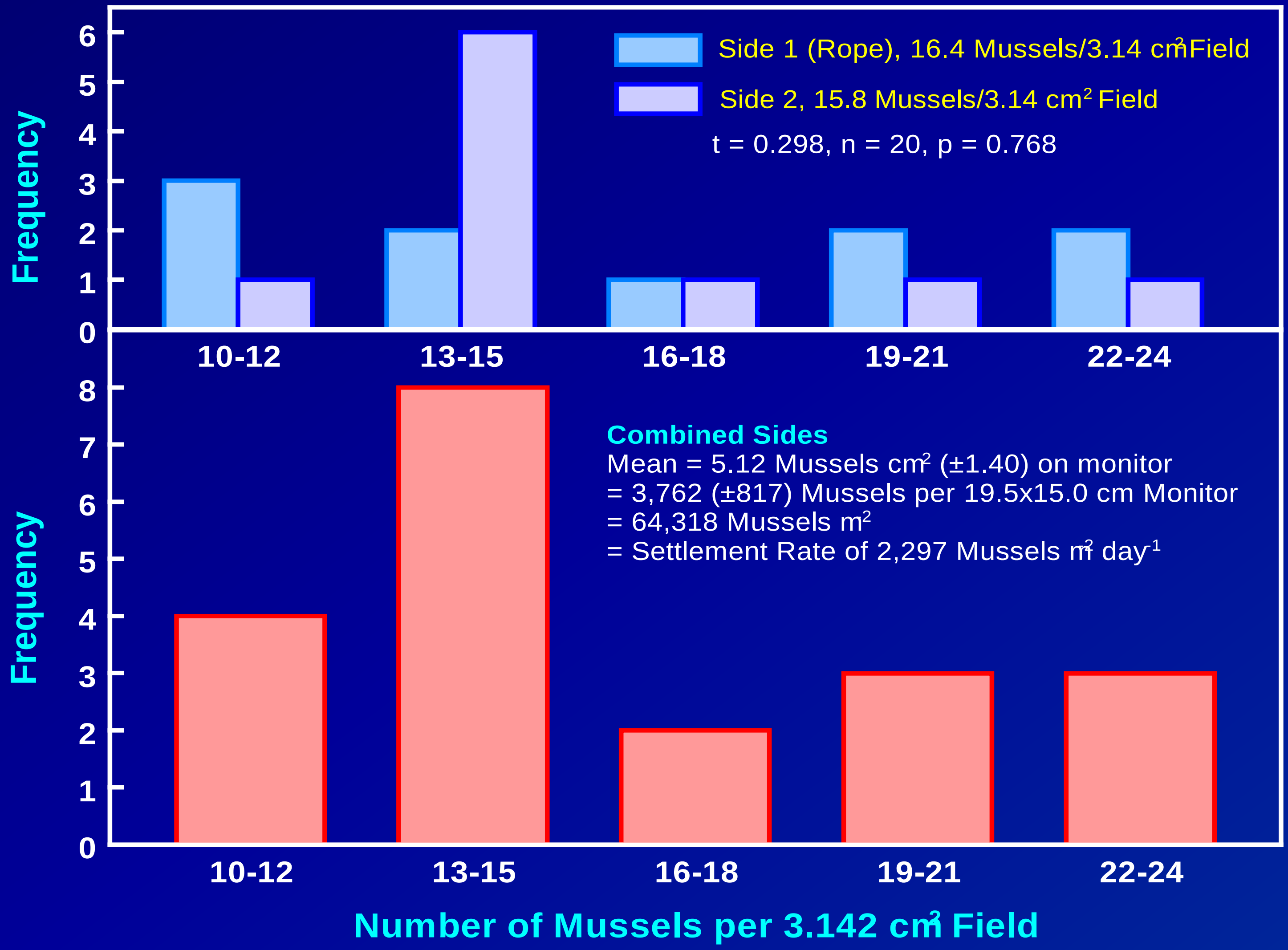


Settlement Monitoring



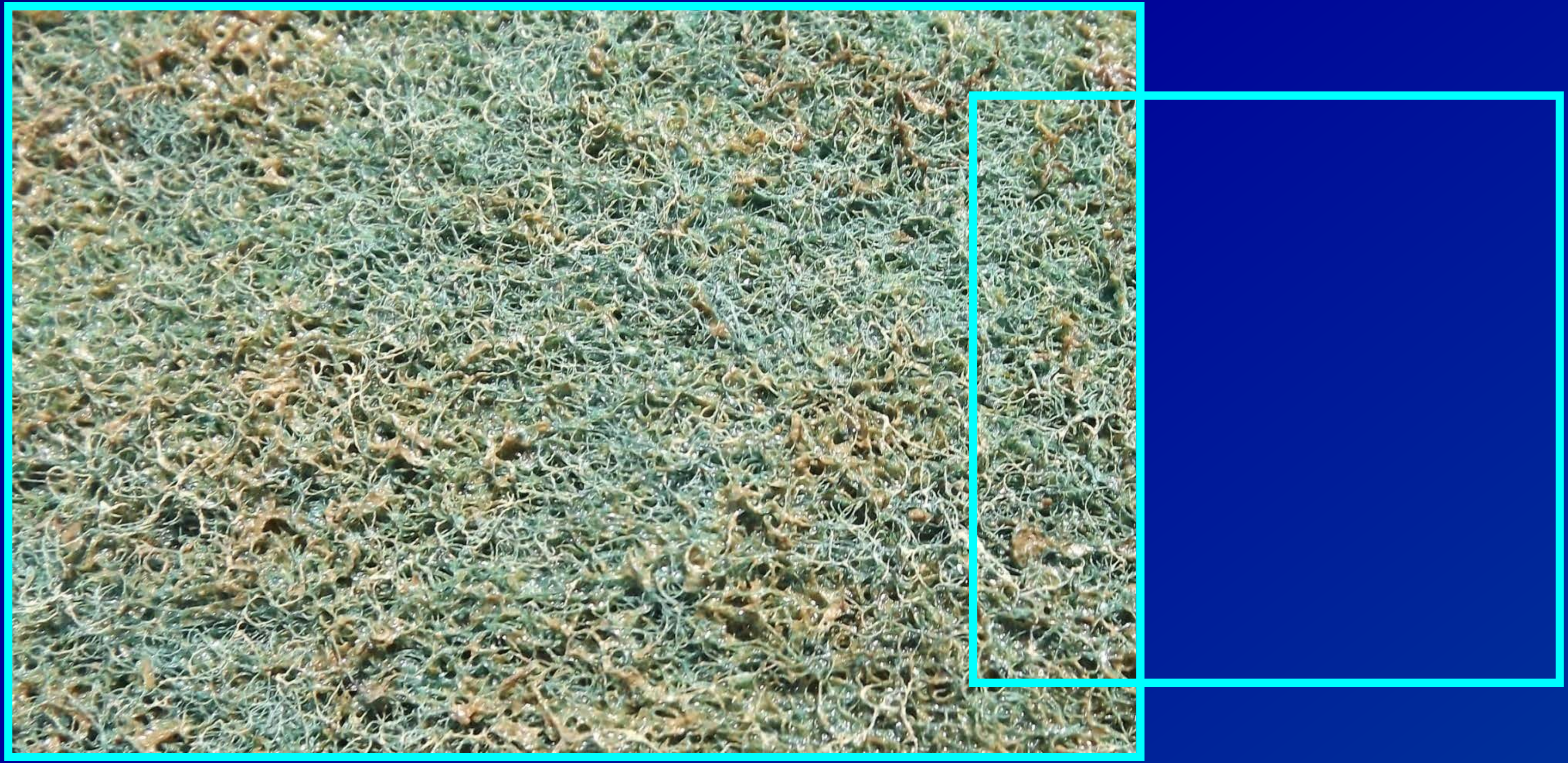
Settlement Density

- Numbers of settled juveniles in 10 randomly selected fields (3.142 cm^2) under a binocular microscope on both sides of settlement monitor

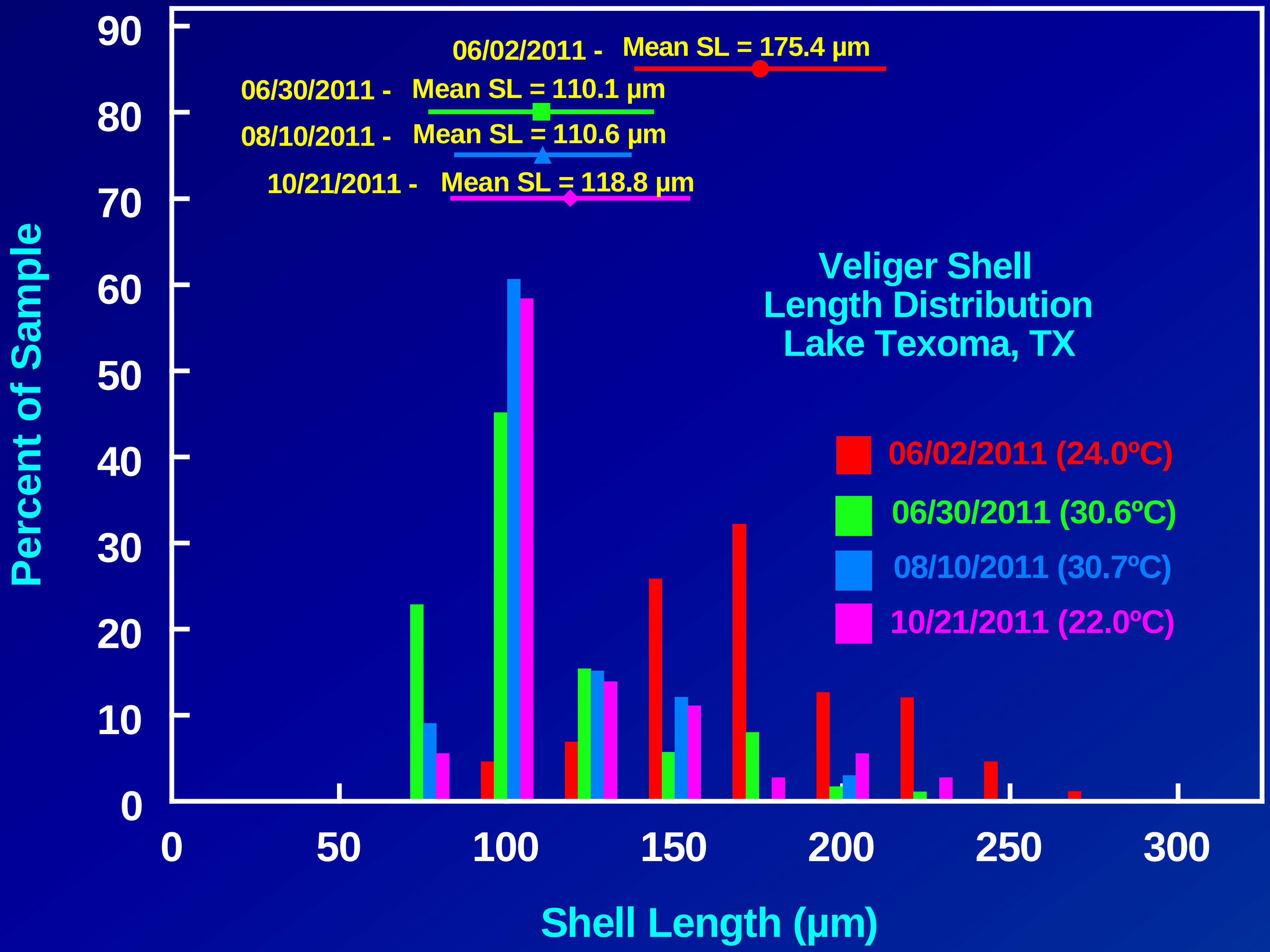


Settlement Monitoring – Late Summer & Fall

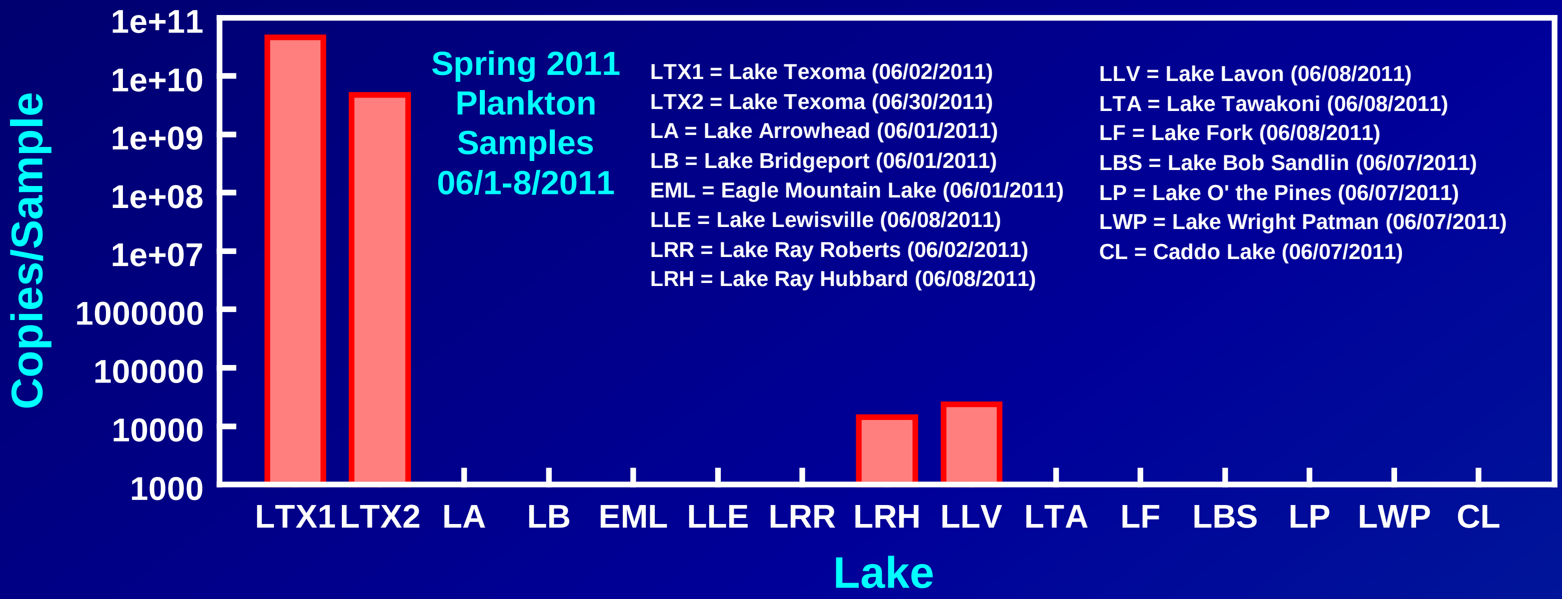
- No settled juvenile mussels recorded on Lake Texoma monitors immersed from 8/10/2011 – 8/24/2011 or 10/21//2011 – 11/19/2011
  - Viable veligers present in the water column during both periods
  - Mean water temperatures
    - 8/10/2011 – 8/24/2011 = 30.12°C ±0.33
    - 10/21/2011 – 11/19/2011 = 18.67°C ±1.55

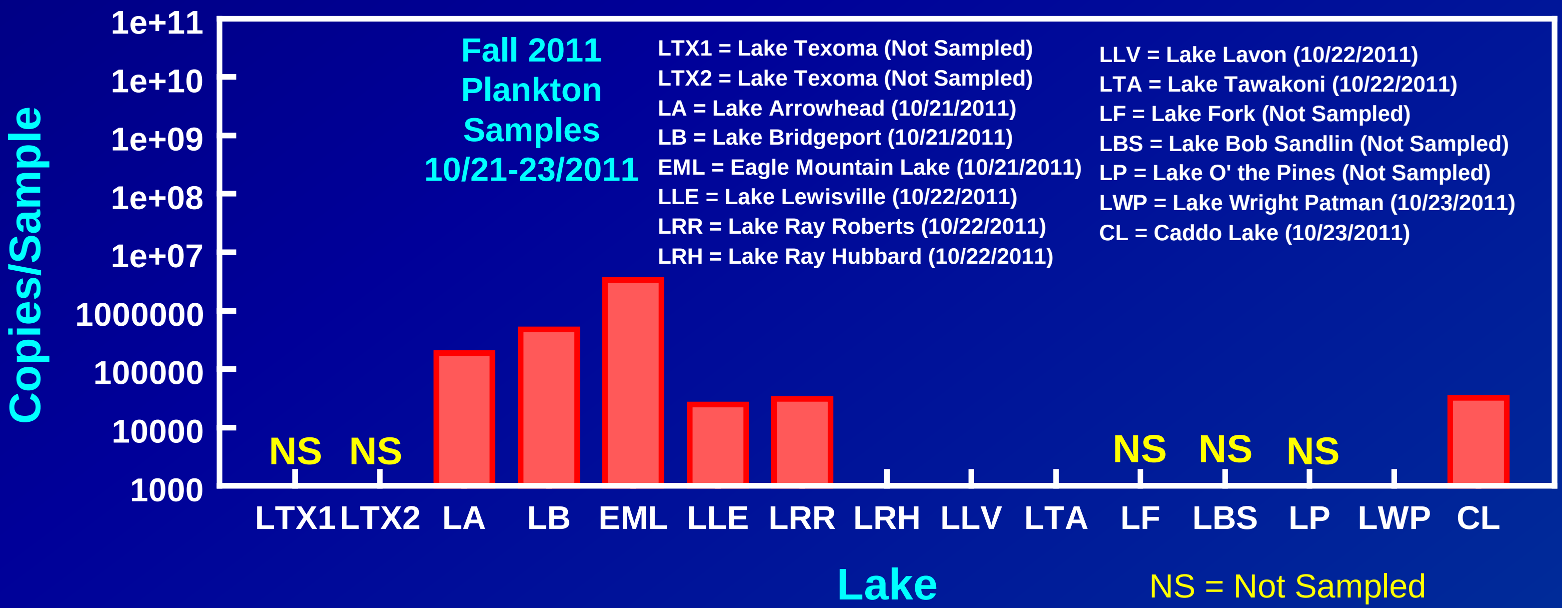


Lake Texoma Veliger Samples: Shell Lengths



Spring and Fall qPCR Results





Conclusions

- Zebra mussels appear to have evolved increased thermal tolerance in the warm water bodies of Kansas and Oklahoma
  - May have allowed zebra mussels to eventually invade Lake Texoma
  - May allow zebra mussels to invade warm southern water bodies
  - Lake Texoma could become an epicenter for zebra mussel dispersal to other warm water bodies in Texas and the Gulf States
- Because of the increased potential to invade warm water bodies, water bodies in the Gulf States should undergo invasion risk assessment for zebra mussels
  - Risk assessment indicated that 11 of 13 lakes in northeastern Texas could support zebra mussels
    - pH, Ca^{2+} concentration, summer surface water temperature
      - Nine of 13 Texas lakes appeared to be at high risk of invasion
    - Boaters appeared to be major vectors for mussel movements between water bodies
      - Analysis of boater movements (100th Meridian Boater Survey)

Conclusions

- Zebra mussel monitoring programs for warm southern water bodies should include:
  - Juvenile settlement monitors (scouring pad monitors)
  - Plankton net sampling for veliger larvae
    - Microscopic examination in field and under polarized light in the laboratory
    - qPCR for mussel DNA in plankton samples
      - Positive qPCR must be corroborated by visual evidence of veliger larvae or settling juveniles
- Imperative to develop a zebra mussel risk assessment and monitoring programs for southern water bodies in order to identify those most vulnerable to invasion
  - Allows prevention and education programs to be focused on water bodies most at risk
  - Allows early detection and rapid response to mussel invasion

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- US Fish and Wildlife Service

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- Lake Ray Roberts Marina (Bill Williams)
- Titus County Freshwater Supply District No. 1 – Lake Bob Sandlin (Judy Barton)
- Kelly Creek Marina – Lake Wright Patman (Leon and Shelley Jennings)
- Johnson Creek Marina - Lake O' the Pines (Sam and Lyda Edwards)
- Popes Landing Marina - Lake Fork (John Goergen)
- Tawakoni Marina (Larry Wright)
- Chandler's Landing Marina - Lake Ray Hubbard (Joel Weiner)
- Collin Park Marina - Lake Lavon (Joe Castro)
- Cottonwood Creek Marina – Lake Lewisville (Jennifer Morris)
- Col. Richard Cary – Caddo Lake

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Thanks
For Your
Attention