Long-term Patterns in Lake Champlain Plankton: the role of Invasive Species and Climate Change

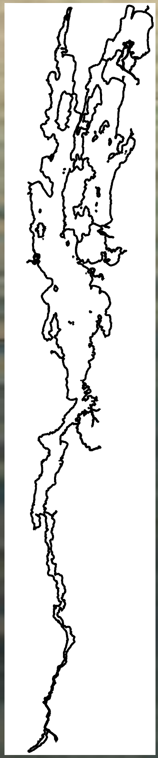
Timothy B. Mihuc
SUNY Plattsburgh Lake Champlain Research Institute

Luke Myers (LCRI) Fred Dunlap (NYDEC)

Graduate students/ staff:
Caren Carling, Shelley Bouyea Casey Binggeli, Mark Lamay, Erin Hayes-Pontius, Jillian Zajac, Joe Connelly, Sarah Glancy
Undergrads- Carrianne Pershyn, Amanda Greene, Amanda Groves, Allison Waring, Lindsay Paul, Gabriella Doud, Erin Moseman
and a whole host of other SUNY Plattsburgh students

Introduction

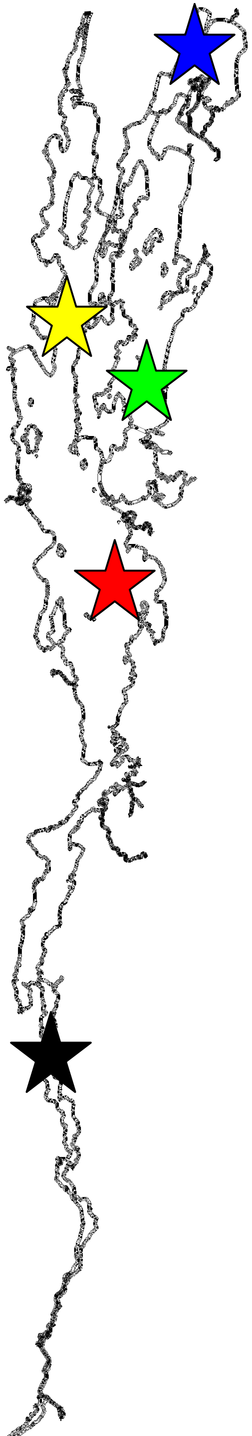
- **200 km in length,**
- **surface area 1130 km^2**
- **mean depth 19.4 meters**
- **3 year water residence time**



Long-Term Water Quality and Biological Monitoring Project

Supported by the Lake Champlain Basin Program (U.S. EPA)

Collaborators- Fred Dunlap (NY DEC), Pete Stengel, Angela Shambaugh, Eric Smeltzer (VT DEC)



Zooplankton trends: NYDEC Monitoring program
5 sites

Summer (July/August) 1992-2009

Station #	**Latitude (North)**	**Longitude (West)**	**Depth (meters)**
★ **50**	45 00.80	73 10.43	04
★ **36**	44 45.37	73 21.30	50
★ **34**	44 42.49	73 13.61	50
★ **19**	44 28.26	73 17.95	100
★ **04**	43 57.10	73 24.47	10

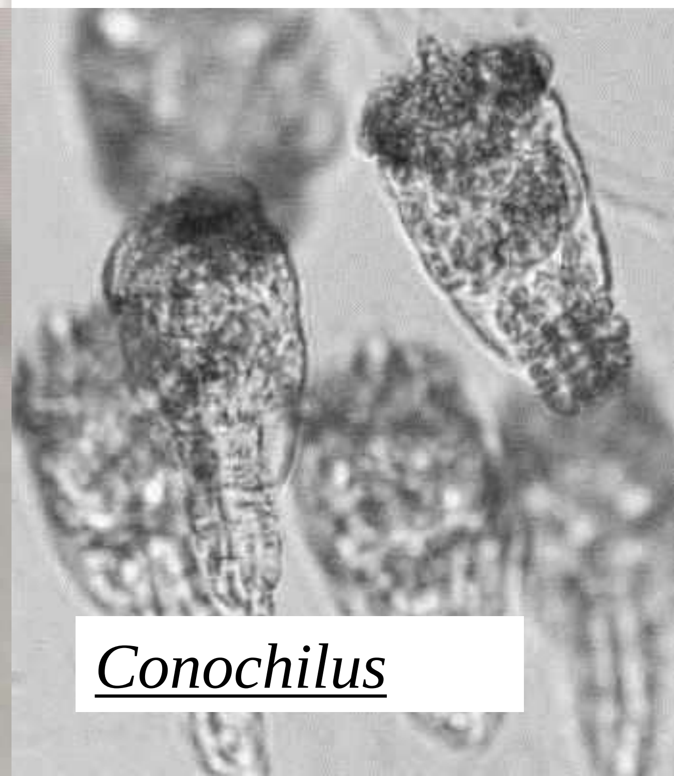
Rotifers

Wheel animals

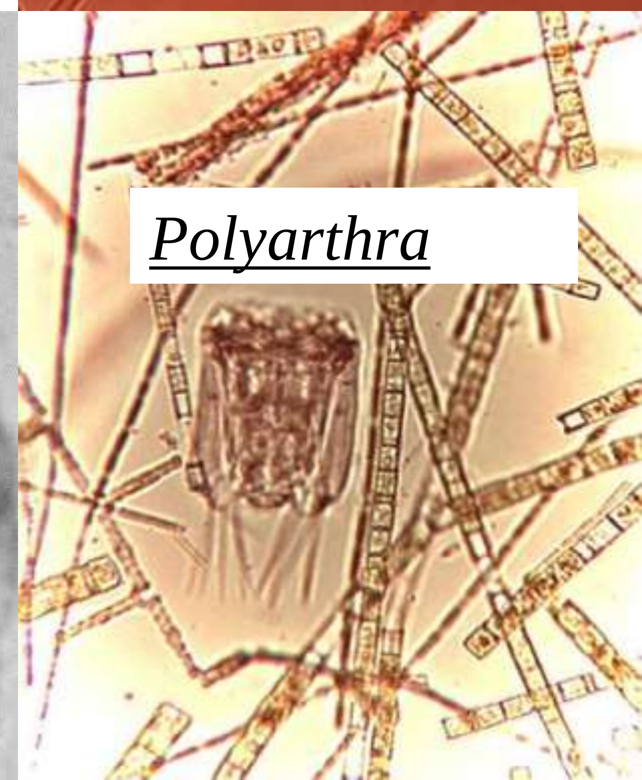
Asplanchna

Kellicottia

Kerratella



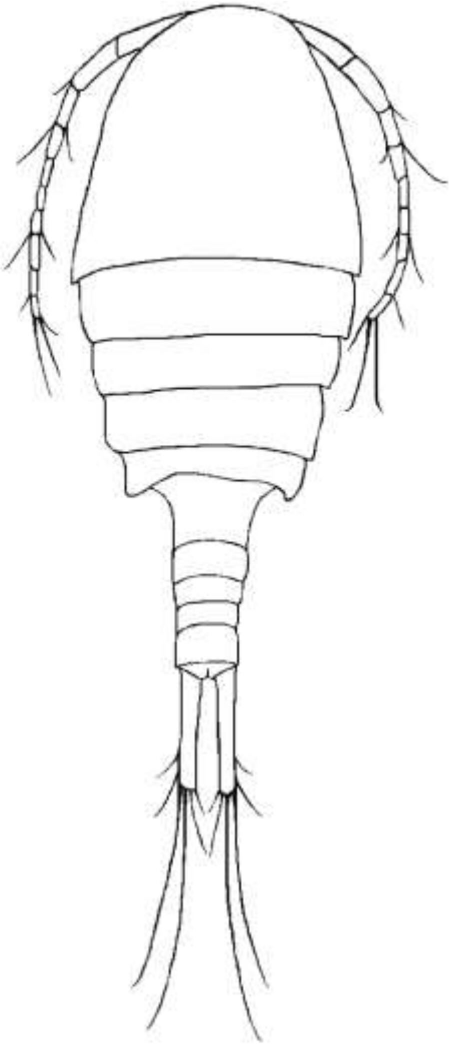
Conochilus



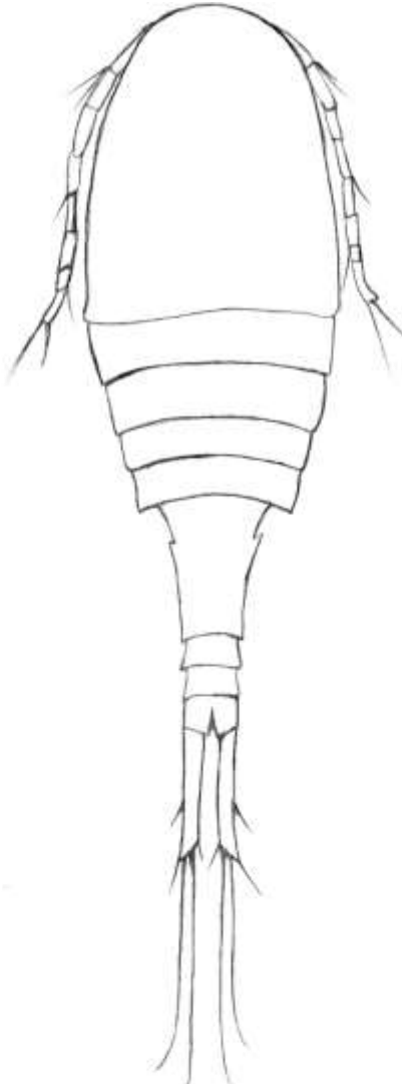
Polyarthra

Key to Zooplankton of Lake Champlain

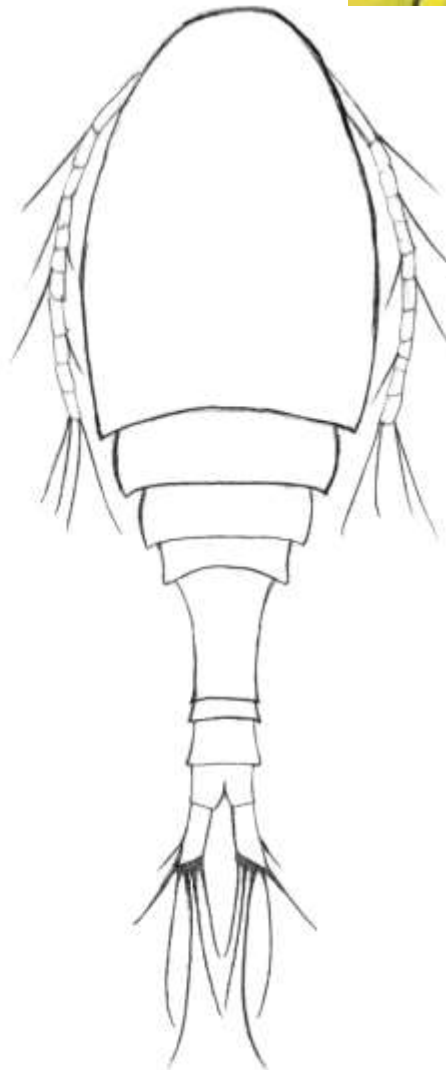
Copepods



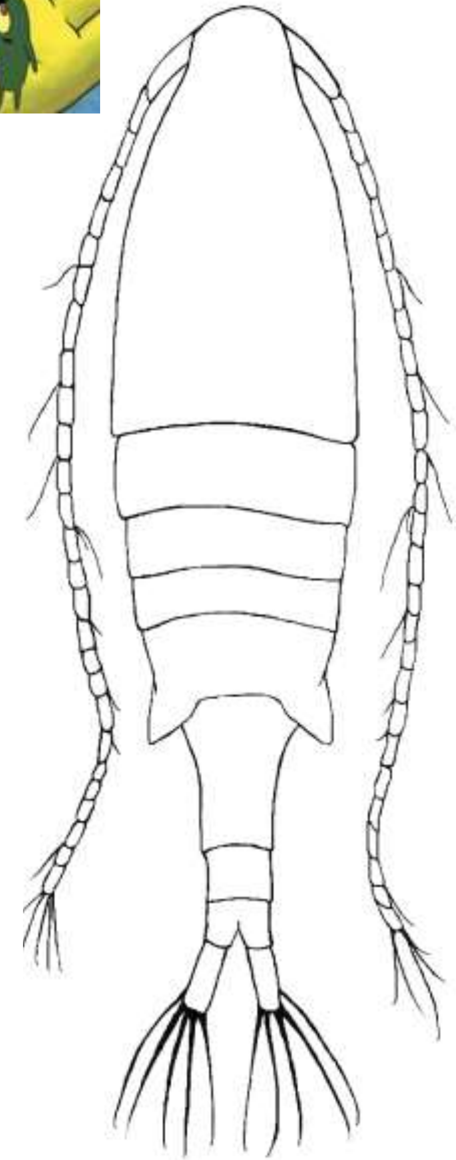
Acanthocyclops



Diacyclops

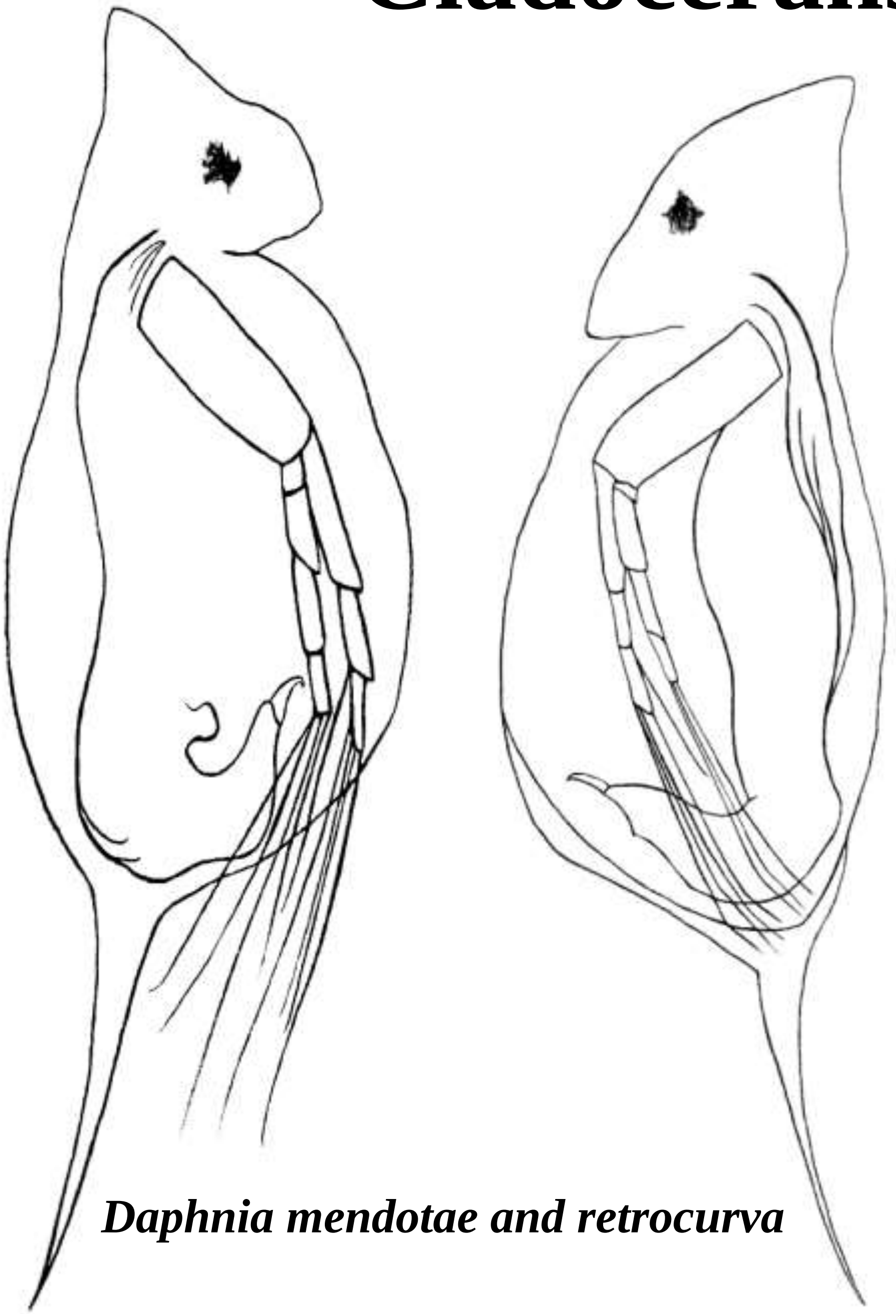


Mesocyclops



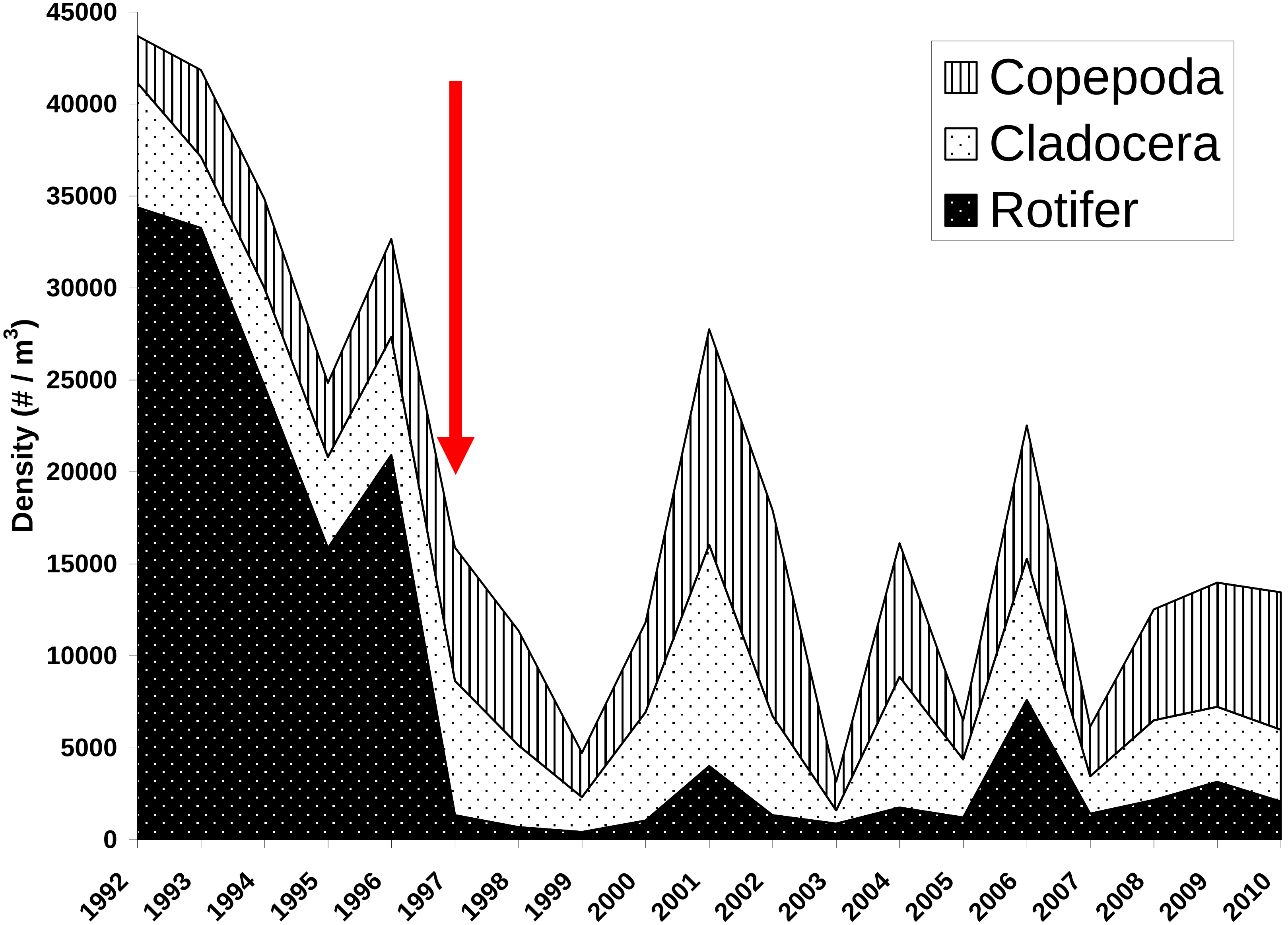
Leptodiaptomus

Cladocerans

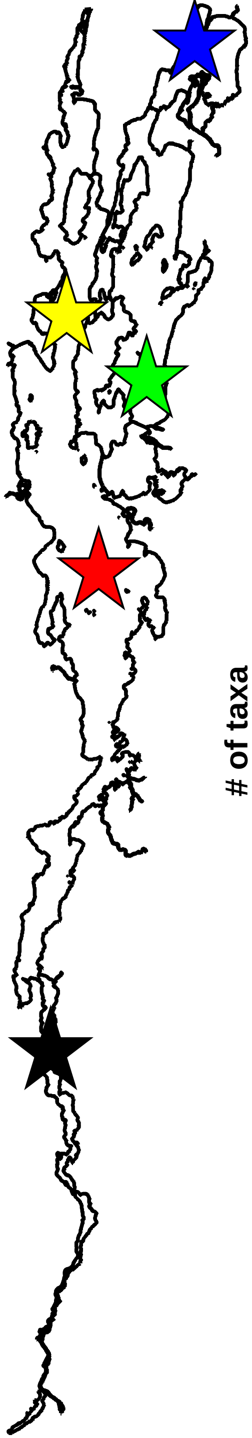


Daphnia mendotae and retrocurva

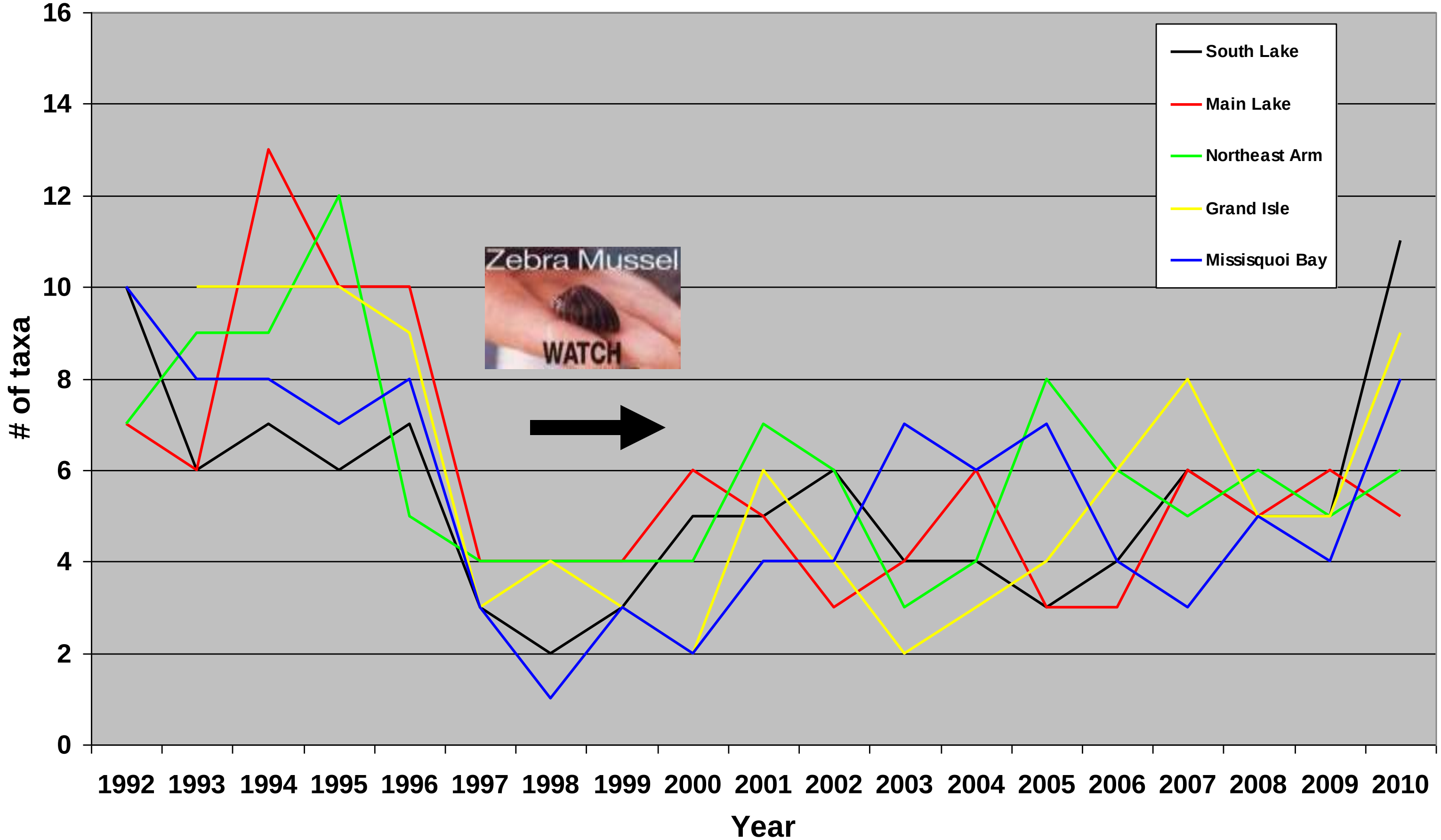
Deep lake study sites



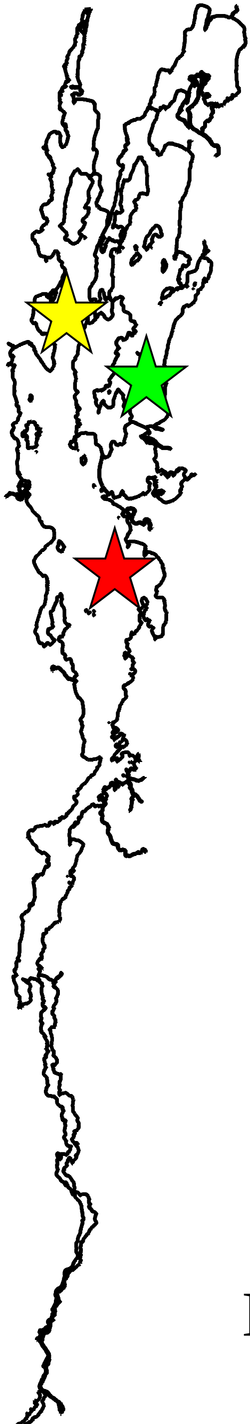
Mihuc et al. 2012

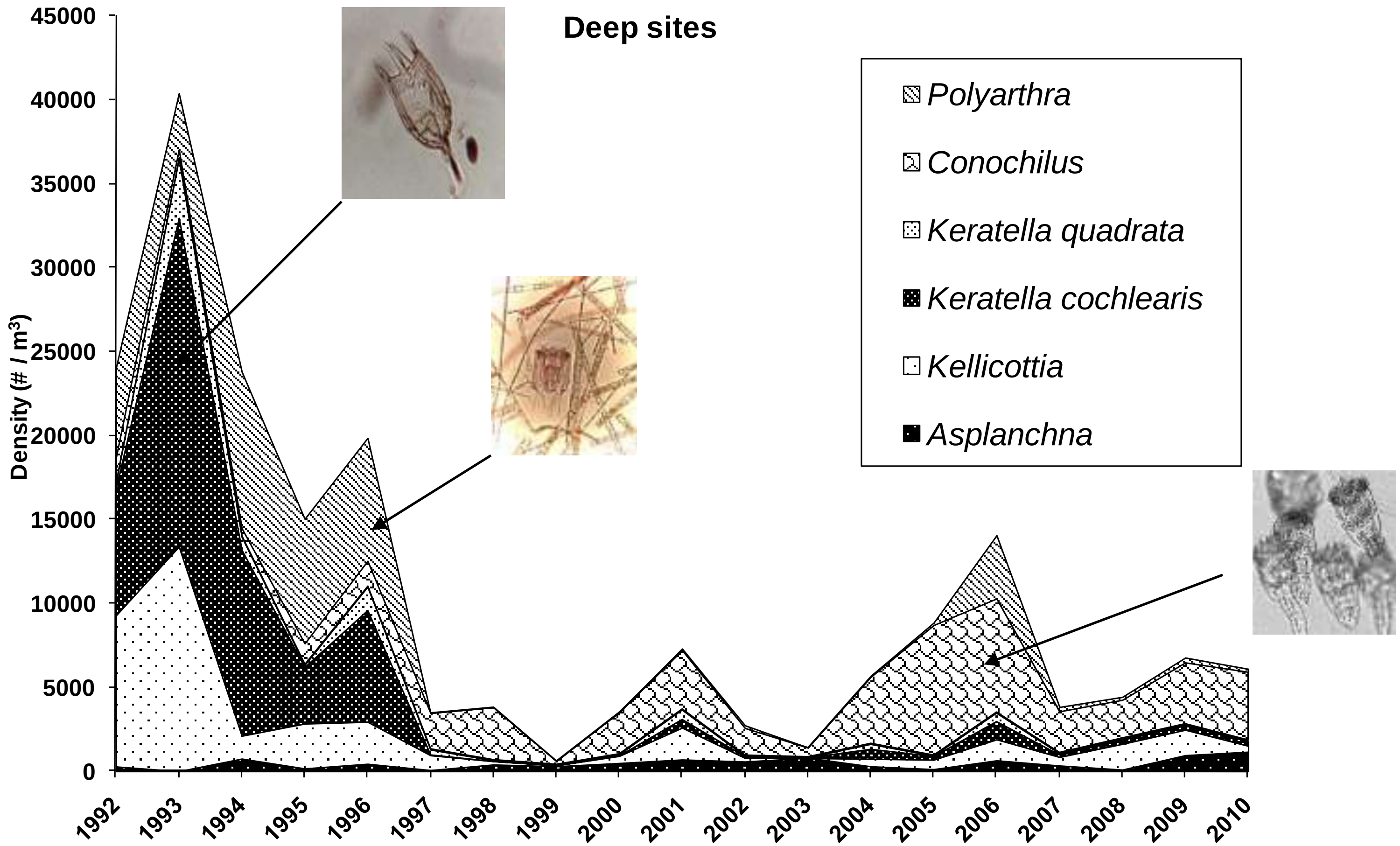


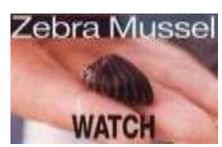
Rotifer taxa richness



Mihuc et al. 2012

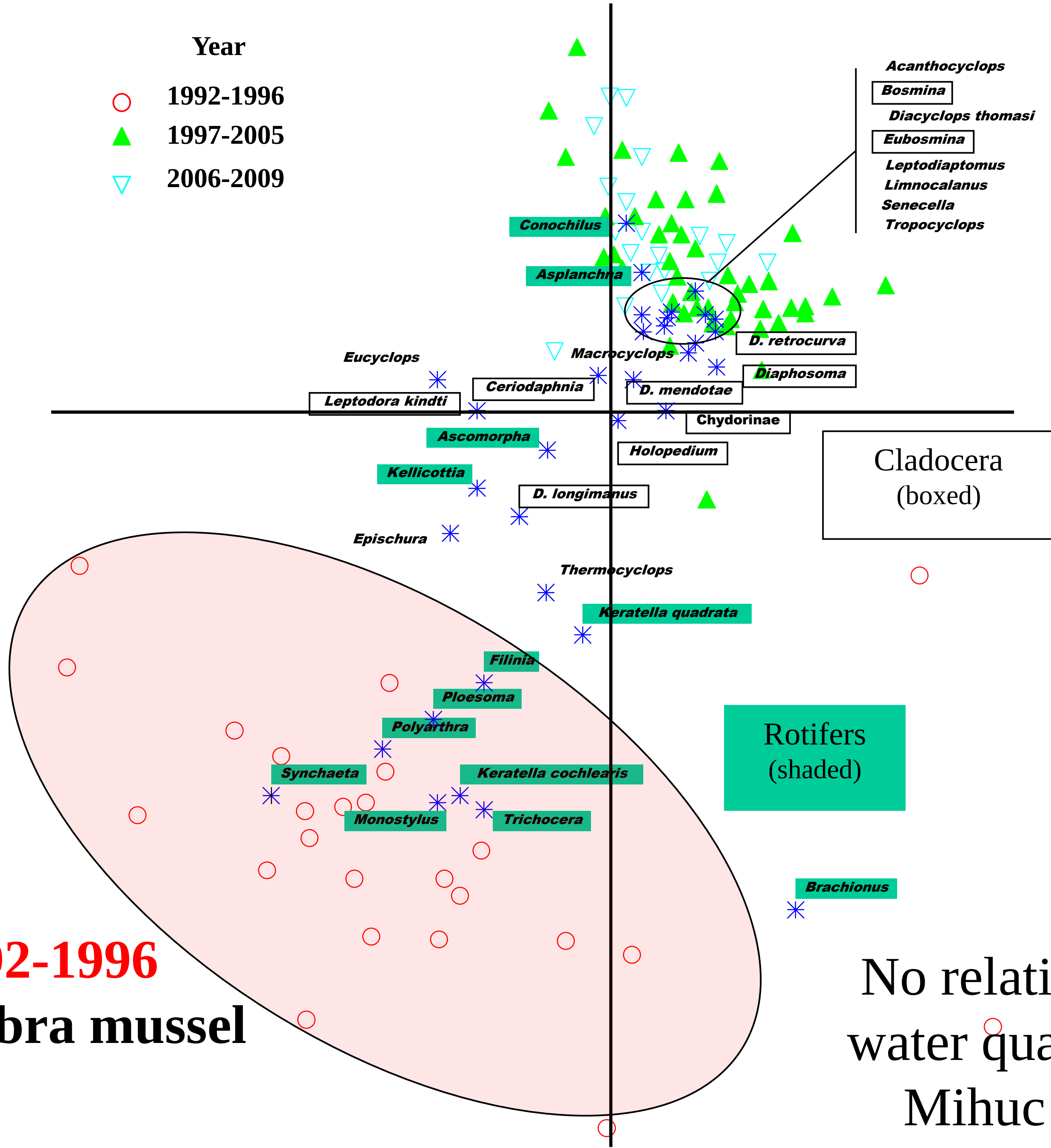






Conochilus SURVIVED

Deep sites Lake Champlain
Mihuc et al. 2012



1992-1996

Pre- zebra mussel

No relationships with water quality variables

Mihuc et al. 2012

Contents lists available at SciVerse ScienceDirect

Journal of Great Lakes Research

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Long-term patterns in Lake Champlain's zooplankton: 1992–2010

Timothy B. Mihuc [a,*], Fred Dunlap [b], Casey Binggeli [a], Luke Myers [a], Carrianne Pershyn [a], Amanda Groves [a], Allison Waring [a]

[a] Lake Champlain Research Institute, SUNY Plattsburgh, Plattsburgh, NY 12901, USA
[b] NY dept. of Environmental Conservation, Ray Brook, NY, USA

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ABSTRACT

We examined patterns in Lake Champlain zooplankton abundance from 1992 to 2010 using summer data from five study sites. Rotifer abundance (#/m^3) for many common taxa such as *Polyarthra*, *Kellicottia*, and *Keratella* declined lakewide in the mid-1990s which coincided with the invasion of zebra mussels (*Dreissena polymorpha*) into Lake Champlain. The only rotifer to increase in density following zebra mussel invasion was *Conochilus* which is a colonial species. Long-term shifts in copepod and cladoceran community composition can be attributed to the arrival of another invasive species in 2004–2005, the alewife (*Alosa pseudoharengus*). Our results support previous findings that alewife predation can impact larger bodied zooplankton within temperate lake systems. Following alewife invasion into Lake Champlain, body length of *Leptodiaptomus* and *Daphnia retrocurva* decreased to a size at or below known alewife feeding preferences. In addition, smaller bodied copepods (primarily *Diacyclops thomasi*) have increased in abundance since alewife invasion while juvenile copepods have declined. Our results suggest that post-alewife zooplankton patterns are most likely due to alewife size-selective feeding strategies. Observed long-term changes in zooplankton community structure have potential implications for the lake's food web dynamics, particularly recent declines in large bodied zooplankton which may release smaller plankton from top-down control.

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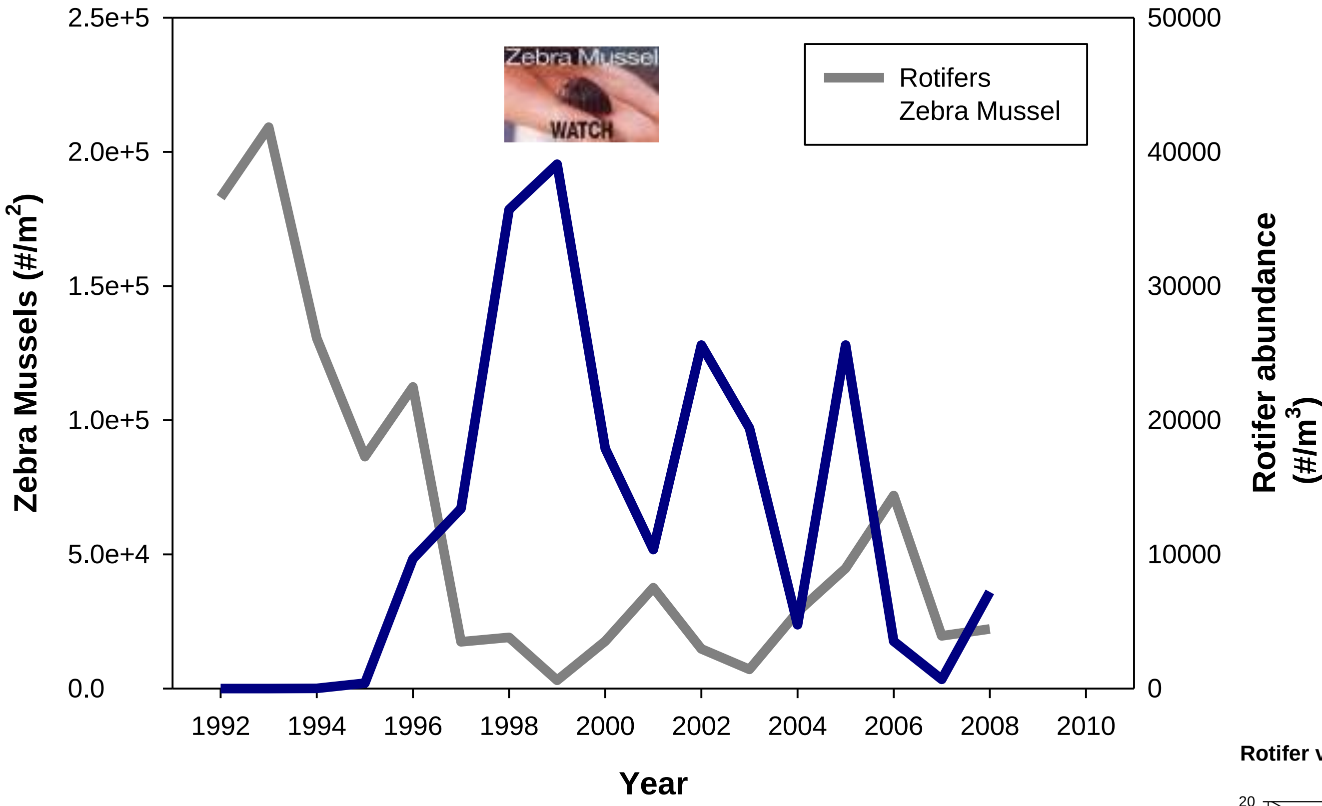
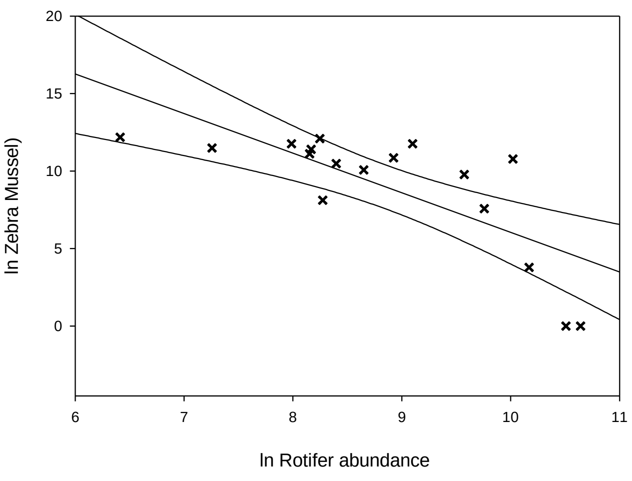
Lake Champlain long-term trends



$r^2 = 0.56$,
$p = <0.001$

Rotifer versus zebra mussel abundance Lake Champlain



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Environmental change in Lake Champlain revealed by long-term monitoring

Eric Smeltzer [a,*], Angela d. Shambaugh [a,1], Pete Stangel [b,2]

[a] Vermont Department of Environmental Conservation, Watershed Management Division, 103 South Main St., Waterbury, VT 05671, USA
[b] Lake Champlain Basin Program, Vermont Department of Environmental Conservation, Watershed Management Division, 103 South Main St., Waterbury, VT 05671, USA

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ABSTRACT

Long-term monitoring data on Lake Champlain spanning the past two to five decades were analyzed to document water quality and biological changes in the lake. August mean surface water temperatures increased during 1964–2009 in most Lake Champlain regions at rates (0.035–0.085 °C/year) similar to what has been observed in the Laurentian Great Lakes and elsewhere. Secchi disk transparency increased by over a meter during 1964–2009 in regions along the main stem of the lake, with much of the increase occurring after the 1993 zebra mussel invasion. Transparency declined in northeastern regions where zebra mussel densities were lower. No trends in hypolimnetic dissolved oxygen concentrations or depletion rates were found in any of the deep lake regions during 1990–2009. Sodium concentrations tripled in the Main Lake region since the 1960s. Chloride increased in the Main Lake by 30% since 1992, but declined in northeastern regions of the lake during recent years, coincident with reductions in road salt use in Vermont. Total phosphorus concentrations decreased during 1979–2009 in southern and northwestern lake regions, but increased by 72% in Missisquoi Bay where chlorophyll-a concentrations doubled over the period. There was a general lakewide trend of decreasing total nitrogen levels during 1992–2009 that may have been due in part to reductions in atmospheric nitrogen loading to the watershed. Cyanobacteria increased their dominance within the phytoplankton community in northeastern regions of the lake since the 1970s.

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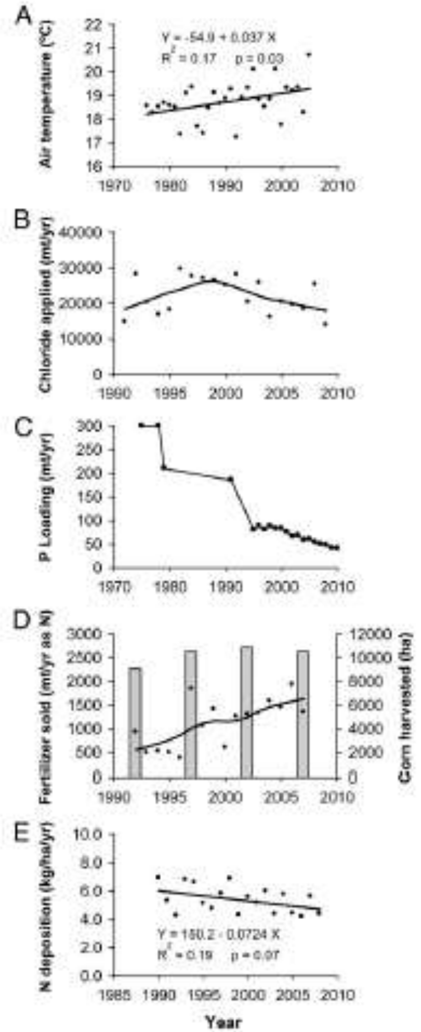
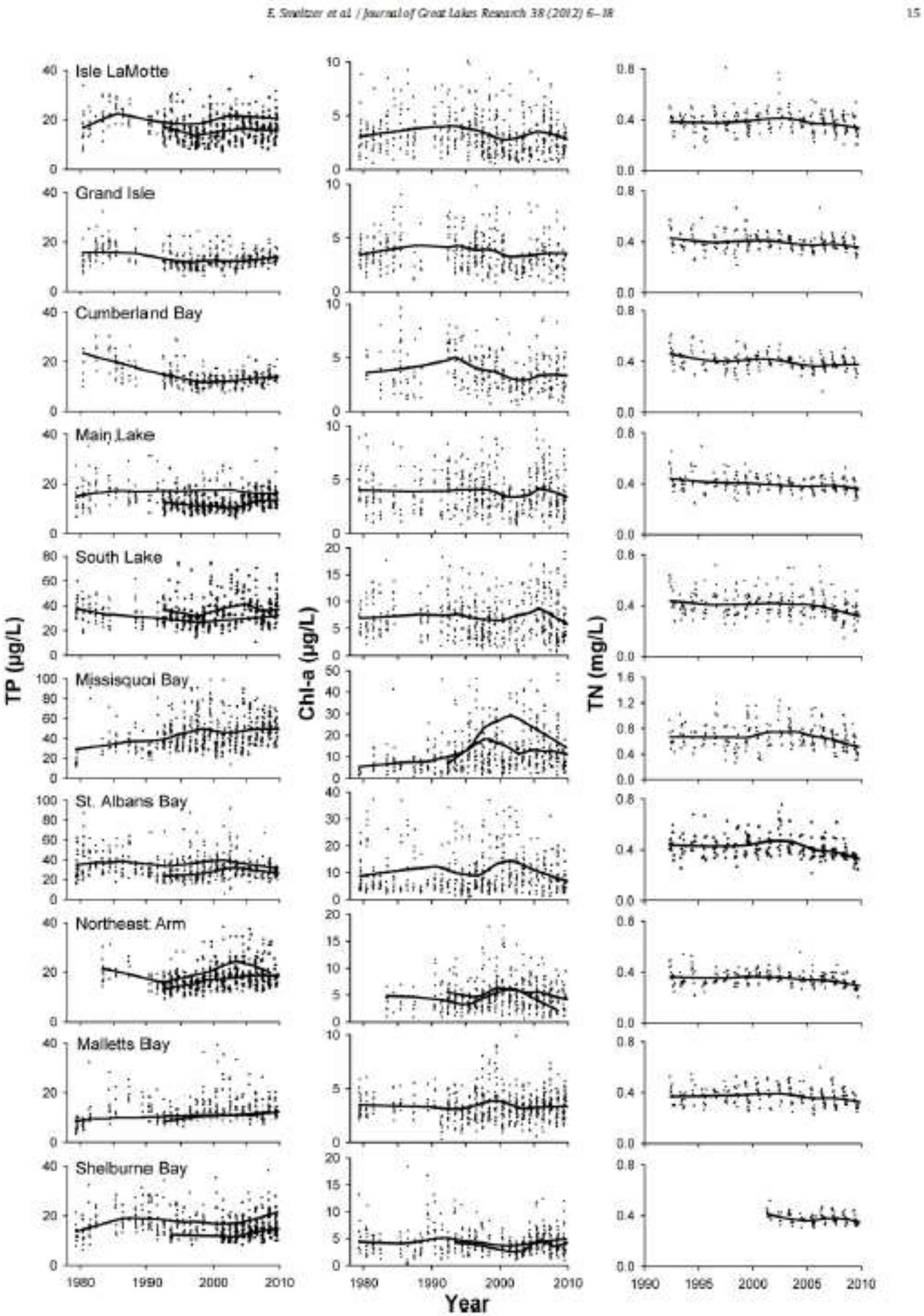


Fig. 1. Trends in Lake Champlain environmental stressors. A. Summer mean air temperature in the Lake Champlain Basin, 1976–2005 (modified from Stager and Thill, 2010). B. Winter road salt application rates (metric tons per year as chloride) for Vermont state highway maintenance districts within the Lake Champlain Basin, 1990–2009 (Vermont Agency of Transportation data). C. Total phosphorus loading to Lake Champlain from Vermont and New York wastewater treatment facilities, 1975–2010 (Smeltzer et al., 2009; Bogdan, 1978). D. Nitrogen fertilizer sold (dots and LOWESS trend line) and area of corn harvested (vertical bars) in Franklin County, VT, 1992–2007. Fertilizer sales data are from the Vermont Agency of Agriculture, Food, and Markets and do not include manure. Corn data are from the U.S. Department of Agriculture Census of Agriculture. E. Annual mean atmospheric wet deposition rates of inorganic nitrogen at Underhill, VT, 1990–2008 (National Atmospheric Deposition Program data).

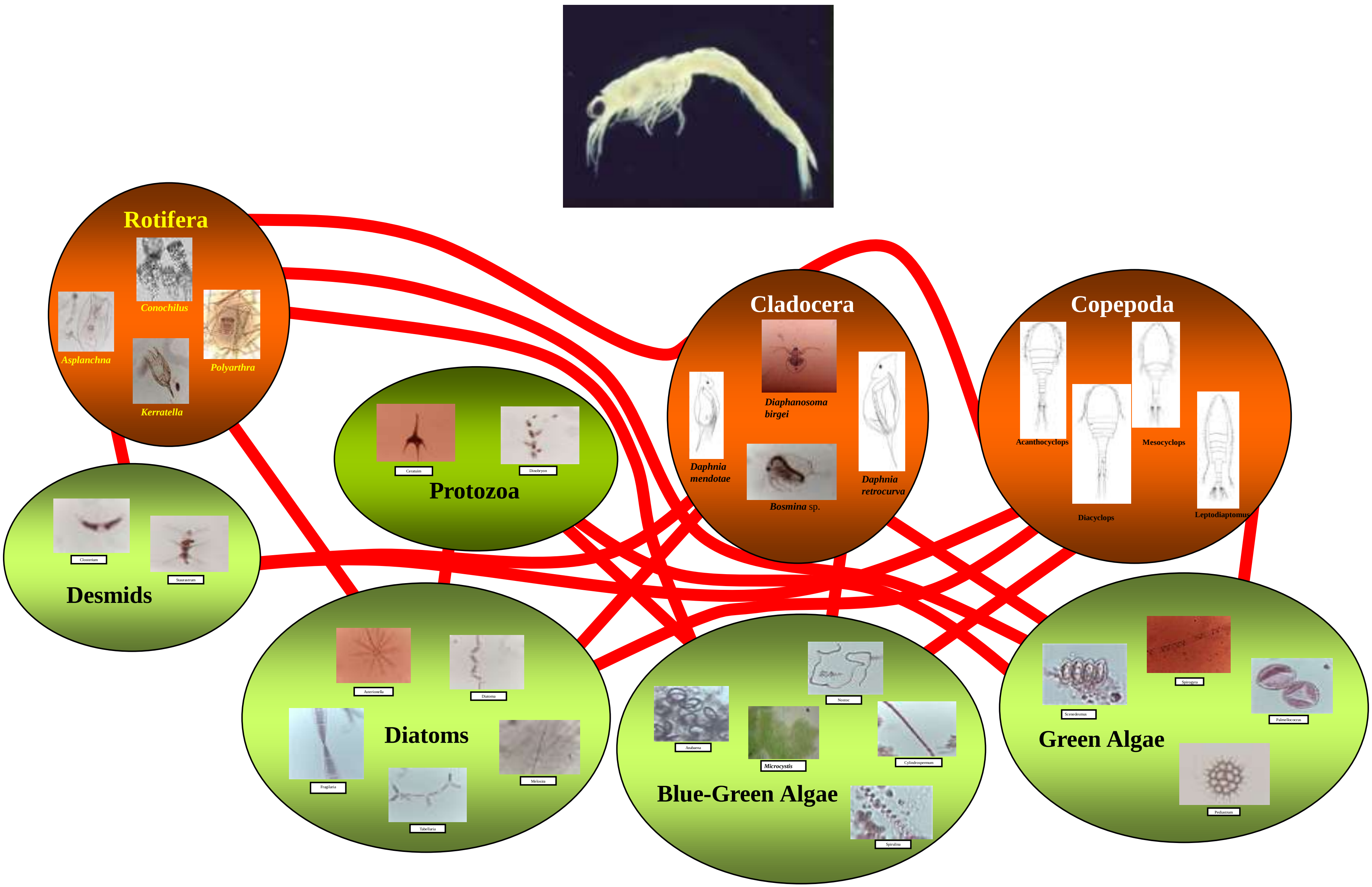
Smeltzer et. al. 2012

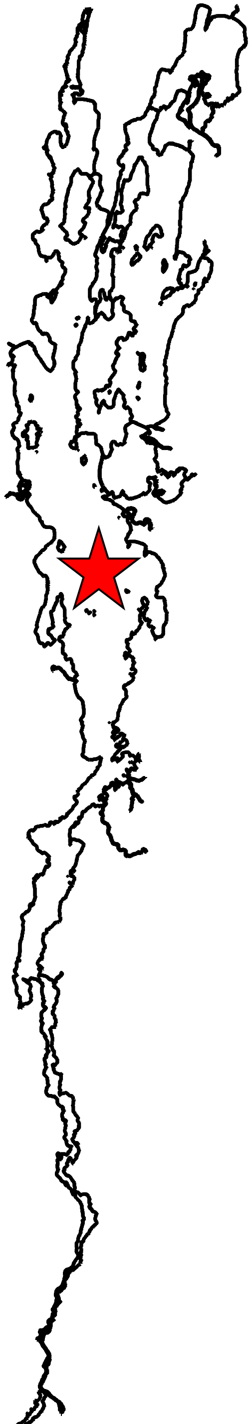
Smeltzer et. al. 2012

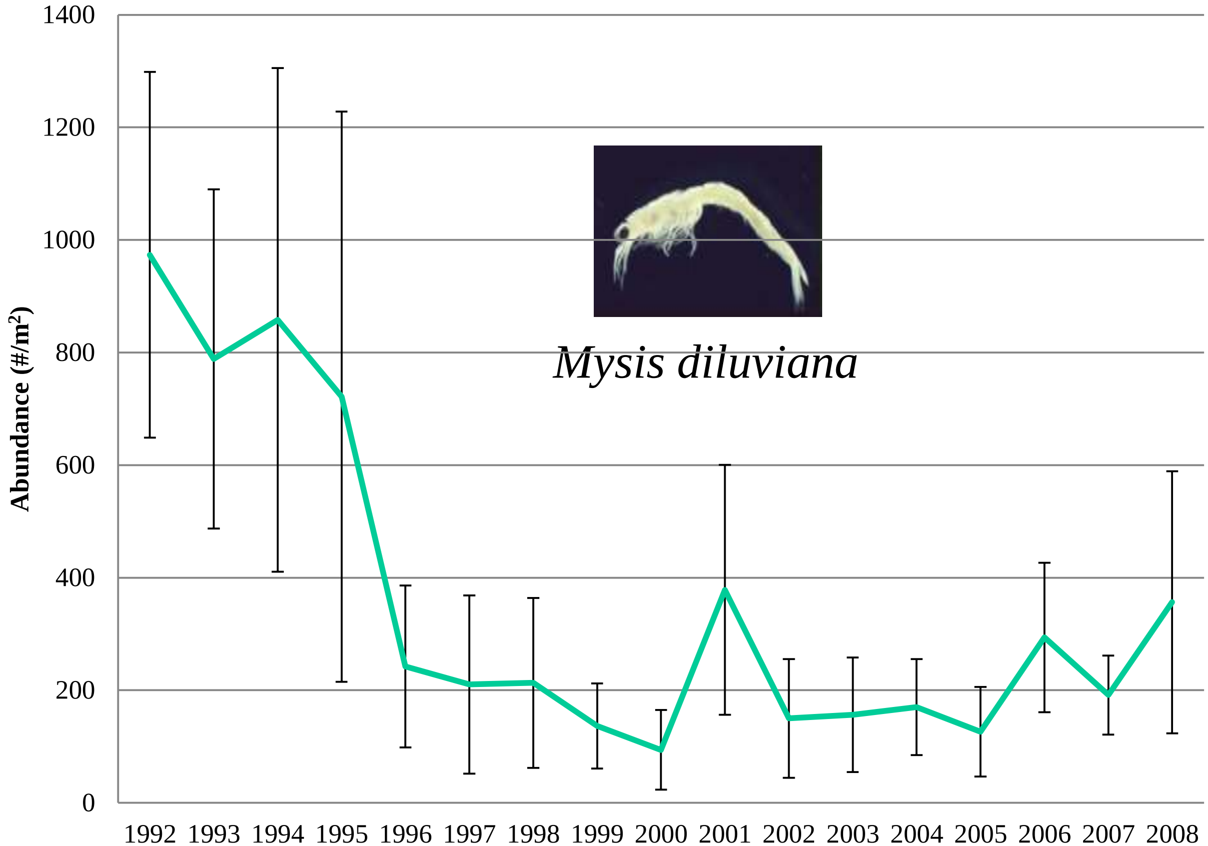


Water quality variables do not explain patterns in the Lake's plankton.

Lake Champlain Food Web

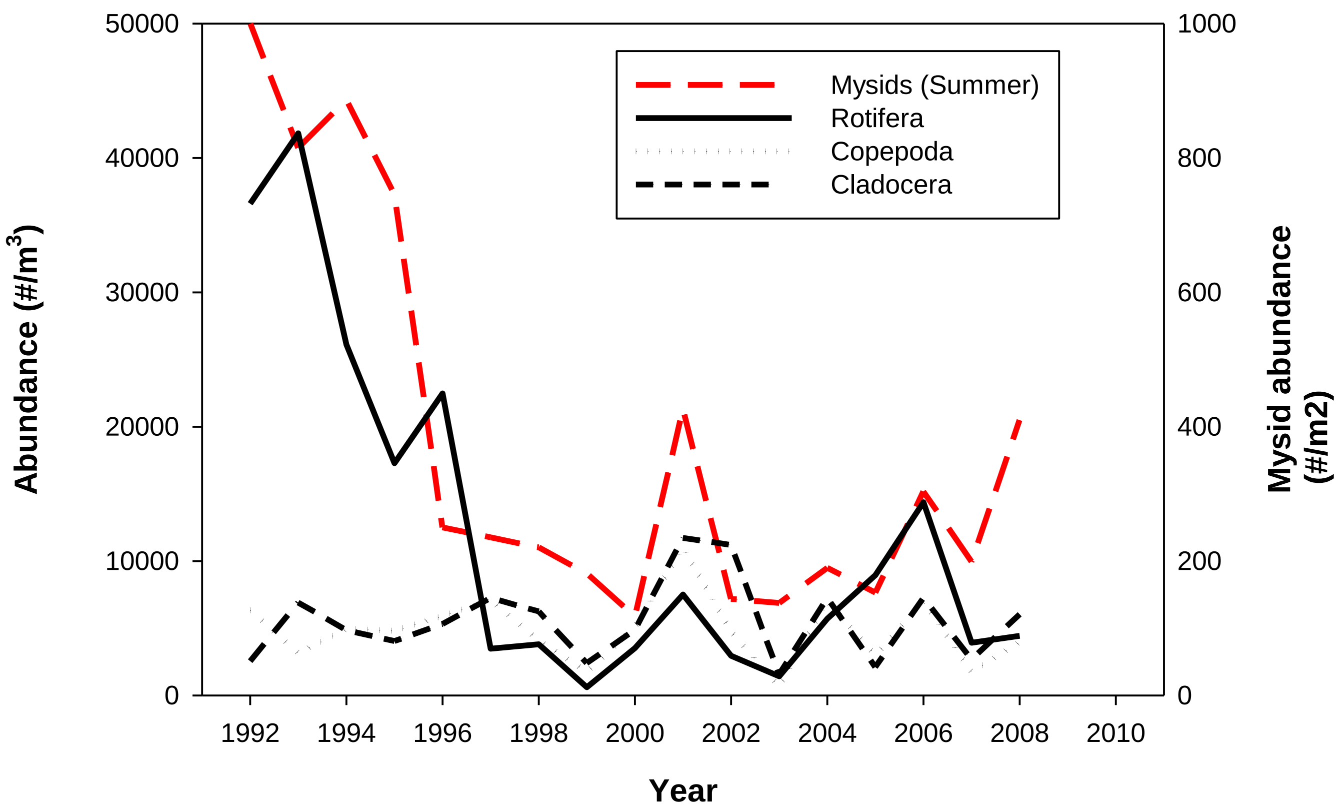


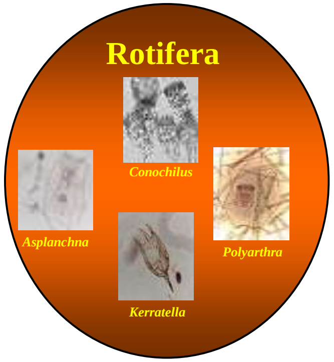


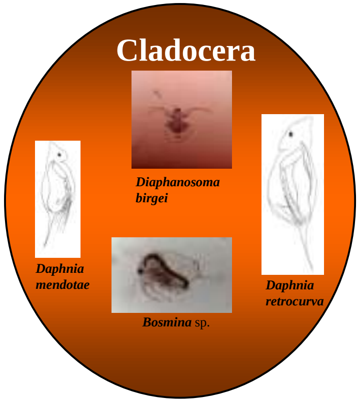


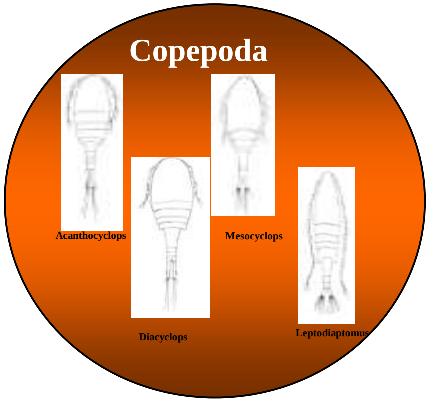
Abundance (#/m²)
1400
1200
1000
800
600
400
200
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Mysis diluviana

Lake Champlain Mysid long-term trends

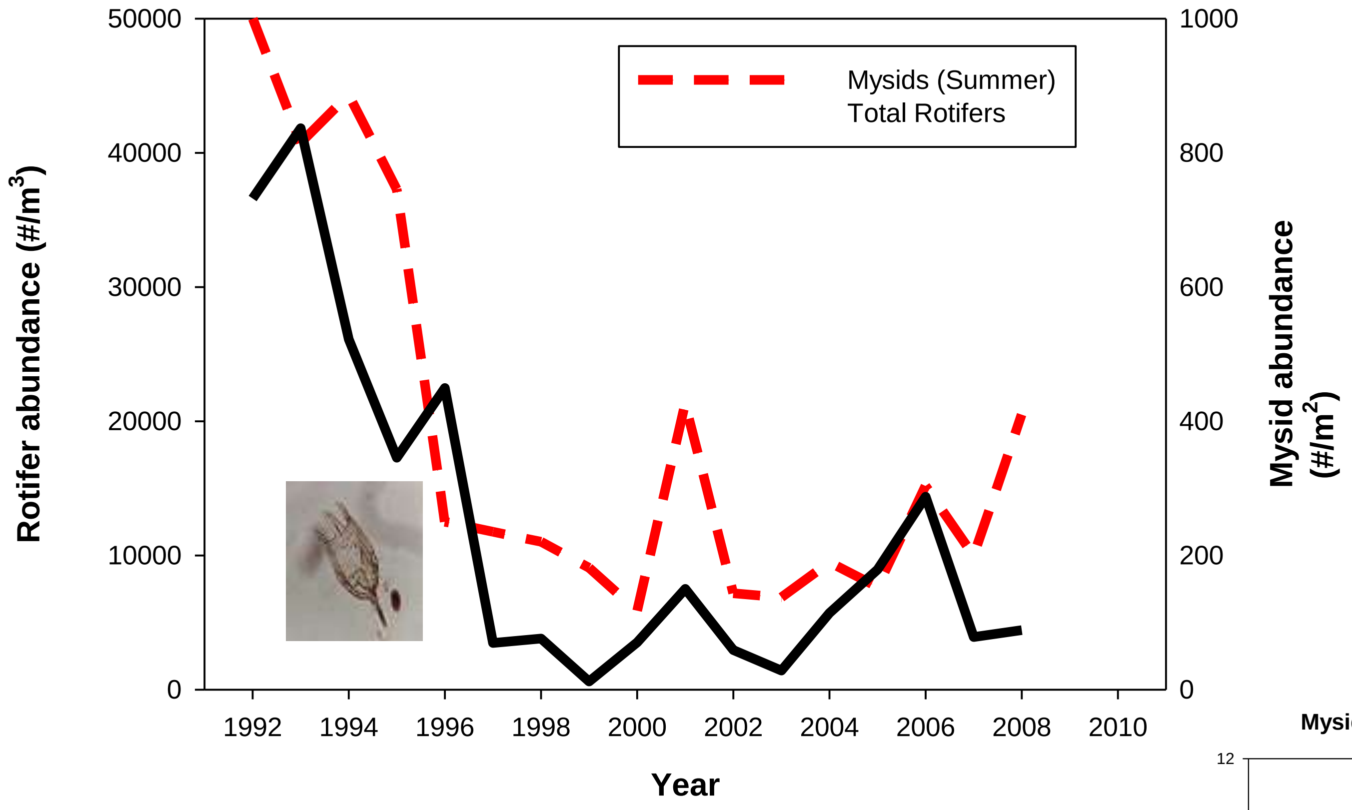




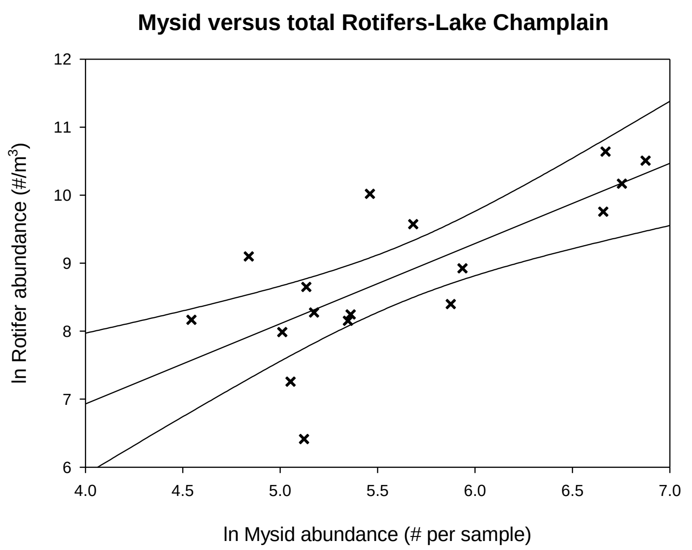




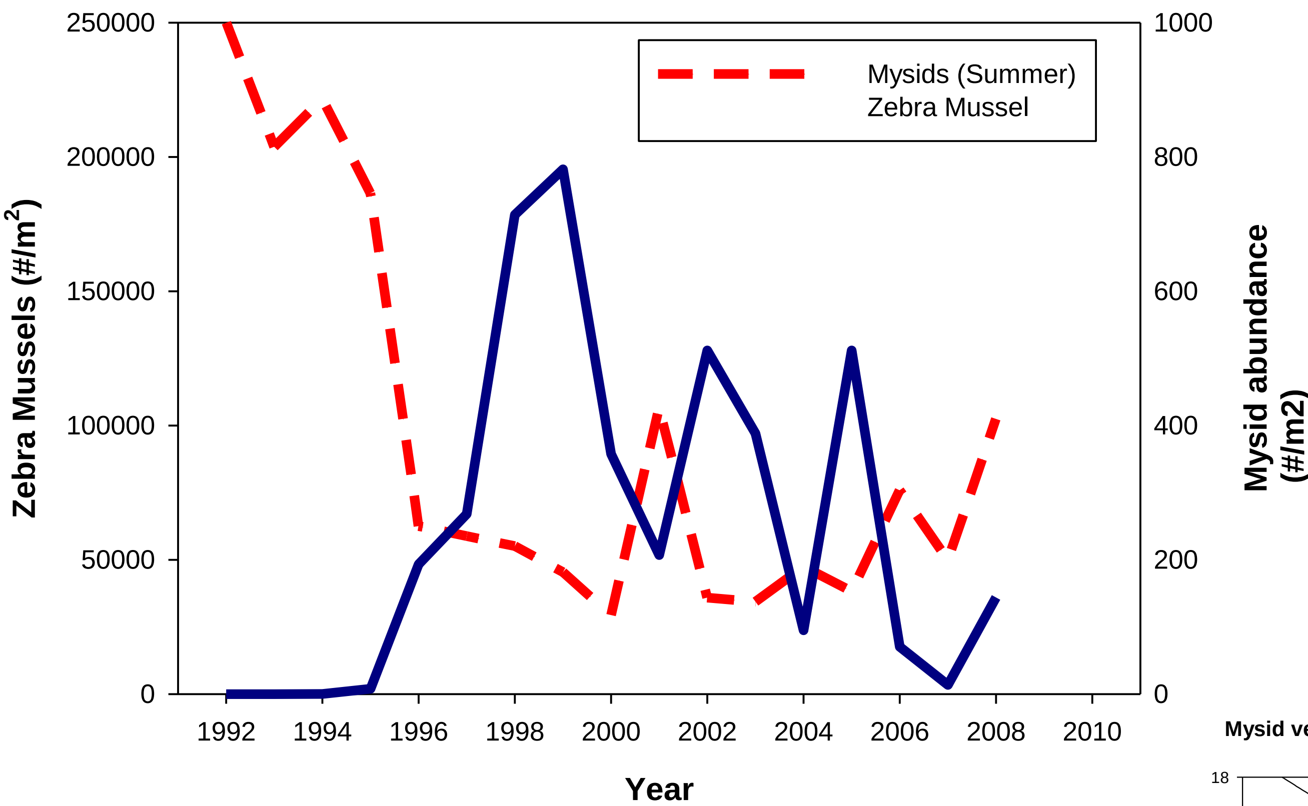
Lake Champlain Mysid long-term trends



$r^2 = 0.56$,
$p<0.001$



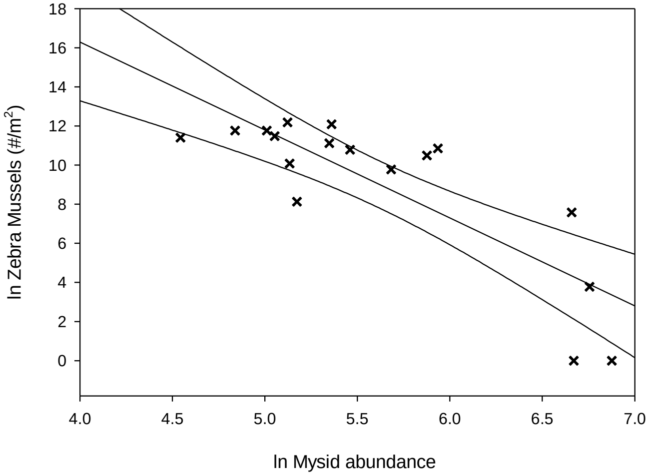
Lake Champlain Mysid long-term trends



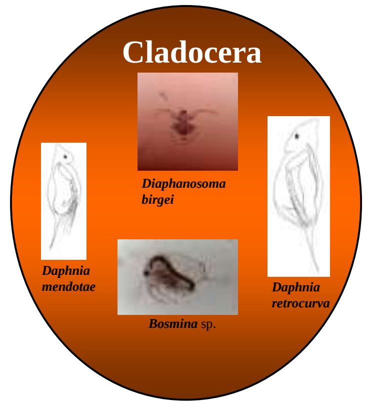
$r^2 = 0.68,$

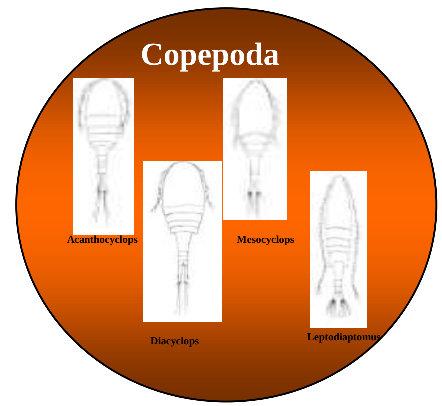
$p = <0.001$

Mysid versus zebra mussel abundance Lake Champlain



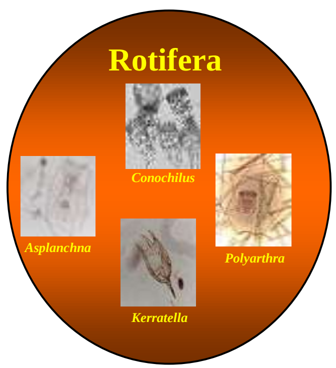
Can we model these relationships?





Trophic cascade

Filtration effect



Order of magnitude decline in abundance

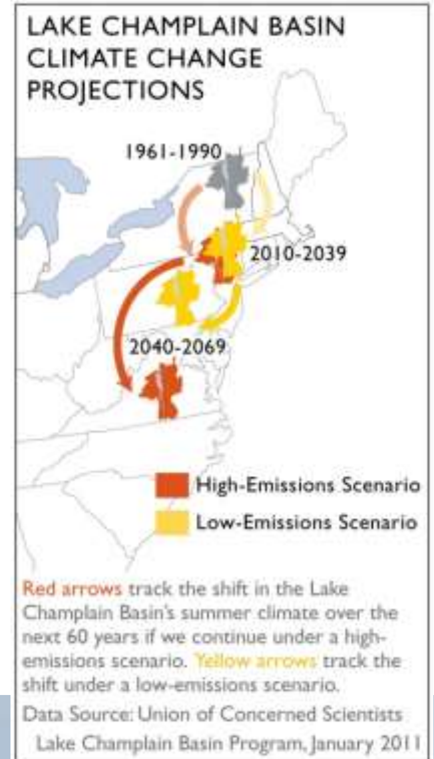
Summary

- **Long-term patterns in Lake Champlain Zooplankton-**
  - ***Zebra Mussel:*** 

    - **Rotifer declines in richness and abundance- Mid 1990s**
    - **Mysid declines correlate with ZM, Rotifer…. Patterns**

Trophic Cascade?

Does climate change influence plankton?



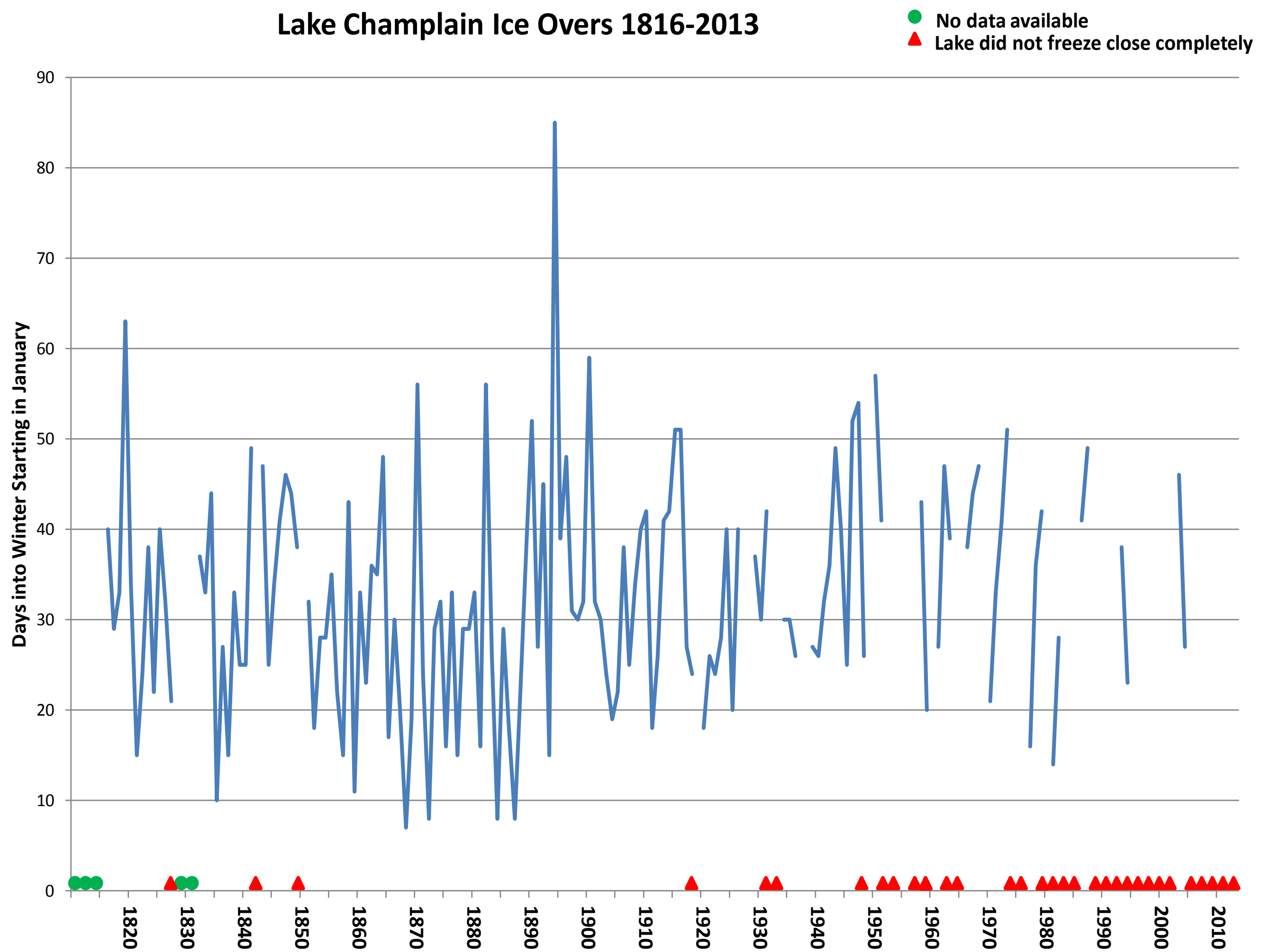


Figure 2: Lake Champlain ice over's 1816-2013. Data used in the creation of this chart was taken from NOAA. (http://www.erh.noaa.gov/btv/climo/lakeclose.shtml)

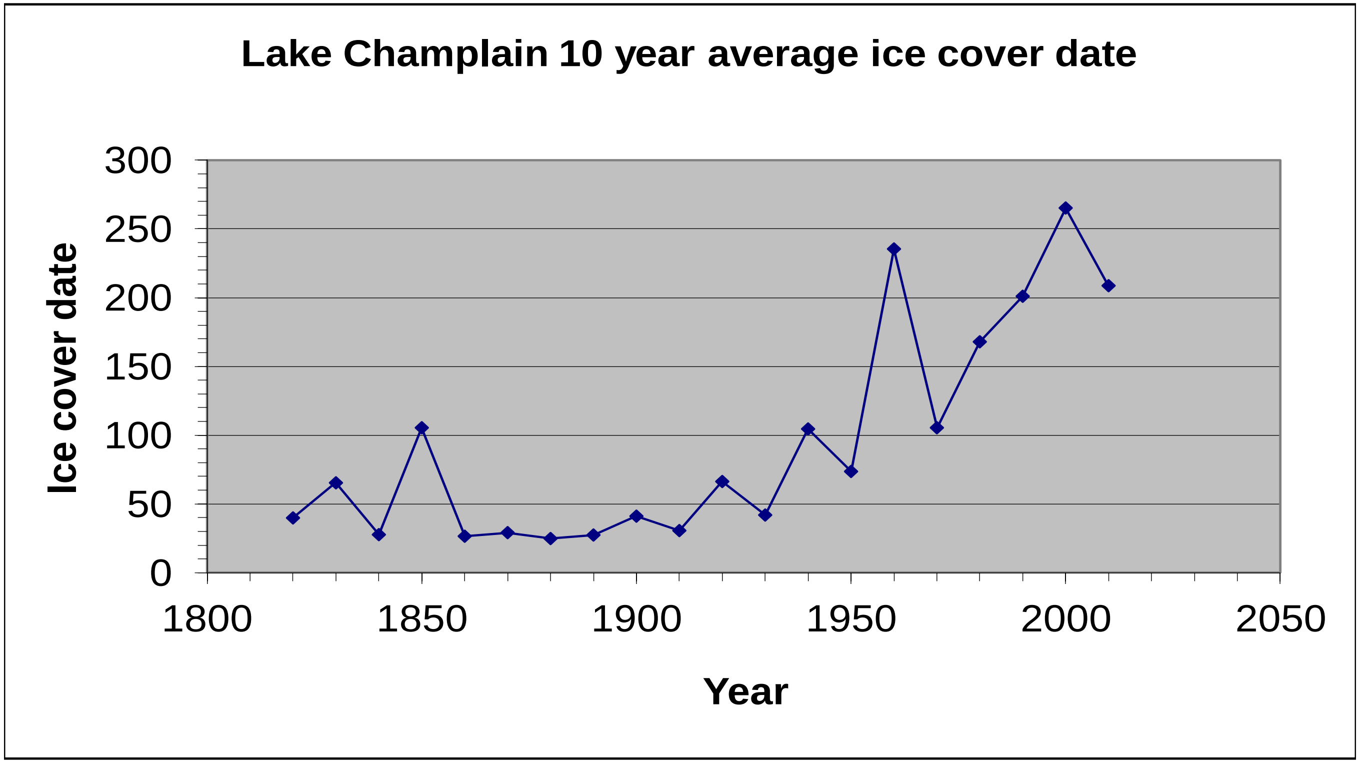
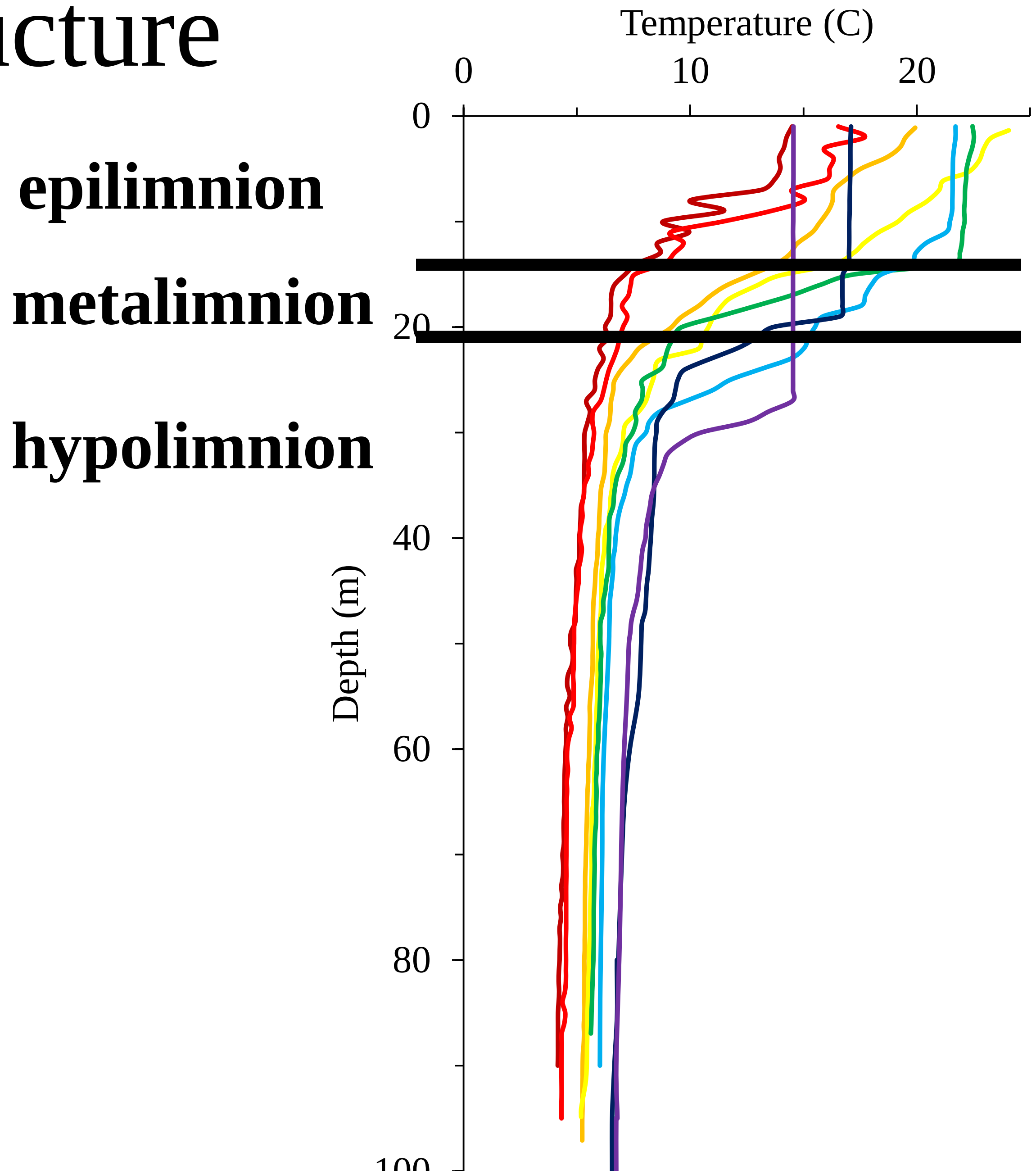
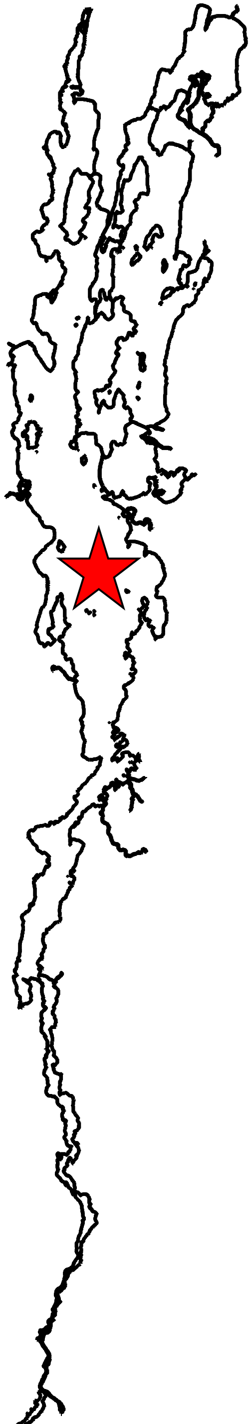
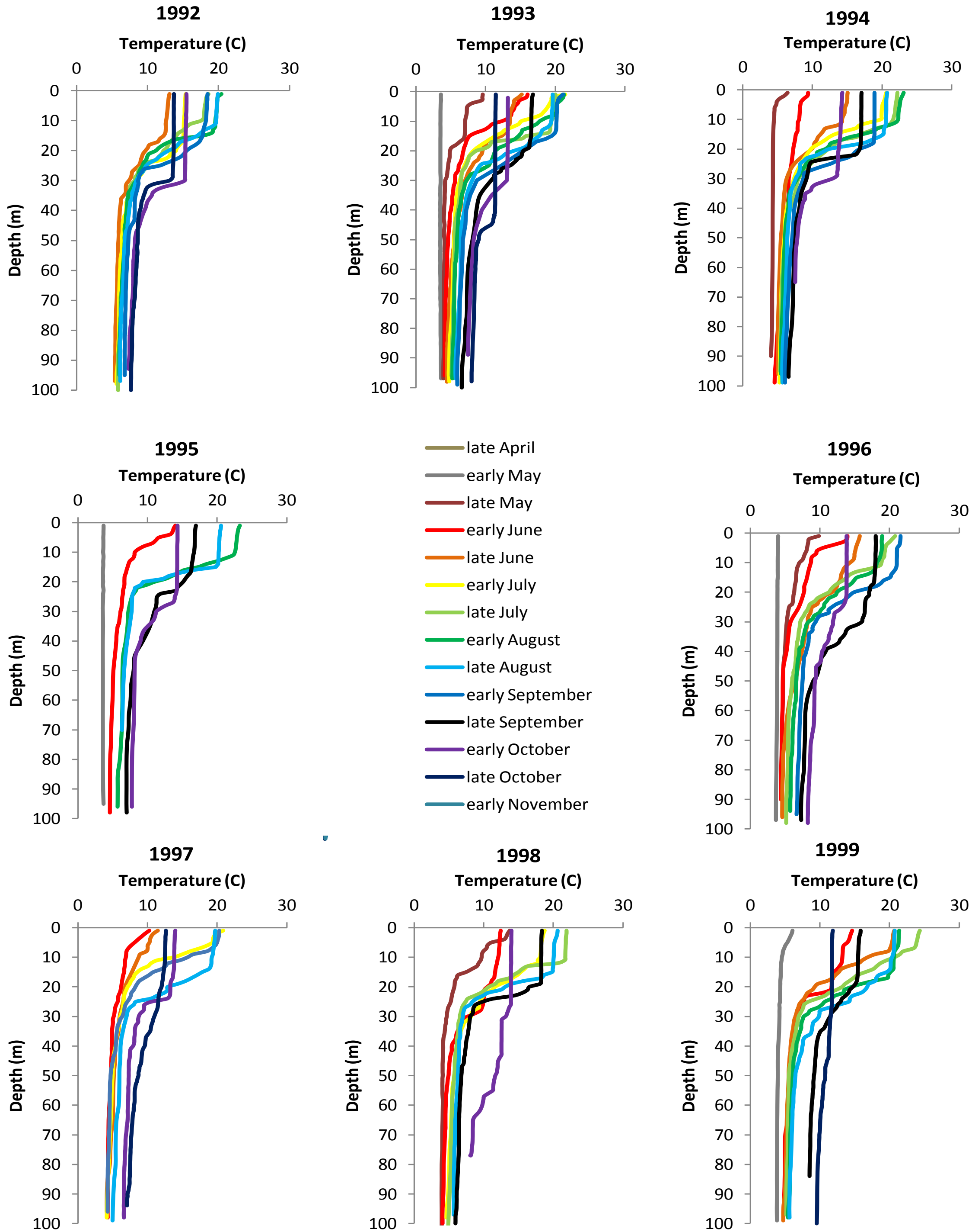


Figure 3: 10 year averages of Lake Champlain ice out data from 1816-2010. Ice out data obtained from NOAA (http://www.weather.gov/btv/lakeclose).

Thermal structure






1992
Temperature (C)
Depth (m)
1993
Temperature (C)
Depth (m)
1994
Temperature (C)
Depth (m)
1995
Temperature (C)
Depth (m)
late April
early May
late May
early June
late June
early July
late July
early August
late August
early September
late September
early October
late October
early November
1996
Temperature (C)
Depth (m)
1997
Temperature (C)
Depth (m)
1998
Temperature (C)
Depth (m)
1999
Temperature (C)
Depth (m)

Station 19

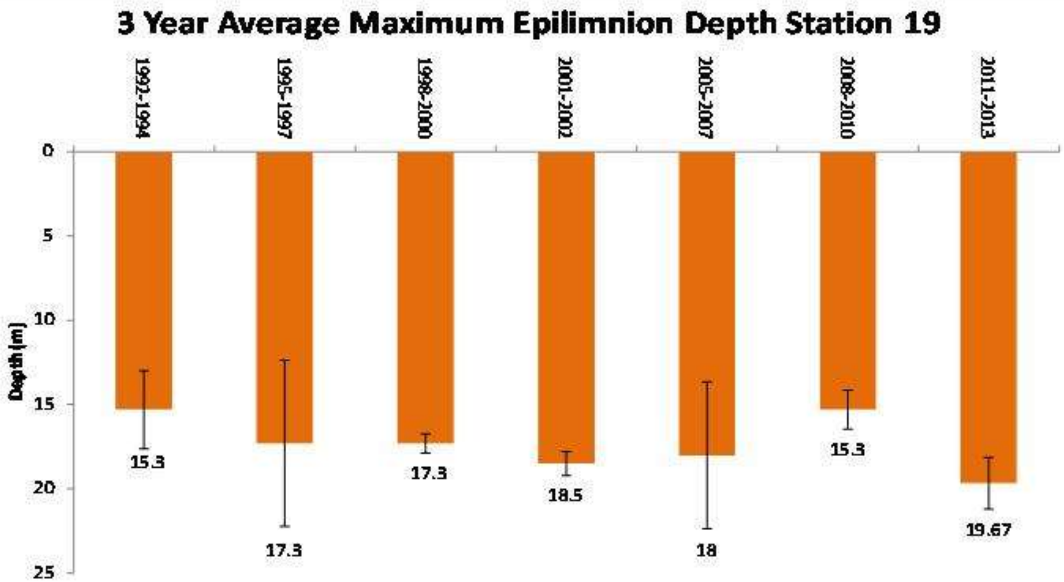


Figure 11: 3 year averages of maximum epilimnion depth at Station 19 from 1992-2013. 2003-2004 data are missing.

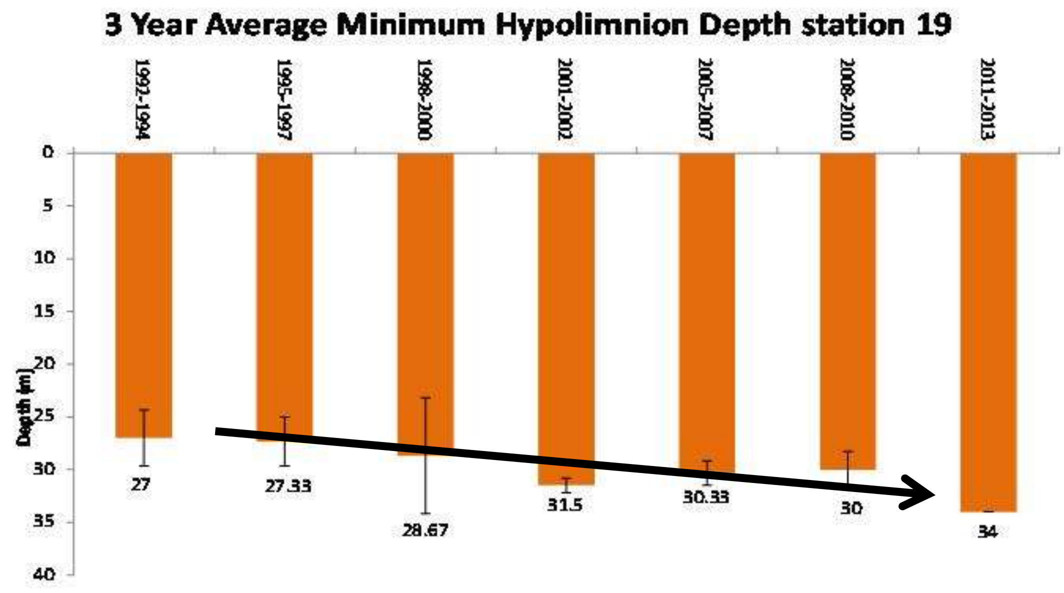
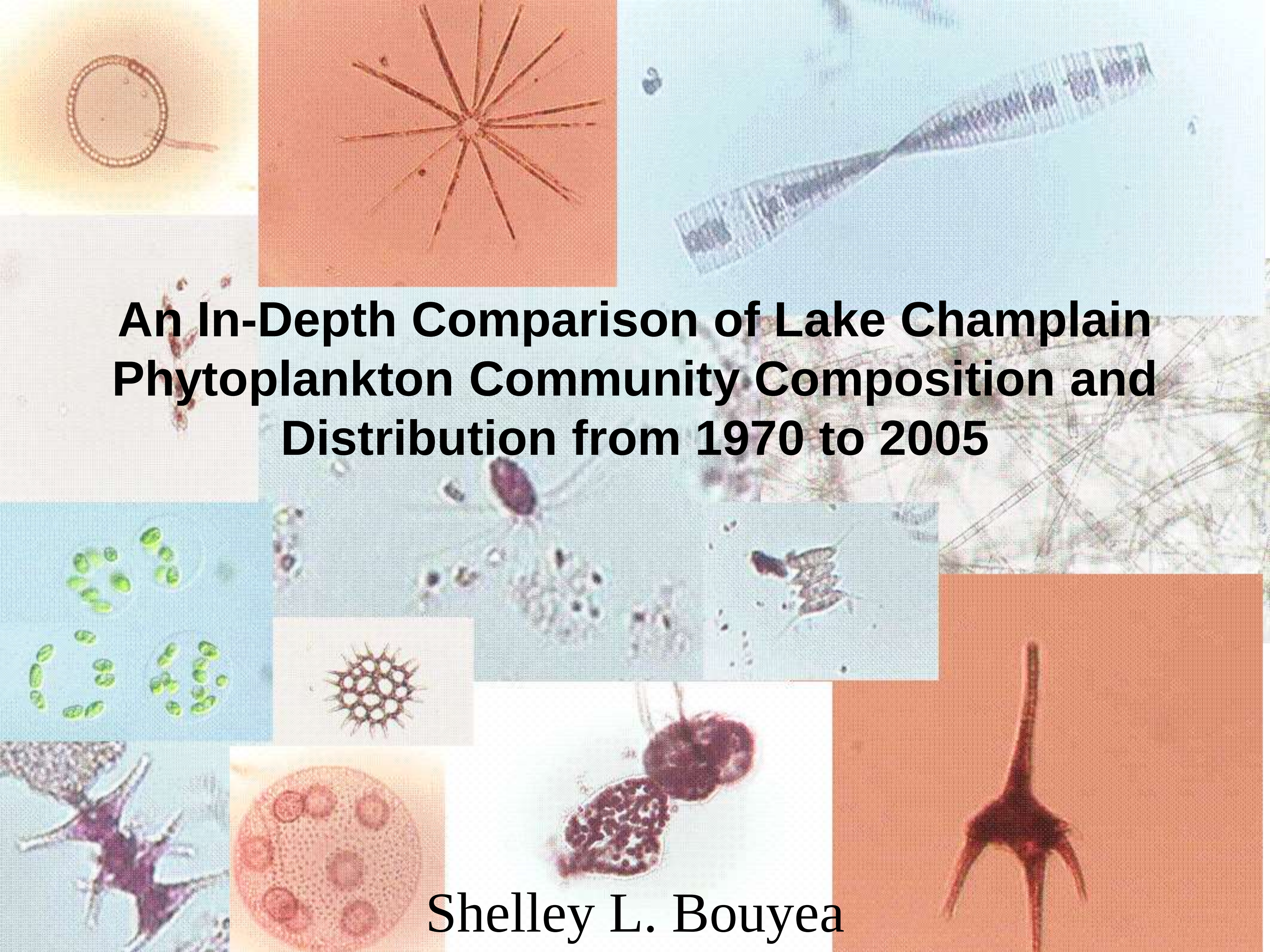


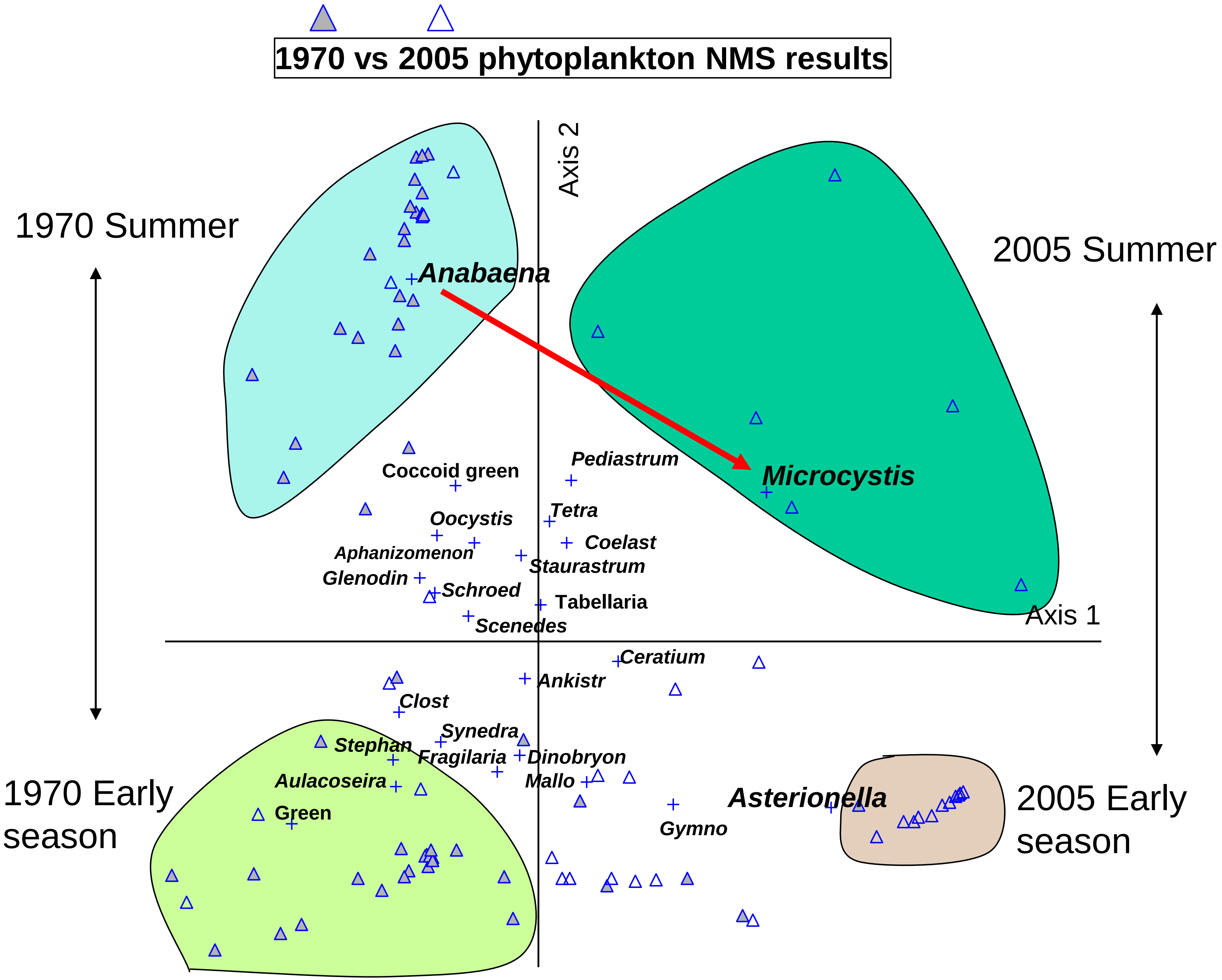
Figure 12: 3 year averages of minimum hypolimnion depth at Station 19 from 1992-2013. 2003-2004 data are missing.

An In-Depth Comparison of Lake Champlain Phytoplankton Community Composition and Distribution from 1970 to 2005



Shelley L. Bouyea

1970 vs 2005 phytoplankton NMS results



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2008, vol. **30**, Part **2**, p. 312–317, Stuttgart, April 2008
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Cyanobacteria in the sixth Great Lake: geospatial pigment mapping and phytoplankton community composition in Missisquoi Bay, Lake Champlain

Timothy B. Mihuc, Carrianne Pershyn, Sean Thomas, Greg Boyer, Mike Satchwell, Jeffry Jones, and Meghan Greene

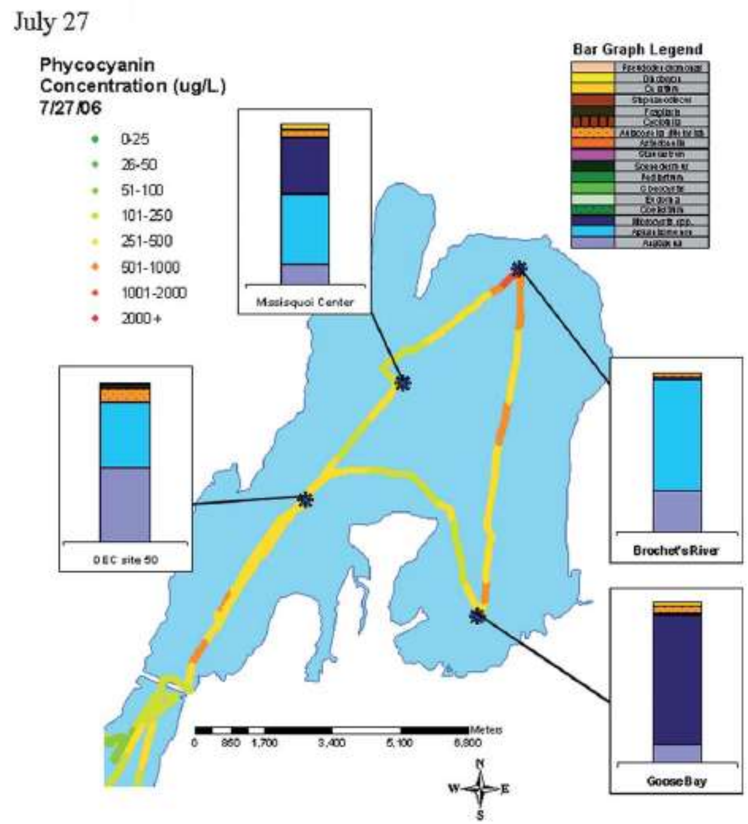
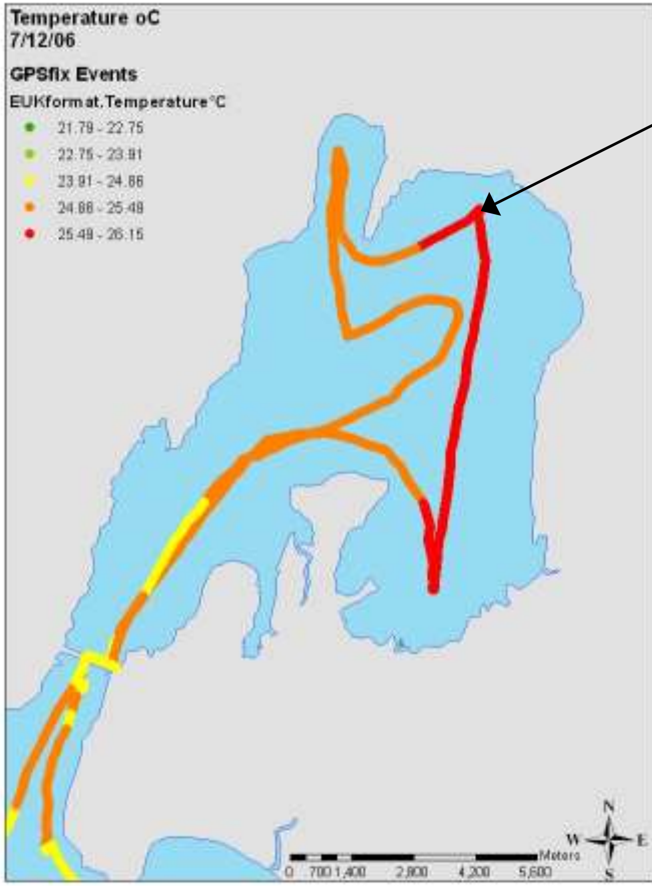
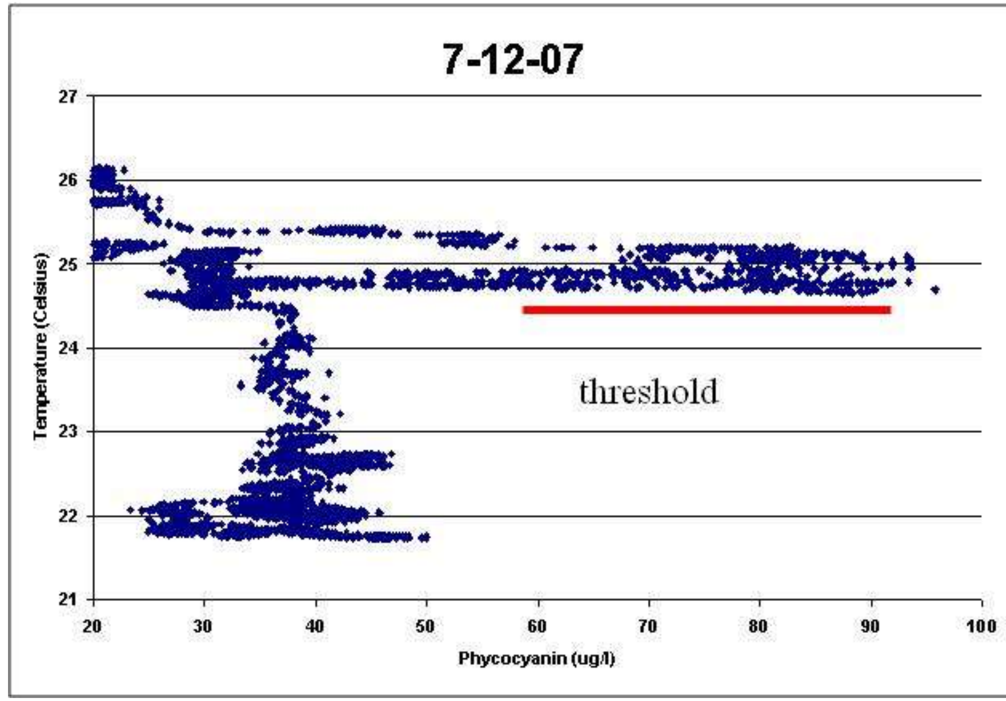


Fig. 2. Bloom map of Missisquoi Bay, Lake Champlain, for 27 July 2006. Phycocyanin concentration (µg/L) is shown along the mapping track with phytoplankton community composition (% composition) at selected locations in the inset graphs. Bar graph legend indicates (from top to bottom) protozoa (entries 1–3), diatoms (entries 4–8; brown-yellow shading), desmids (Staurastrum, pink), green algae (entries 10–14; green shades), and Cyanobacteria (last 3 entries; blue shading).





- **Species composition for all sites in Missisquoi Bay was dominated by diatoms, namely Aulacoseira.**
- ***Microcystis spp.* and *Aphanizomenon spp.* were present in low abundance at Venise Bay, QC and Brochet's River, QC, which may be attributed to the higher water temperatures in that part of the bay on this date**
- **A temperature threshold may exist for large bloom formation.**

Harmful Algae 8 (2009) 715–725

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journal homepage: www.elsevier.com/locate/hal

The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of *Microcystis* during cyanobacteria blooms

Timothy W. Davis [a], Dianna L. Berry [a], Gregory L. Boyer [b], Christopher J. Gobler [a,*]

[a] School of Marine and Atmospheric Sciences, Stony Brook University, Southampton, NY, United States
[b] Chemistry Department, State University of New York, College of Environmental Science and Forestry, Syracuse, NY, United States

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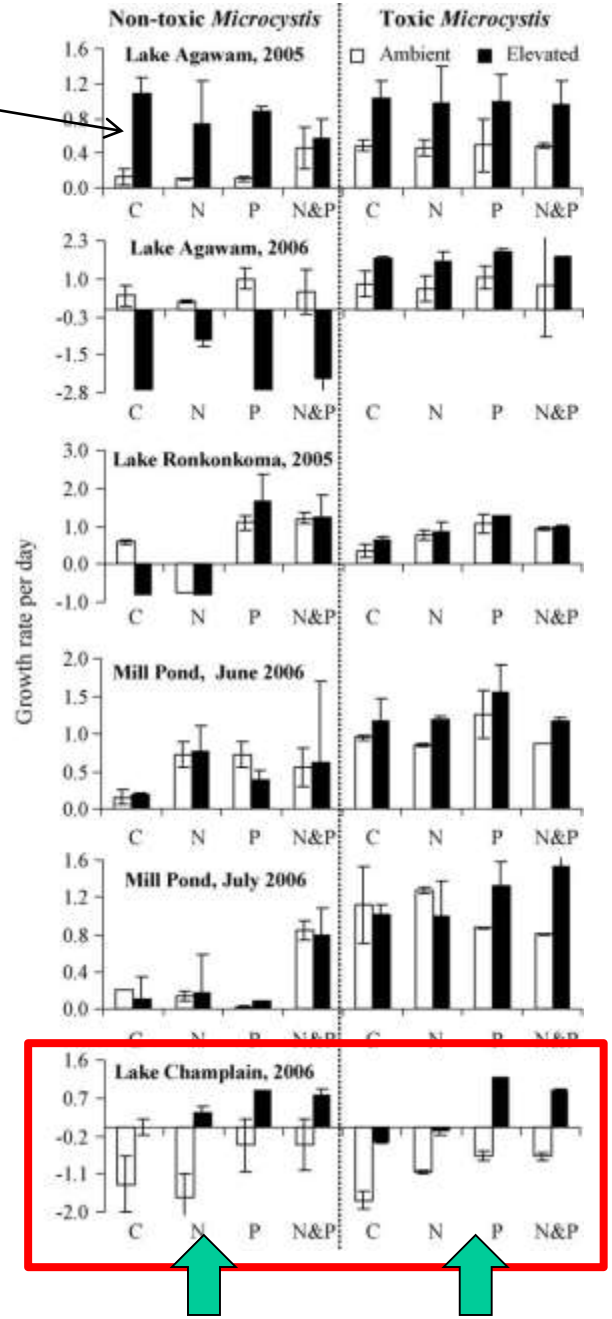
ABSTRACT

In temperate latitudes, toxic cyanobacteria blooms often occur in eutrophied ecosystems during warm months. Many common bloom-forming cyanobacteria have toxic and non-toxic strains which co-occur and are visually indistinguishable but can be quantified molecularly. Toxic *Microcystis* cells possess a suite of microcystin synthesis genes (*mcyA–mcyJ*), while non-toxic strains do not. For this study, we assessed the temporal dynamics of toxic and non-toxic strains of *Microcystis* by quantifying the microcystin synthetase gene (*mcyD*) and the small subunit ribosomal RNA gene, 16S (an indicator of total *Microcystis*), from samples collected from four lakes across the Northeast US over a two-year period. Nutrient concentrations and water quality were measured and experiments were conducted which examined the effects of elevated levels of temperatures (+4 °C), nitrogen, and phosphorus on the growth rates of toxic and non-toxic strains of *Microcystis*. During the study, toxic *Microcystis* cells comprised between 12% and 100% of the total *Microcystis* population in Lake Ronkonkoma, NY, and between 0.01% and 6% in three other systems. In all lakes, molecular quantification of toxic (*mcyD*-possessing) *Microcystis* was a better predictor of *in situ* microcystin levels than total cyanobacteria, total *Microcystis*, chlorophyll *a*, or other factors, being significantly correlated with the toxin in every lake studied. Experimentally enhanced temperatures yielded significantly increased growth rates of toxic *Microcystis* in 83% of experiments conducted, but did so for non-toxic *Microcystis* in only 33% of experiments, suggesting that elevated temperatures yield more toxic *Microcystis* cells and/or cells with more *mcyD* copies per cell, with either scenario potentially yielding more toxic blooms. Furthermore, concurrent increases in temperature and P concentrations yielded the highest growth rates of toxic *Microcystis* cells in most experiments suggesting that future eutrophication and climatic warming may additively promote the growth of toxic, rather than non-toxic, populations of *Microcystis*, leading to blooms with higher microcystin content.

Elevated temperature



Non-toxic Toxic

Fig. 6. Net growth rates of toxic Microcystis (right half of figure) and nontoxic Microcystis (left half of figure) during nutrient amendment experiments (t = 72 h) conducted in various systems during the 2005 and 2006 field seasons at ambient (white bars) and elevated (black bars) temperatures. C: control; N: nitrate; P: rthophosphate. Error bars represent 1 SD of triplicate experimental bottles.

Davis et al. 2009

"During the Lake Champlain experiment, ambient water temperatures were 24.9 2.0 8C. Experimentally enhanced temperatures (29.1 1.3 8C) significantly increased the growth rates of both toxic and non-toxic Microcystis populations by 80% and 101% respectively ($p < 0.001$; Table 3; Fig. 6)."

"Finally, nutrients (N or P) interacted with temperature, to enhance toxic Microcystis growth rates ($p < 0.01$; Table 3; Fig. 6) with the enhanced P and temperature treatment yielding the highest growth rates of any population among all treatments (1.17 0.03 d1)."

What do we know?

- Invasive species (Zebra mussel) impact planktonic communities
- Some trends (shifts in phytoplankton) may be linked to climate change.
- Water quality variables do not explain long-term patterns in the Lake's zooplankton

Lake Champlain zooplankton community dynamics following an extreme flood event

Erin Hayes-Pontius
M.S. Natural Science
research thesis
SUNY Plattsburgh

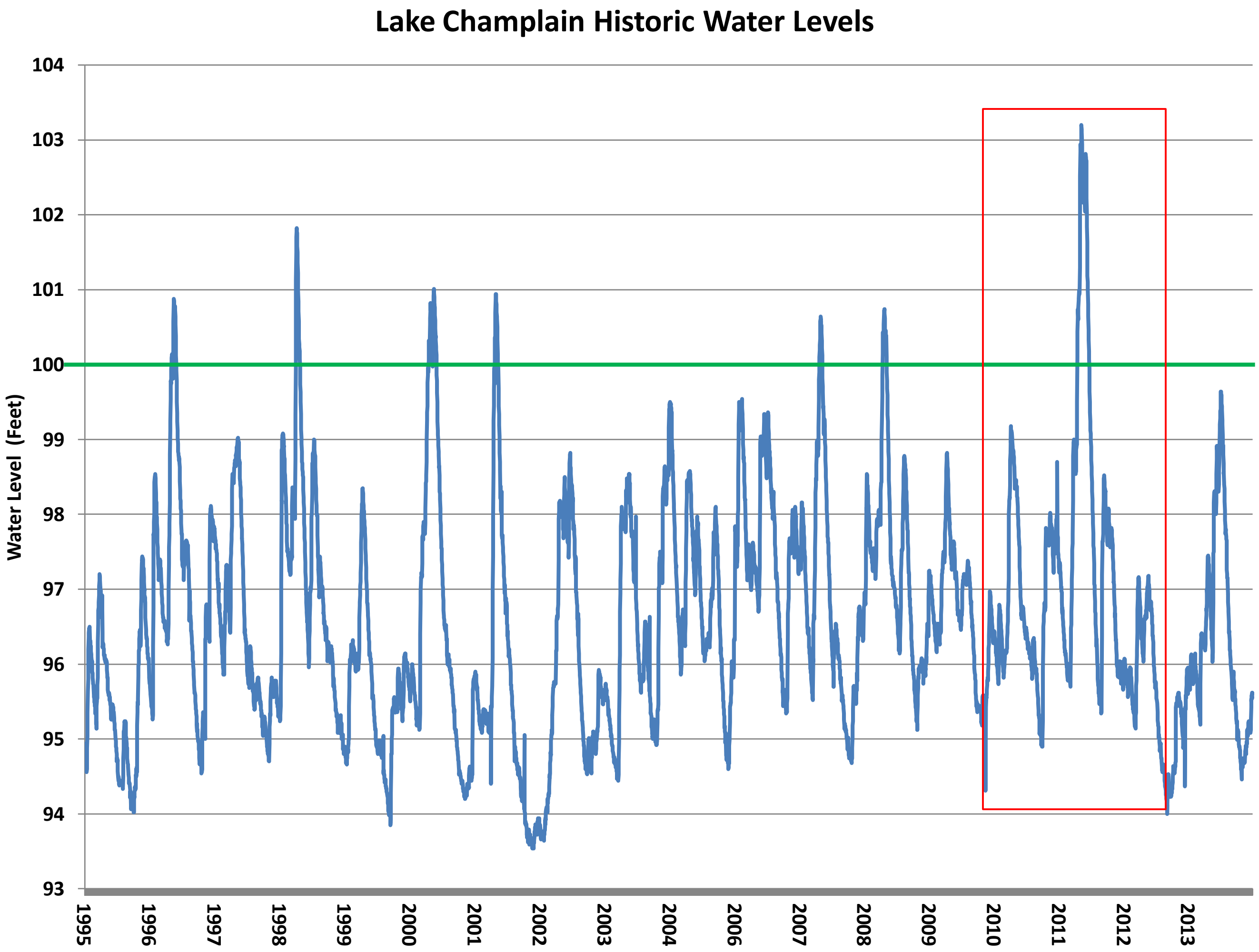
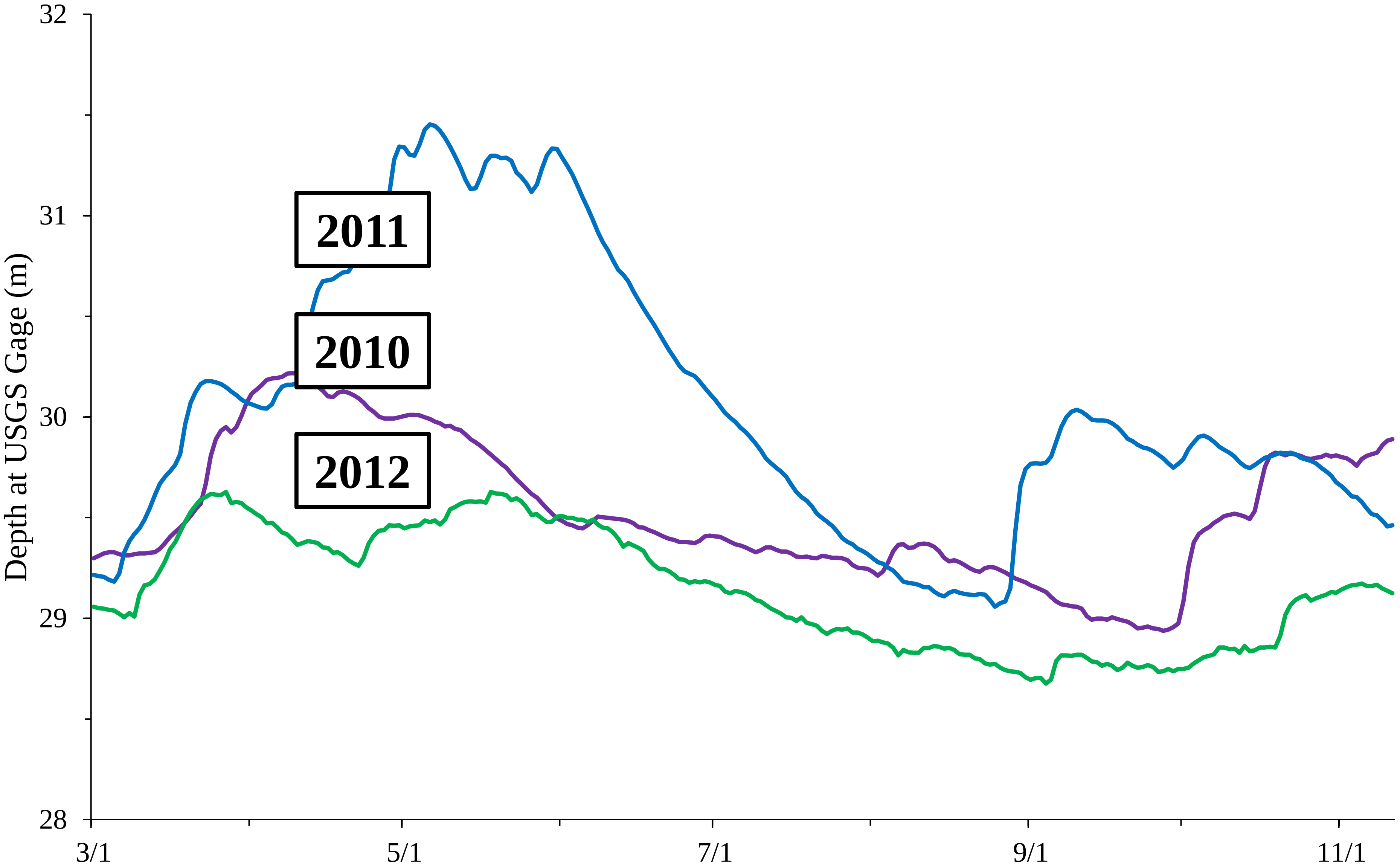


Figure 1: Lake Champlain historic water levels 1995-2013. The green line represents the national weather service flood level. Data used in the creation of this chart was taken from NOAA. (http://www.erh.noaa.gov/btv/html/lake.php)

Intro- lake depth



Sediment plumes

These photos are from the Lake Champlain Basin Program

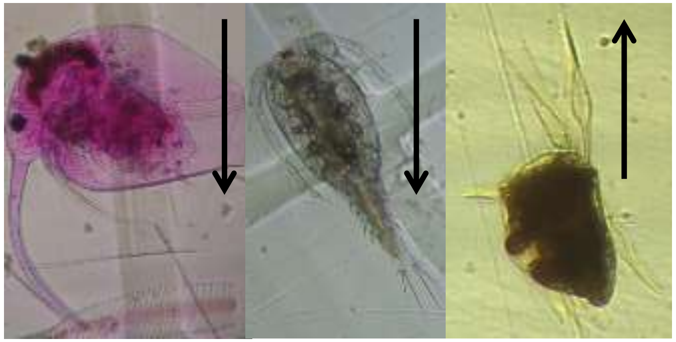
The flooding

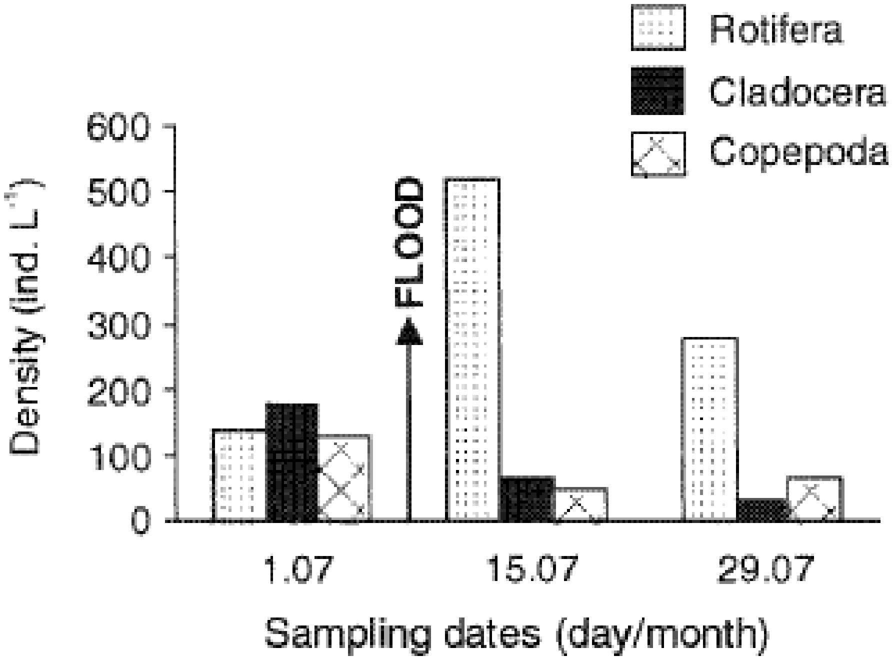
- Lack of literature from large lakes

- What happens?

Flood responses

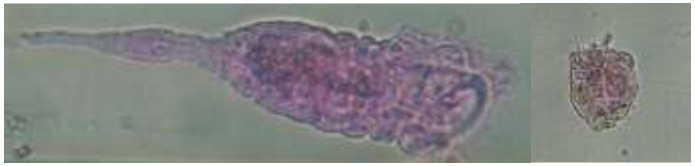
- Overall decreases in density
- Some groups may benefit



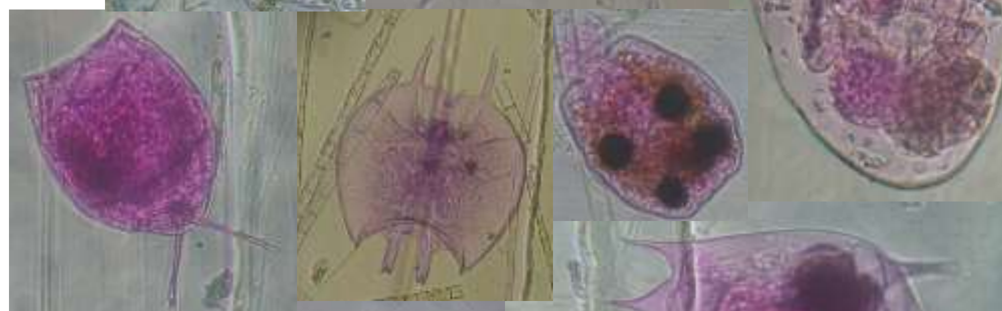


Godlewska et al. 2003

Flood responses

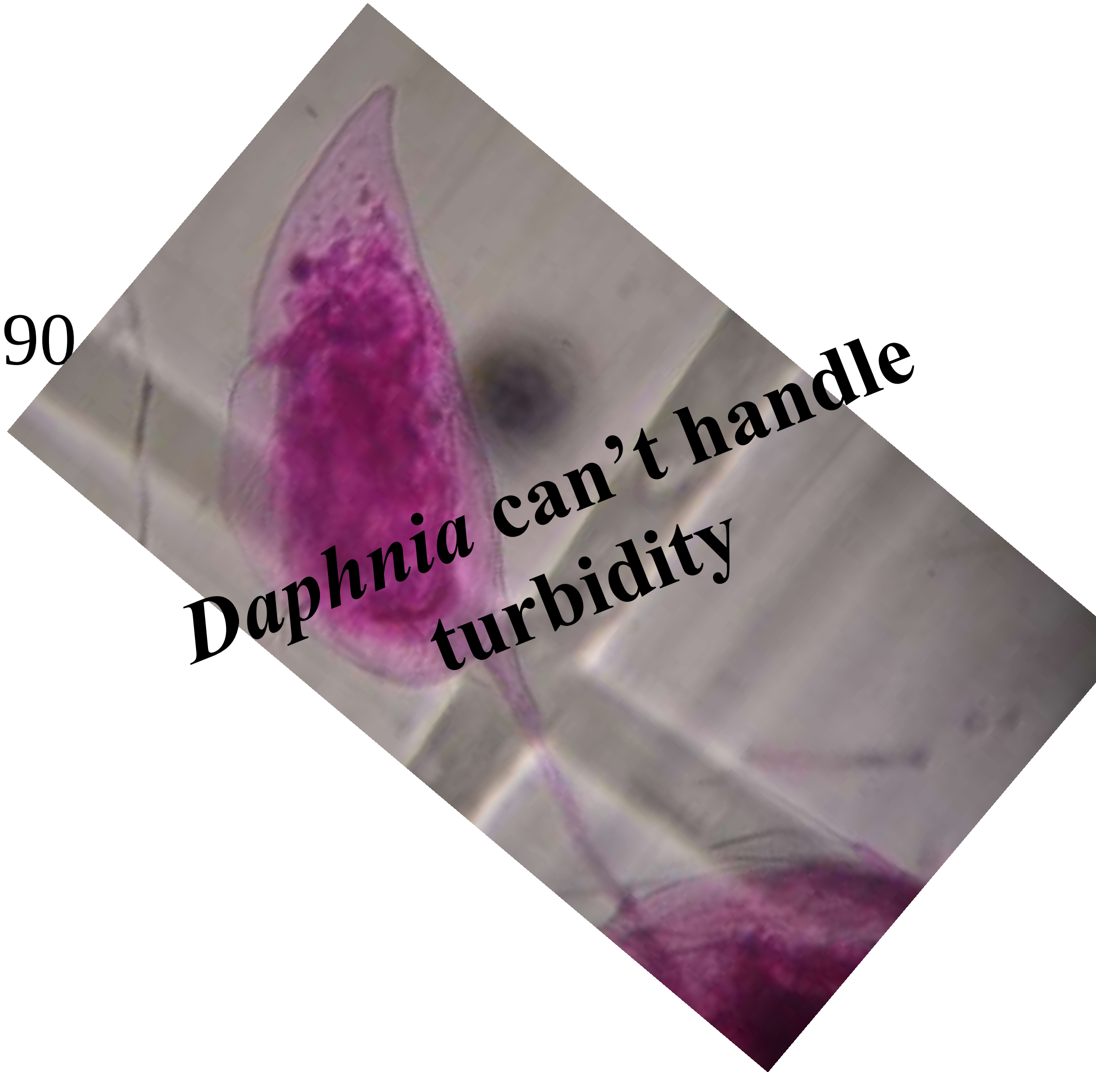


- Not everyone agrees
  - Rotifers increase in density
    - Kirk and Gilbert 1990
    - Godlewska et al. 2003
  - Rotifers do not respond
    - Pollard et al. 1998

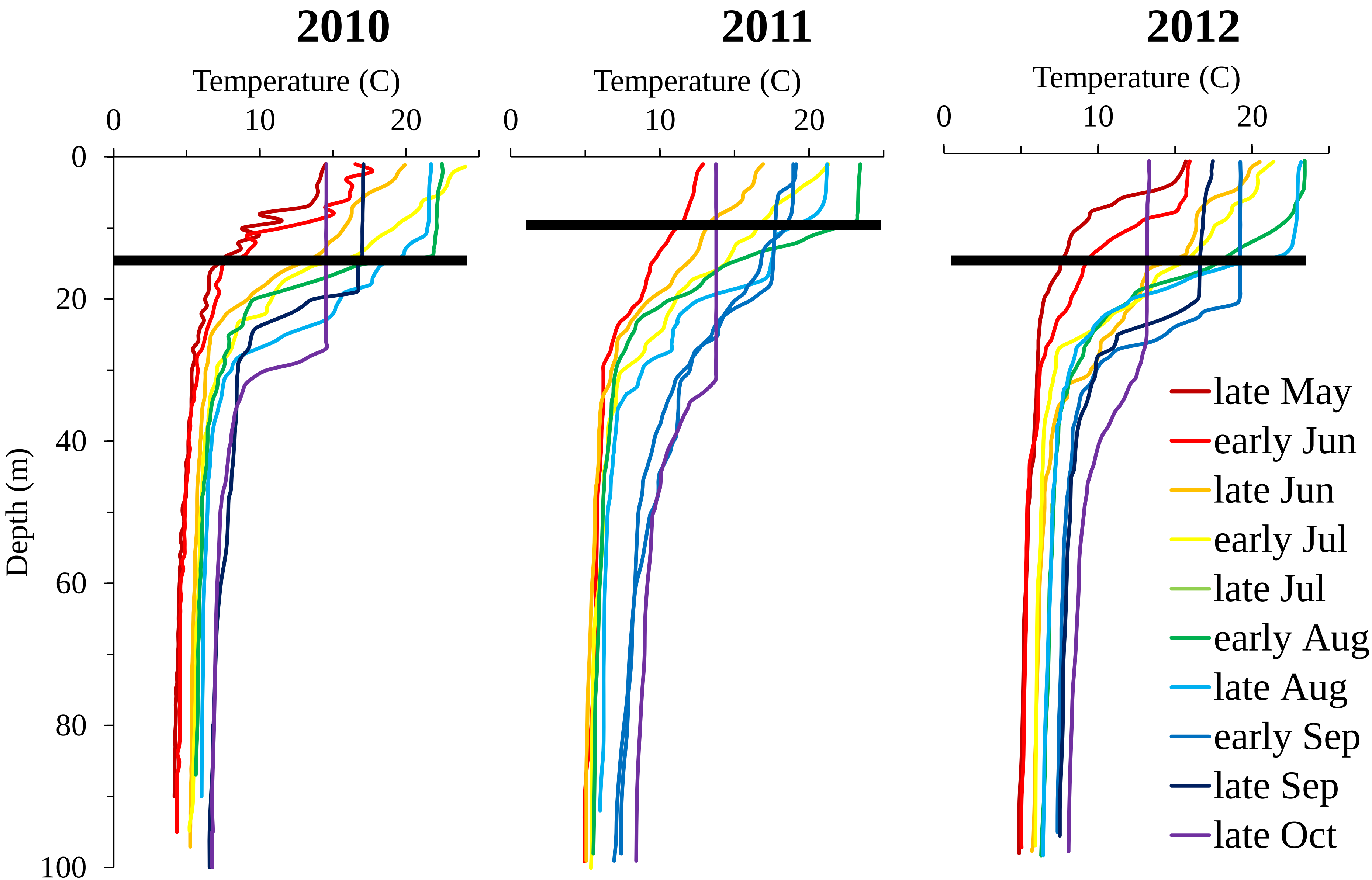



Flood responses

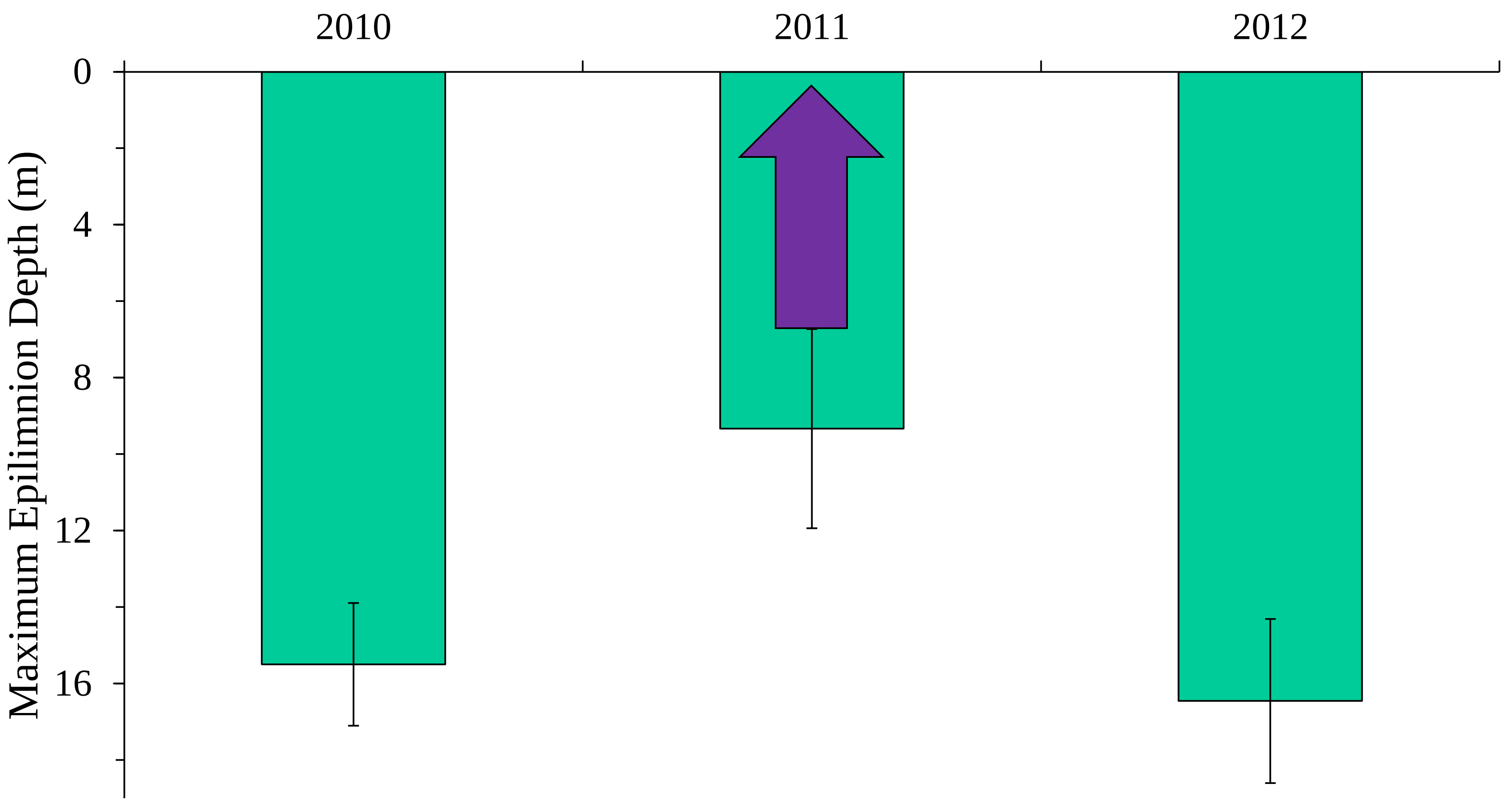
- Everyone agrees…
  - Arruda et al. 1983
  - Hart 1986
  - Threlkeld 1986
  - Kirk and Gilbert 1990
  - Dejen et al. 2004
  - Schou et al. 2009



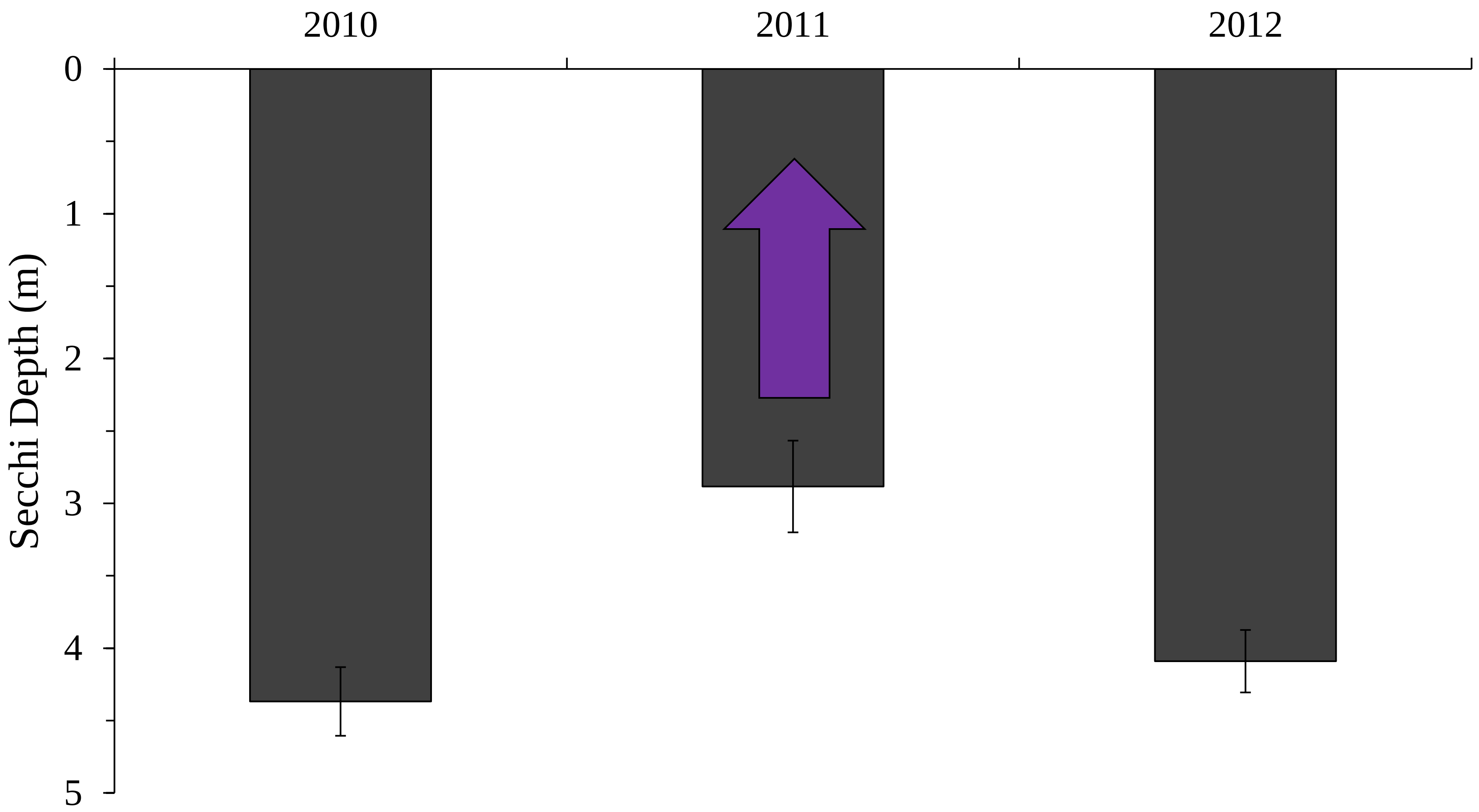
Results- vertical profiles



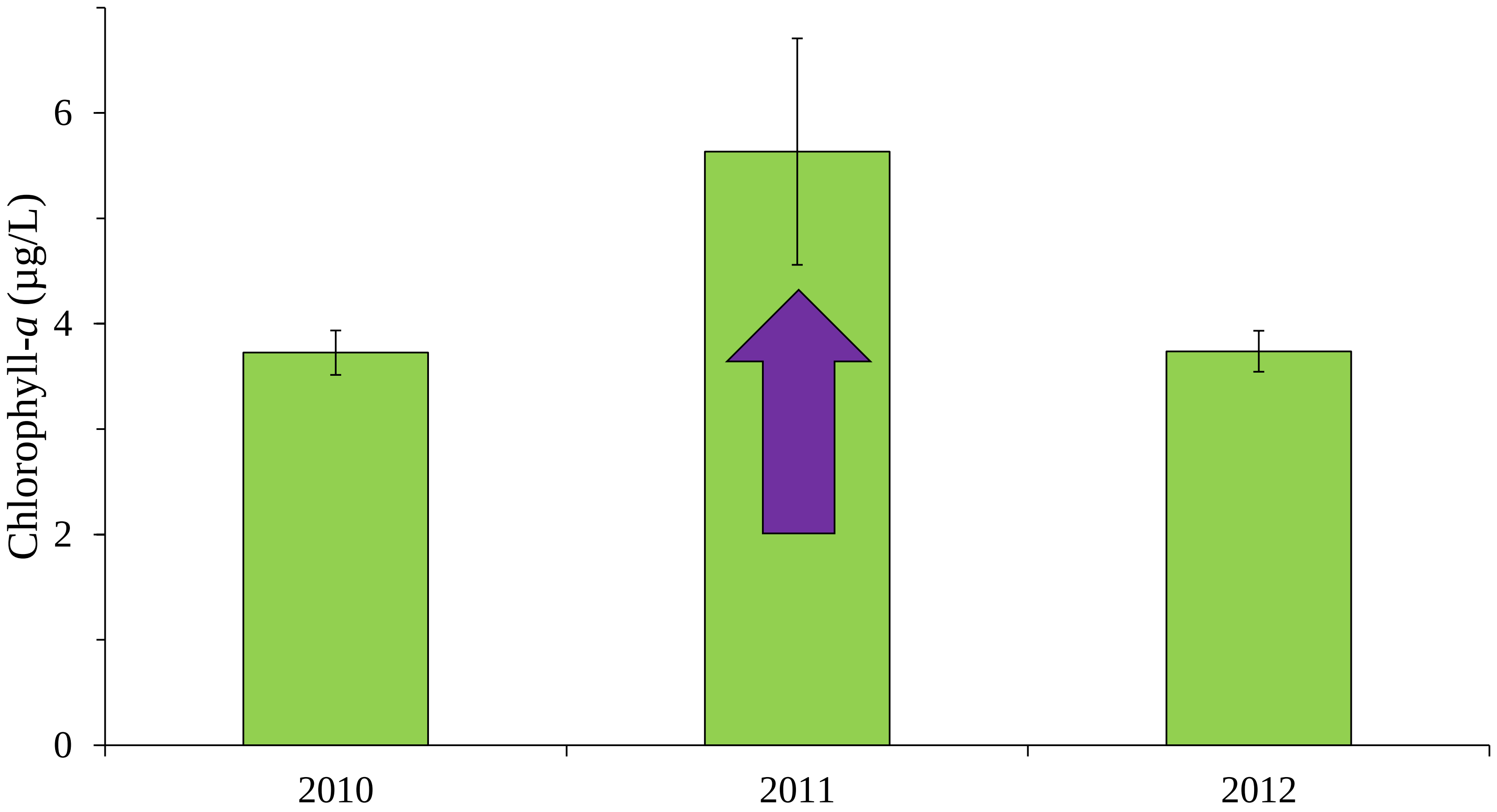
Results- thermal structure



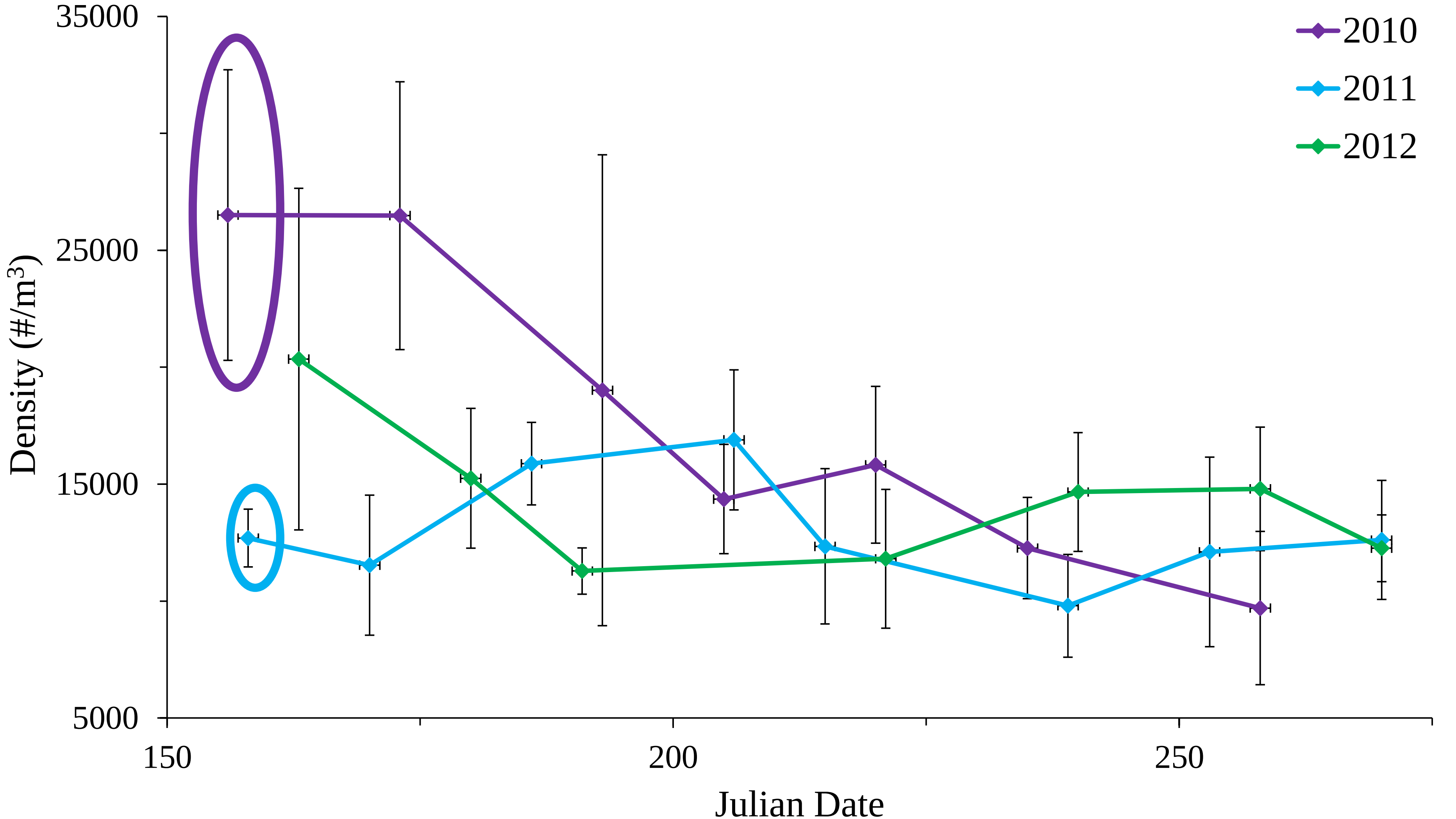
Results- Secchi depth



Results- chlorophyll-*a* concentrations



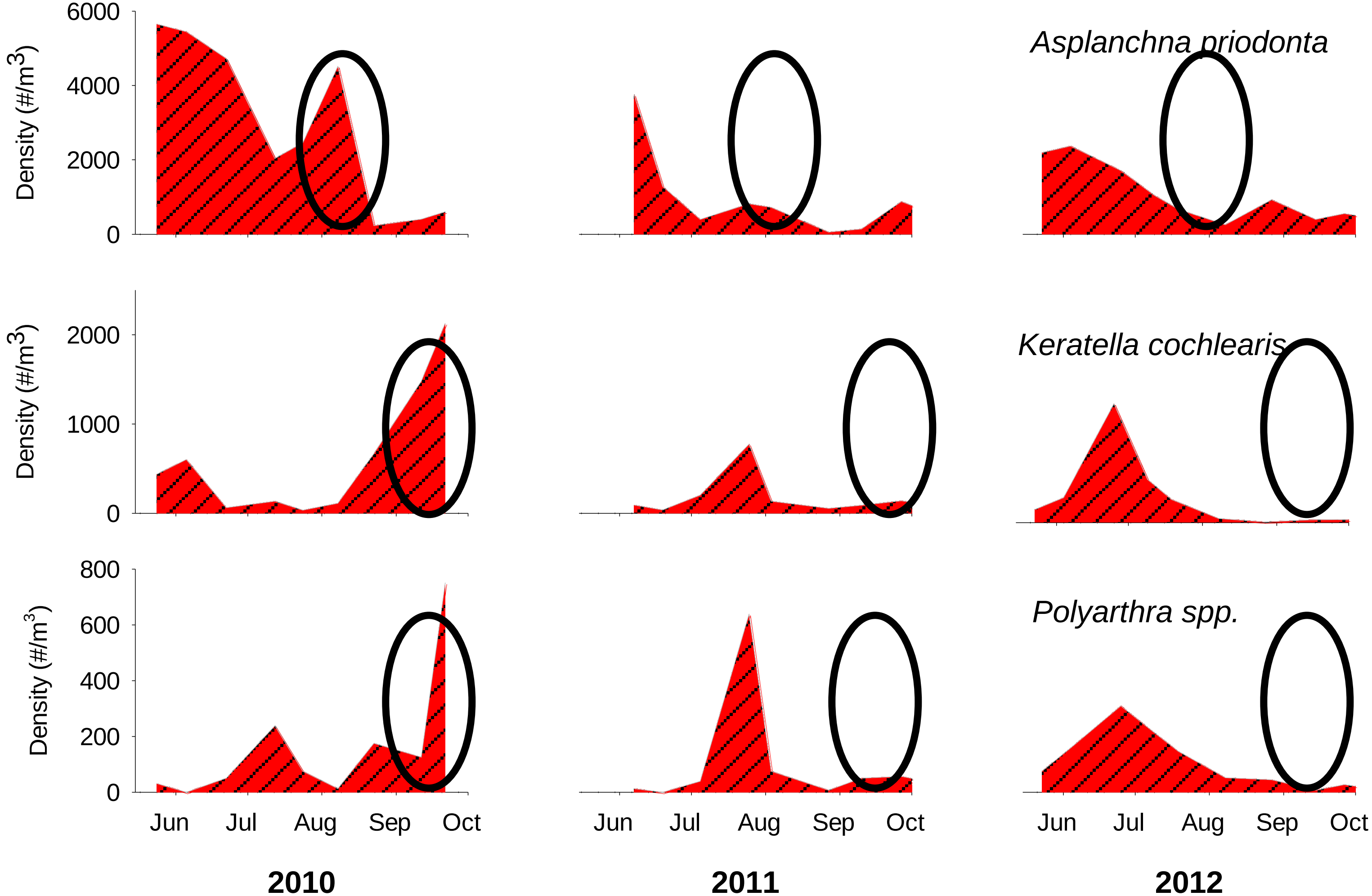
Results- total zooplankton density



Types of responses
Immediate and lasting negative response

Category	**Taxon**	**Response**	**2010**	**2011**	**2012**
Asplanchnid rotifer	*Asplanchna priodonta*	Immediate and lasting disadvantage	^	v	v
Brachionid rotifer	*Keratella cochlearis*		^	v	v
Synchaetid rotifer	*Polyarthra spp.*		^	v	v
Daphnid cladoceran	*Daphnia retrocurva*	Delayed disadvantage	^	^	v
Calanoid copepod	Diaptomidae		^	^	v
Cyclopoid copepod	*Mesocyclops edax*		>	^	v
Conochilid rotifer	*Conochilus unicornis*	Immediate disadvantage	^	v	^
Synchaetid rotifer	*Ploesoma spp.*		^	v	^
Daphnid cladoceran	*Ceriodaphnia reticulata*	Delayed advantage	v	v	^
Bosminid cladoceran	*Eubosmina coregoni*		v	v	^
Cyclopoid copepod	*Tropocyclops prasinus mexicanus*		>	v	^

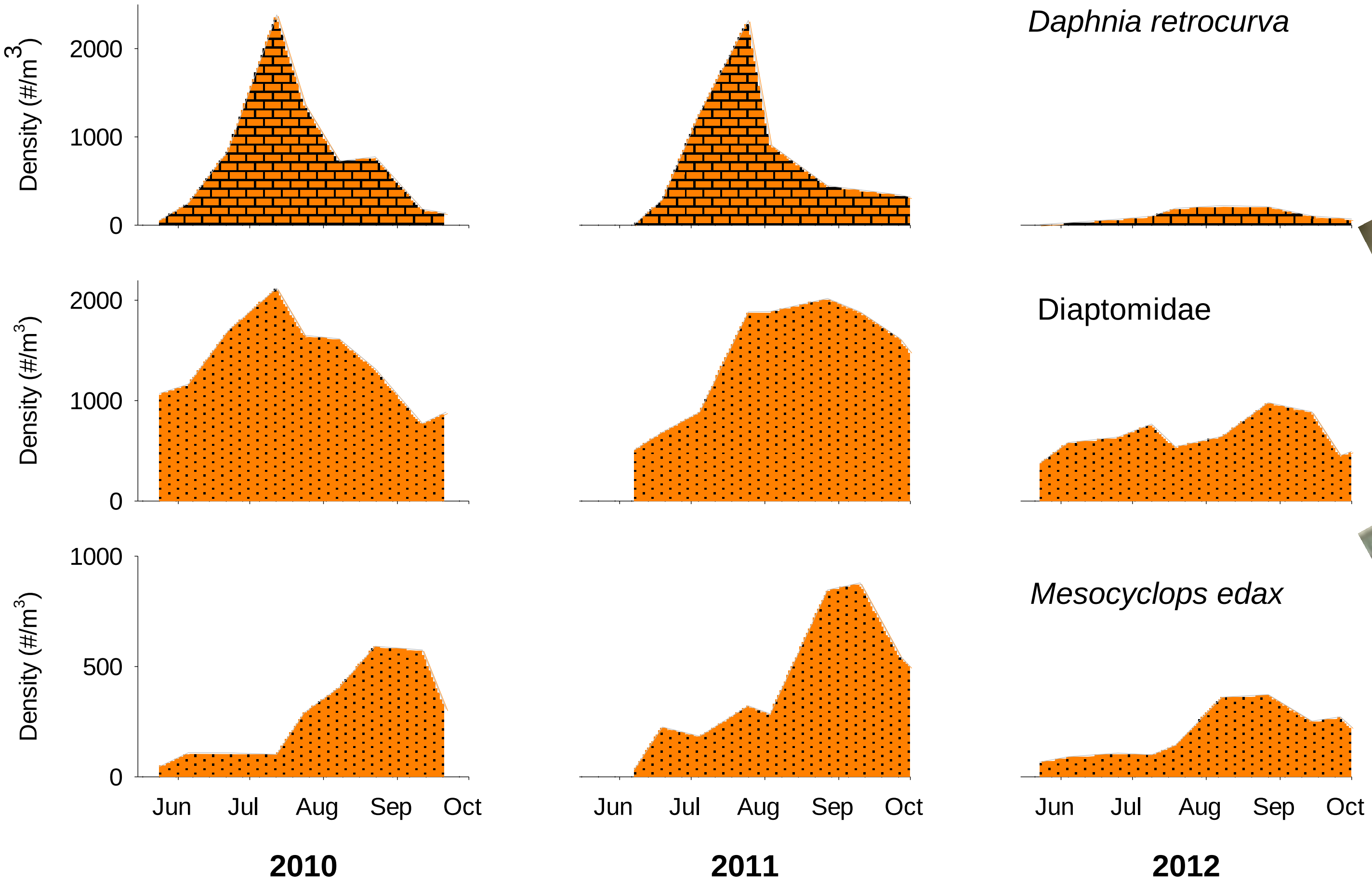
Immediate and lasting negative response



Delayed negative response

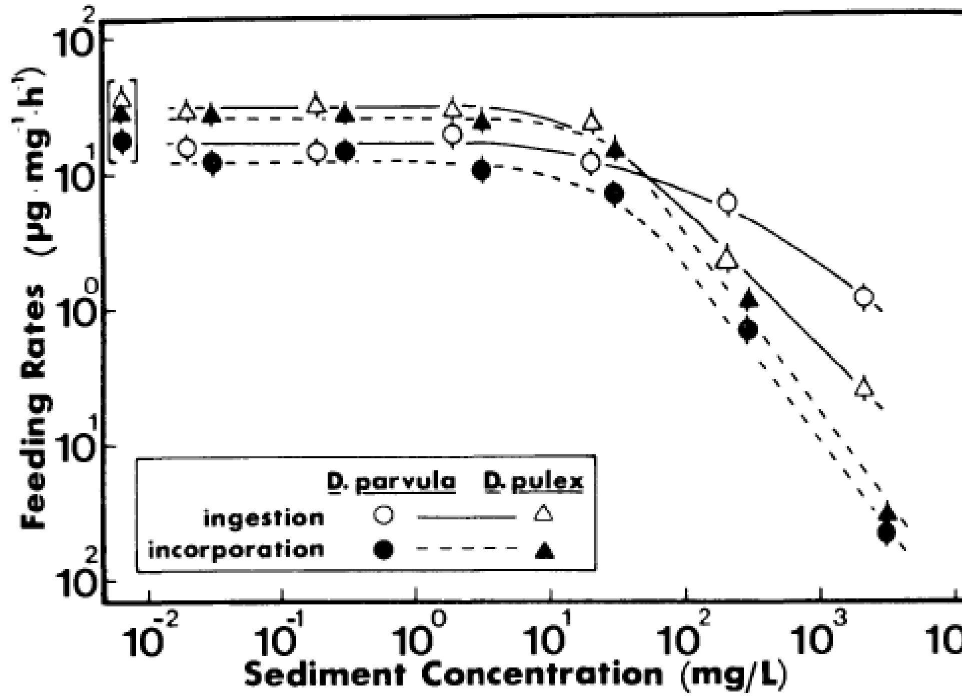
Category	**Taxon**	**Response**	**2010**	**2011**	**2012**
Asplanchnid rotifer	*Asplanchna priodonta*	Immediate and lasting disadvantage	^	v	v
Brachionid rotifer	*Keratella cochlearis*		^	v	v
Synchaetid rotifer	*Polyarthra spp.*		^	v	v
Daphnid cladoceran	*Daphnia retrocurva*	Delayed disadvantage	^	^	v
Calanoid copepod	Diaptomidae		^	^	v
Cyclopoid copepod	*Mesocyclops edax*		>	^	v
Conochilid rotifer	*Conochilus unicornis*	Immediate disadvantage	^	v	^
Synchaetid rotifer	*Ploesoma spp.*		^	v	^
Daphnid cladoceran	*Ceriodaphnia reticulata*	Delayed advantage	v	v	^
Bosminid cladoceran	*Eubosmina coregoni*		v	v	^
Cyclopoid copepod	*Tropocyclops prasinus mexicanus*		>	v	^

Delayed negative response



Daphnia and turbidity

- Daphnia feeding rates decrease as sediment concentration increases

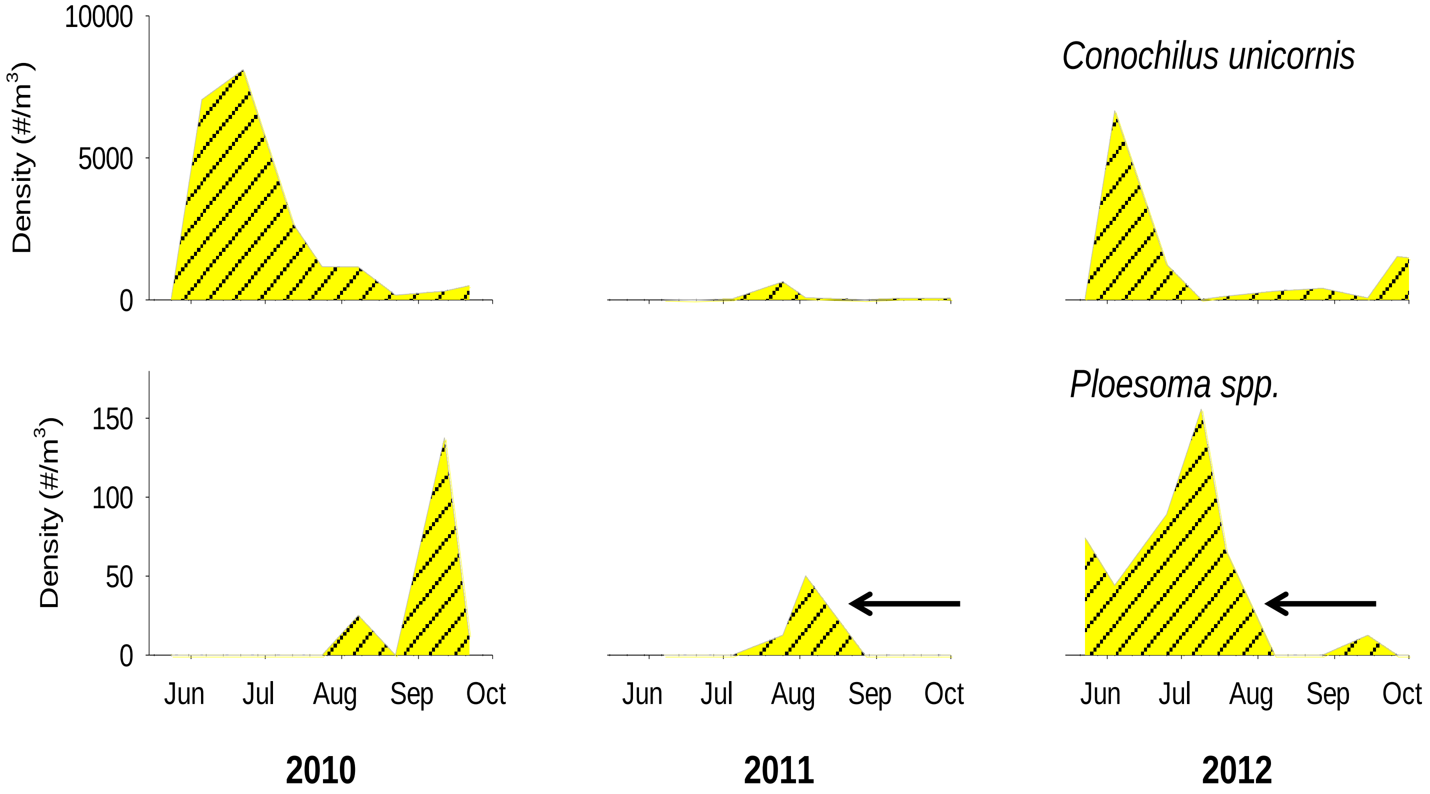


Arruda et al. 1983

Immediate negative response

Category	**Taxon**	**Response**	**2010**	**2011**	**2012**
Asplanchnid rotifer	*Asplanchna priodonta*	Immediate and lasting disadvantage	^	v	v
Brachionid rotifer	*Keratella cochlearis*		^	v	v
Synchaetid rotifer	*Polyarthra spp.*		^	v	v
Daphnid cladoceran	*Daphnia retrocurva*	Delayed disadvantage	^	^	v
Calanoid copepod	Diaptomidae		^	^	v
Cyclopoid copepod	*Mesocyclops edax*		>	^	v
Conochilid rotifer	*Conochilus unicornis*	Immediate disadvantage	^	v	^
Synchaetid rotifer	*Ploesoma spp.*		^	v	^
Daphnid cladoceran	*Ceriodaphnia reticulata*	Delayed advantage	v	v	^
Bosminid cladoceran	*Eubosmina coregoni*		v	v	^
Cyclopoid copepod	*Tropocyclops prasinus mexicanus*		>	v	^

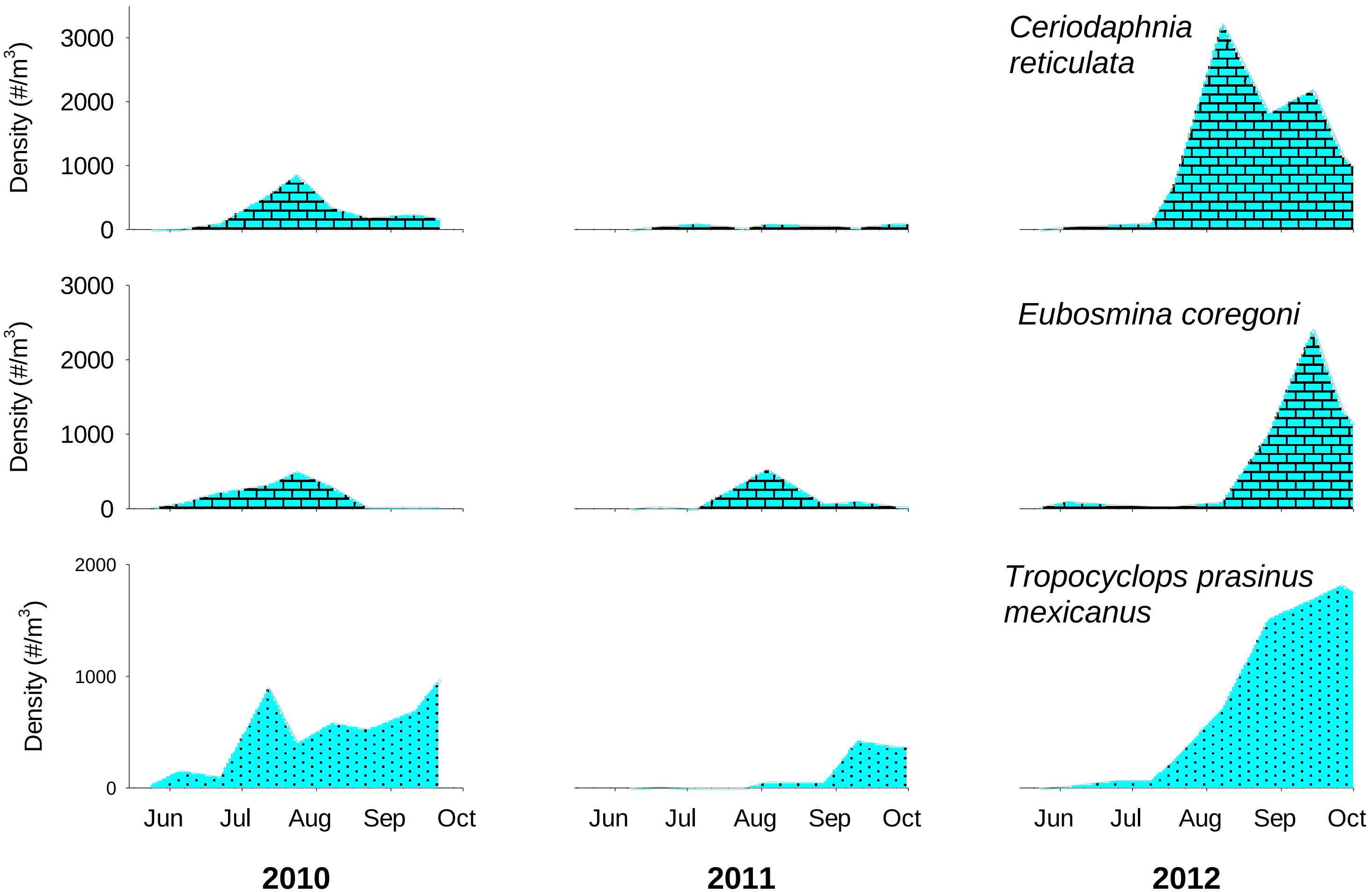
Immediate negative response

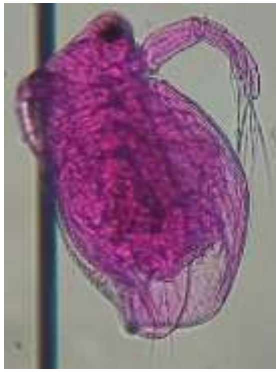


Delayed positive response

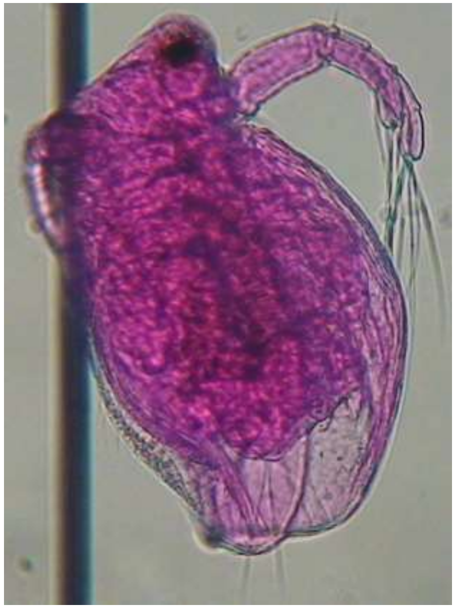
Category	Taxon	Response	2010	2011	2012
Asplanchnid rotifer	*Asplanchna priodonta*	Immediate and lasting disadvantage	^	v	v
Brachionid rotifer	*Keratella cochlearis*		^	v	v
Synchaetid rotifer	*Polyarthra spp.*		^	v	v
Daphnid cladoceran	*Daphnia retrocurva*	Delayed disadvantage	^	^	v
Calanoid copepod	Diaptomidae		^	^	v
Cyclopoid copepod	*Mesocyclops edax*		>	^	v
Conochilid rotifer	*Conochilus unicornis*	Immediate disadvantage	^	v	^
Synchaetid rotifer	*Ploesoma spp.*		^	v	^
Daphnid cladoceran	*Ceriodaphnia reticulata*	Delayed advantage	v	v	^
Bosminid cladoceran	*Eubosmina coregoni*		v	v	^
Cyclopoid copepod	*Tropocyclops prasinus mexicanus*		>	v	^

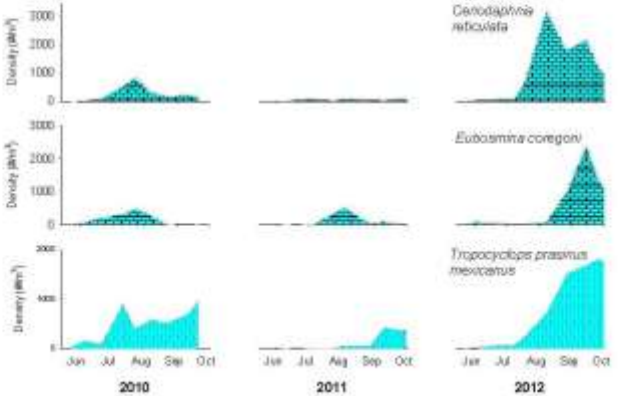
Delayed positive response



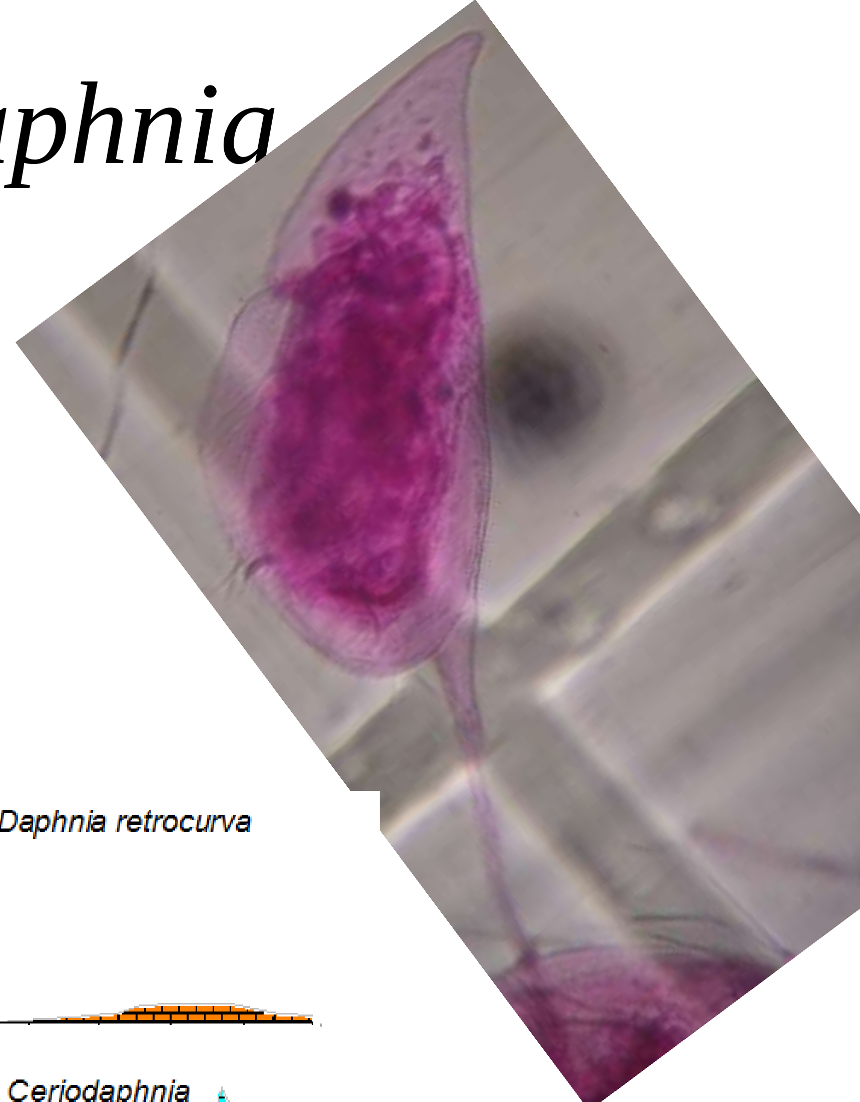


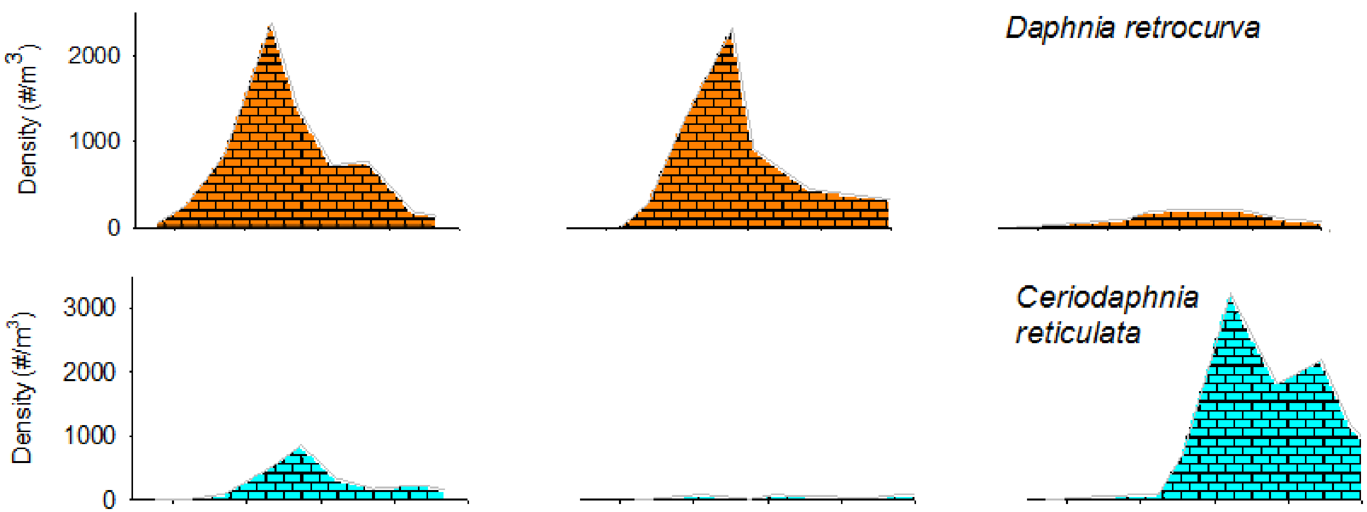
Who we might see more of:



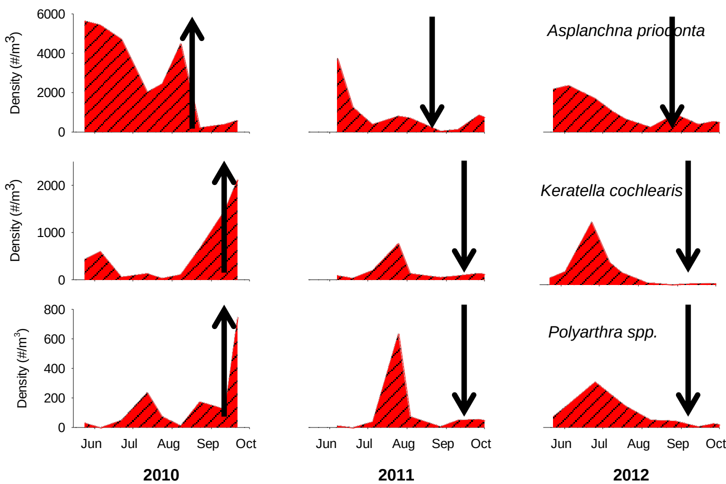


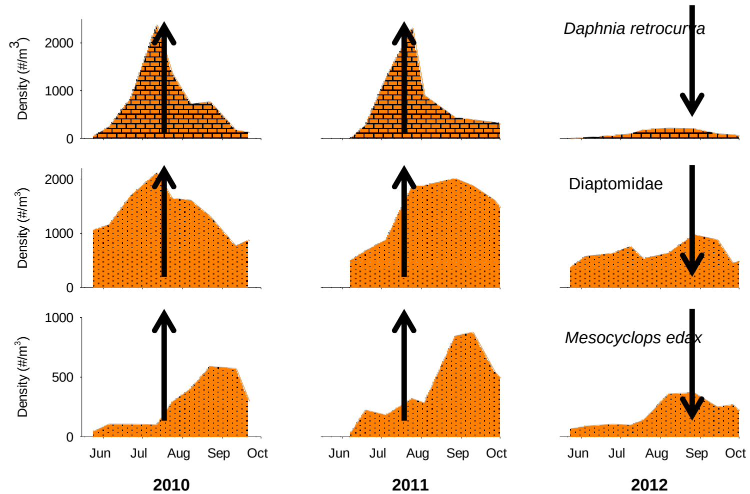
Ceriodaphnia vs. *Daphnia*

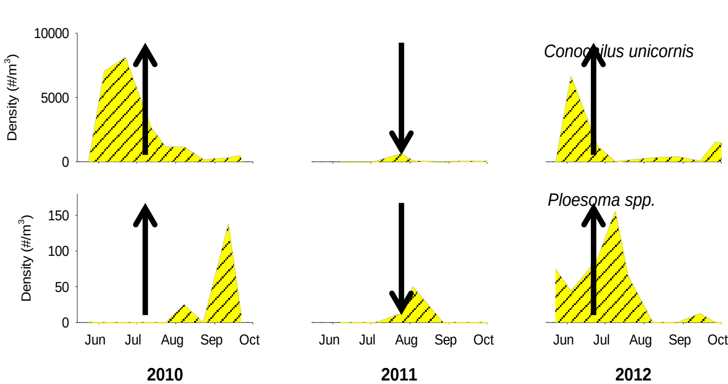


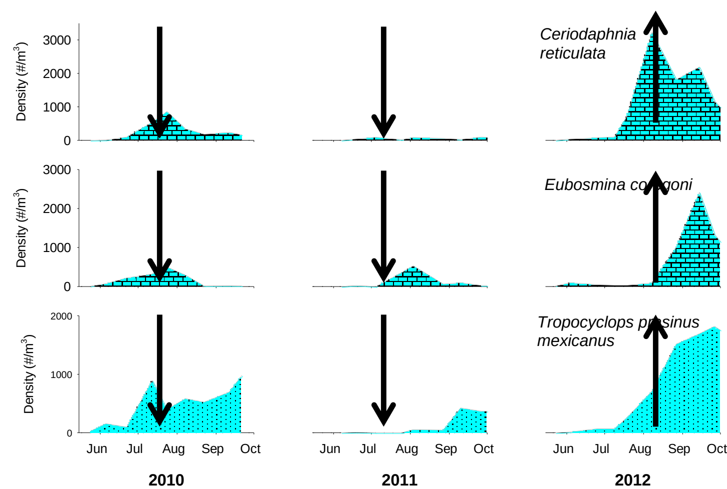


So, everything's always changing, right?





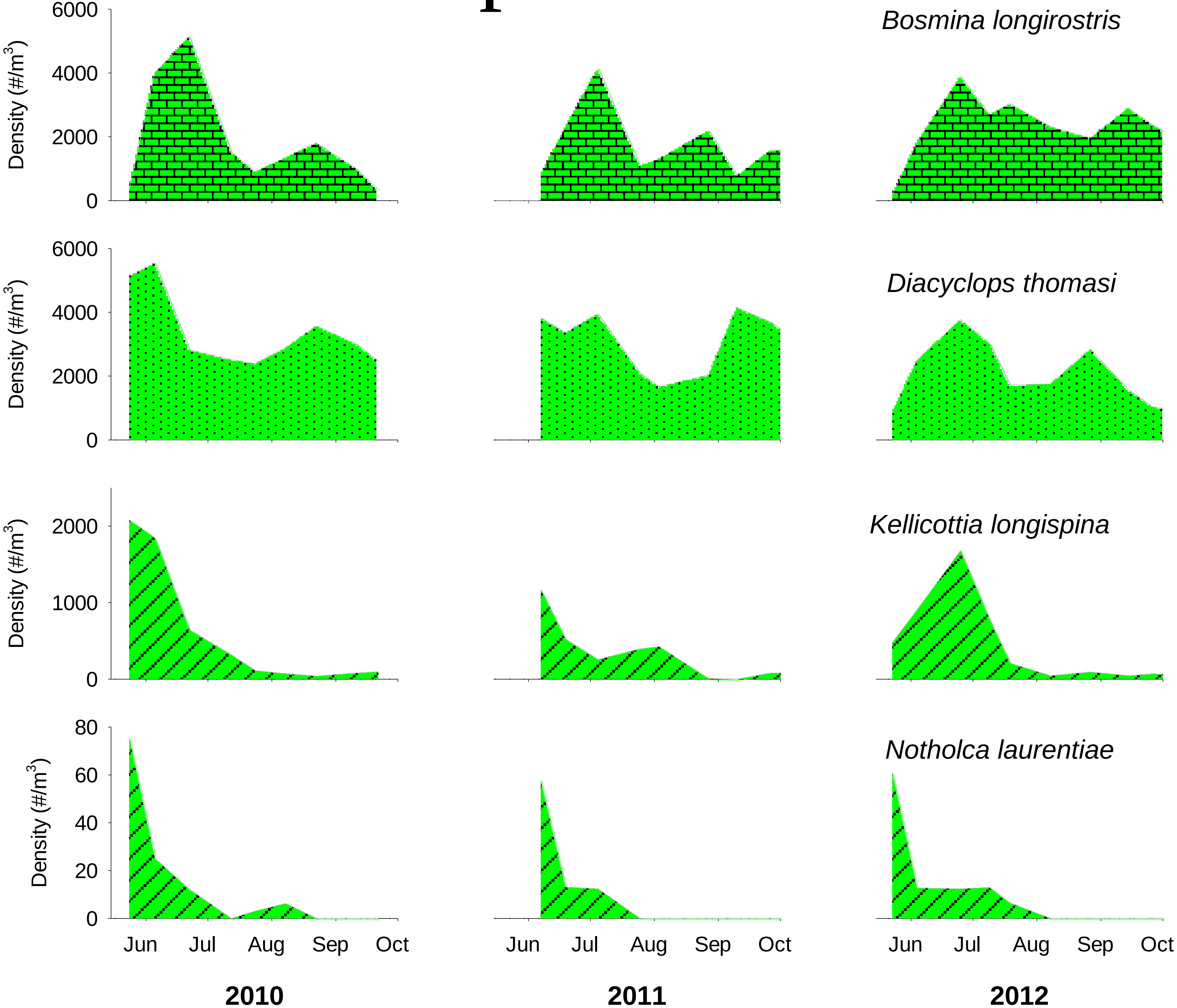


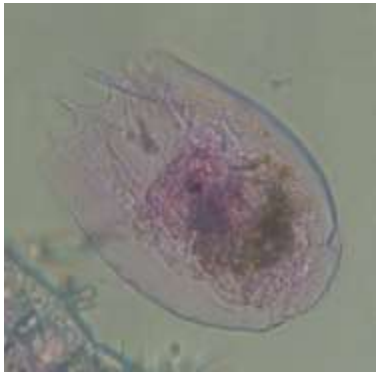


Neutral response

Category	Taxon	Response	2010	2011	2012
Asplanchnid rotifer	*Asplanchna priodonta*	Immediate and lasting disadvantage	^	v	v
Brachionid rotifer	*Keratella cochlearis*		^	v	v
Synchaetid rotifer	*Polyarthra spp.*		^	v	v
Daphnid cladoceran	*Daphnia retrocurva*	Delayed disadvantage	^	^	v
Calanoid copepod	Diaptomidae		^	^	v
Cyclopoid copepod	*Mesocyclops edax*		>	^	v
Conochilid rotifer	*Conochilus unicornis*	Immediate disadvantage	^	v	^
Synchaetid rotifer	*Ploesoma spp.*		^	v	^
Bosminid cladoceran	*Bosmina longirostris*	Neutral response	>	>	>
Cyclopoid copepod	*Diacyclops thomasi*		>	>	>
Brachionid rotifer	*Kellicottia longispina*		>	>	>
Brachionid rotifer	*Notholca laurentiae*		>	>	>
Daphnid cladoceran	*Ceriodaphnia reticulata*	Delayed advantage	v	v	^
Bosminid cladoceran	*Eubosmina coregoni*		v	v	^
Cyclopoid copepod	*Tropocyclops prasinus mexicanus*		>	v	^

Neutral response

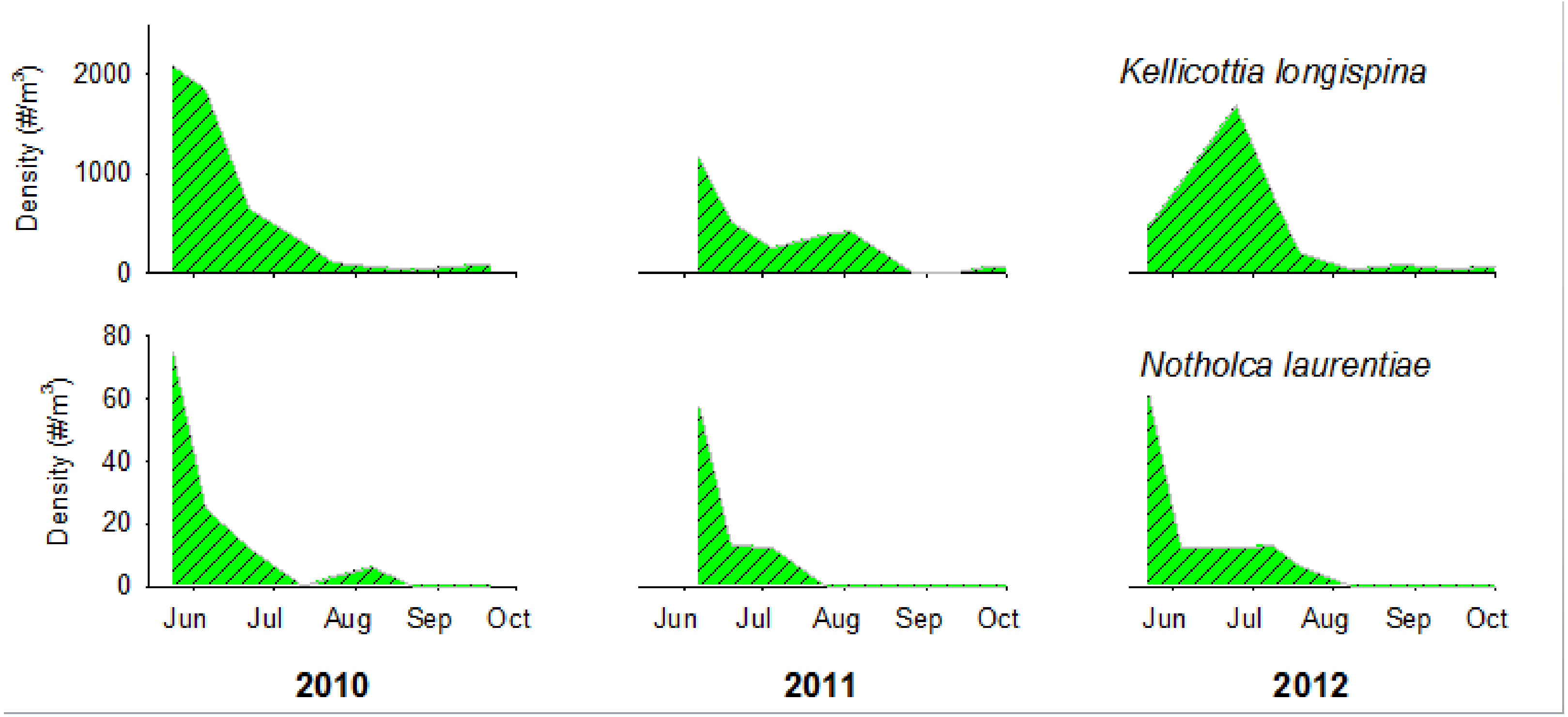


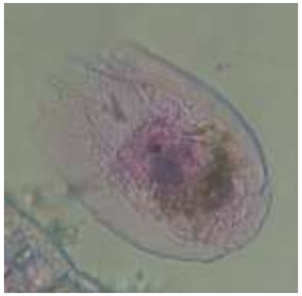


Diacyclops thomasi

the dominant copepod since 1930

Is early seasonality an advantage in flood years?





Summary

– *Long-term patterns:*

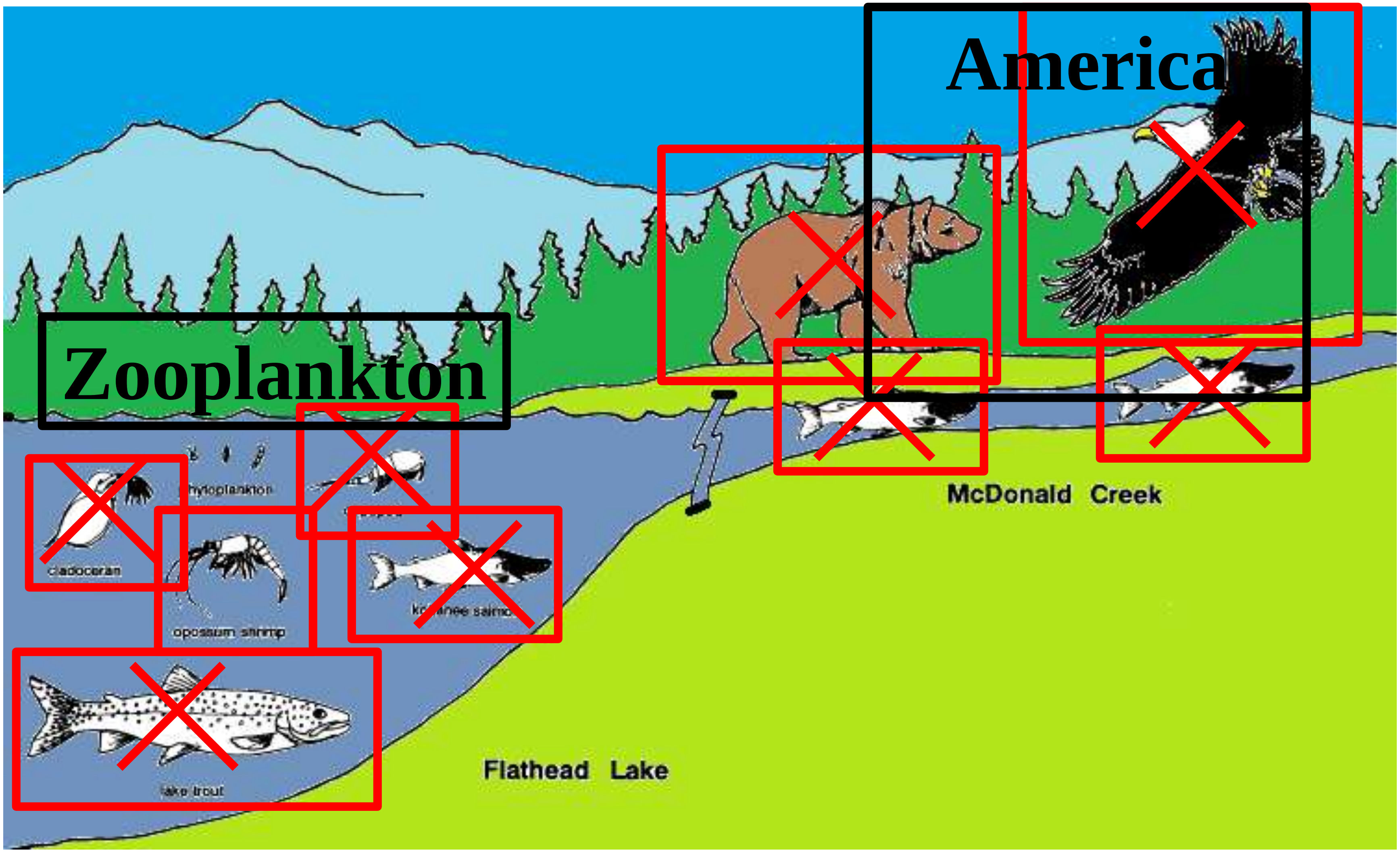
Rotifer declines in richness and abundance- Mid 1990s

- **Mysid declines → Zebra Mussel, Rotifer relationships**
- **Phytoplankton community shifts**
  - » **long-term climate change?**

--- Flooding / climate change:

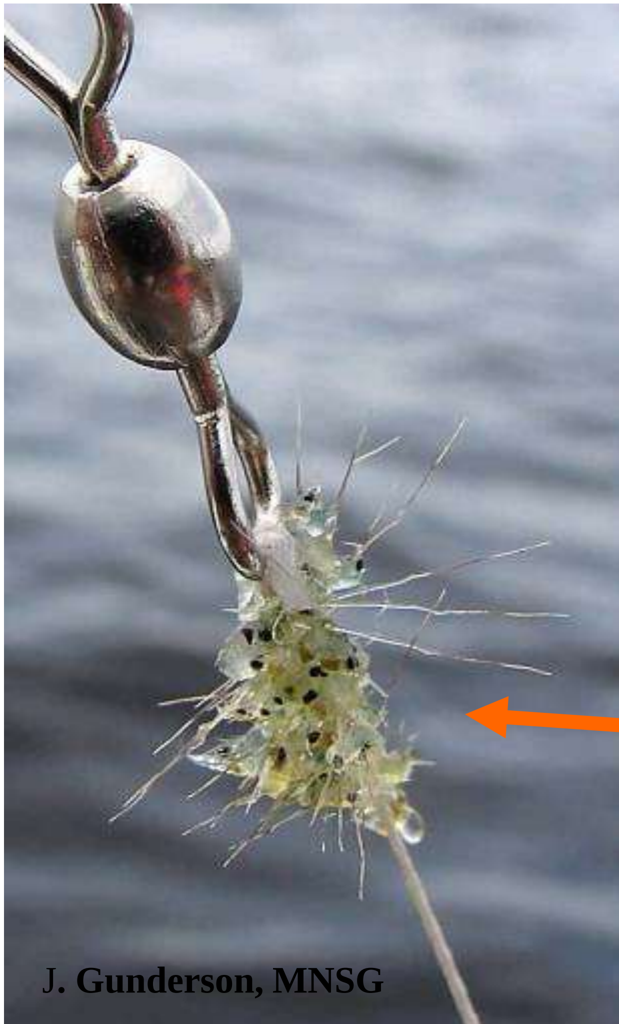
Community shifts based on autecological responses.

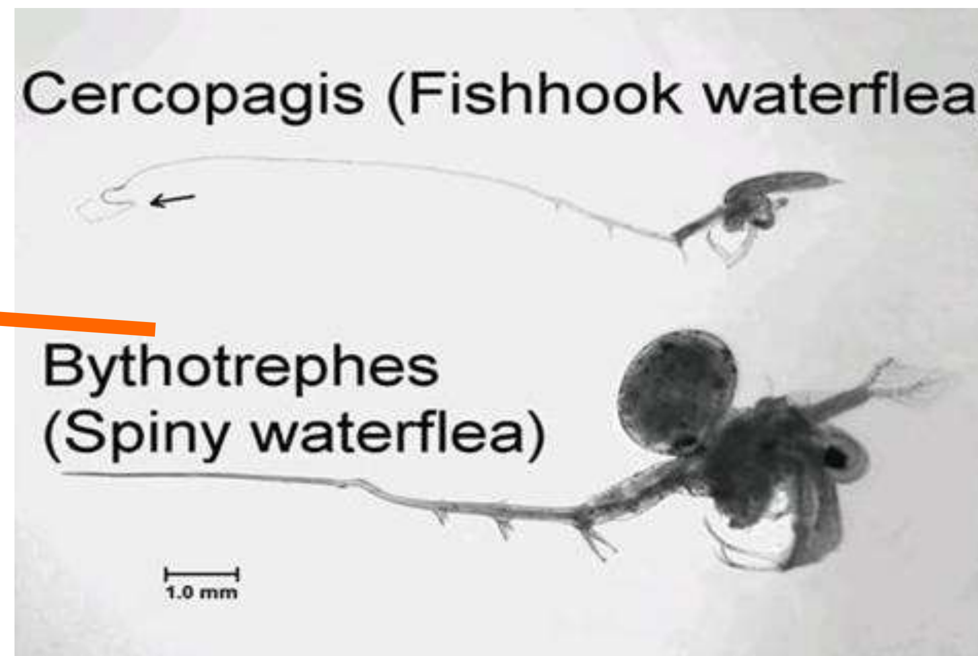
Why you should care about plankton



Questions?

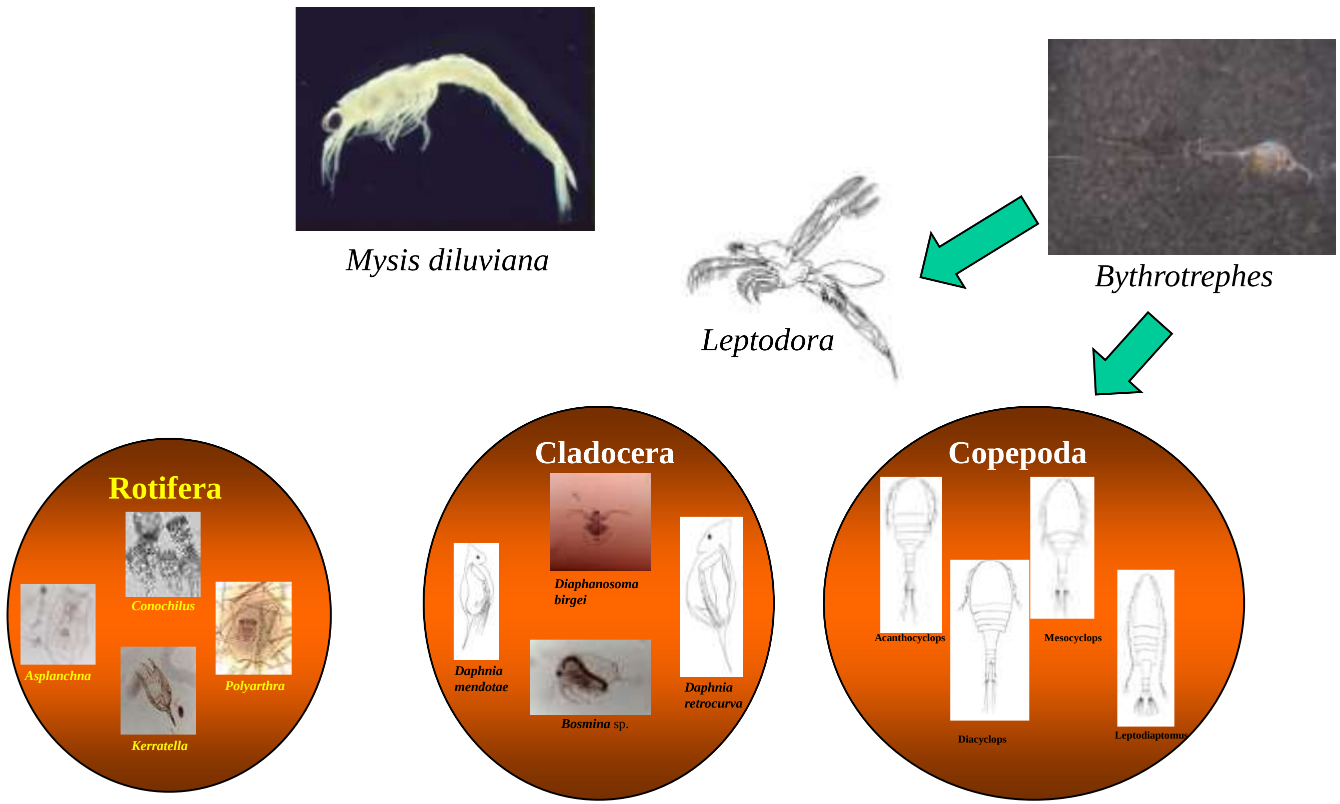
Future Invasive Zooplankton





Lake George= Spiny waterflea source

Lake Champlain Food Web



STOP AQUATIC HITCHHIKERS!™

Prevent the transport of nuisance species.
Clean all recreational equipment.
www.ProtectYourWaters.net

Aquatic Invaders to Look Out For:


H. Smith, APIPP

Water Chestnut
- Triangular leaves & toothed edges
- Forms dense floating mats
- Seeds & plants attach to trailers


J.E. Marsden, UVM & D. Jude

Zebra/Quagga Mussel
- Tiny, "D" or oval shaped striped shells
- Covers hard surfaces & sharp shells cut feet
- Shells attach to plants & boat bottoms


A. Fox, Bugwood.org & Michigan DNR

Eurasian Watermilfoil
- Feathery leaves in whorls of 4
- Forms dense beds
- Plant fragments attach to boats & trailers


DFWR, R.J. Henderson, MN Sea Grant

Spiny Waterflea
- Tiny, ½" crustacean with long, barbed tail
- Competes with fish for food
- Masses collect on fishing line


D. Mainhart, E. Valdez, Bugwood.org

Hydrilla
- Blade-like leaves in whorls of 4-8
- Forms dense beds
- Plant fragments attach to boats & trailers


J. Gunderson & D. Jude, Bugwood.org

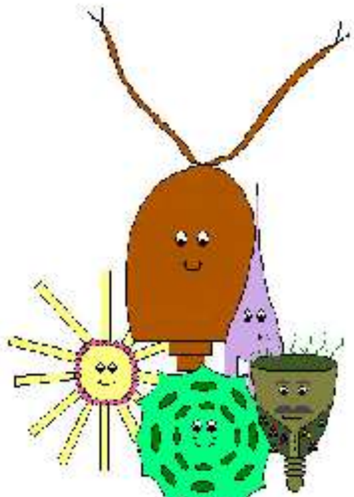
Live Bait
- Non-native crayfish and minnows
- Alters aquatic habitats & may carry pathogens
- Often released or illegally stocked

The Watershed Stewardship Program (WSP) is a collaborative education program offered at water access sites in the Adirondack and Champlain regions to prevent the spread of aquatic invasive species and help preserve the integrity of water resources and local economies.

Adirondack Park Invasive Plant Program | Lake George Association | Lake Champlain Basin Program | Adirondack Watershed Institute of Paul Smith's College | NYS Dept. of Environmental Conservation

For more information go to www.adkinvasives.com, www.lcbp.org, or www.dec.ny.gov/animals/48221.html.

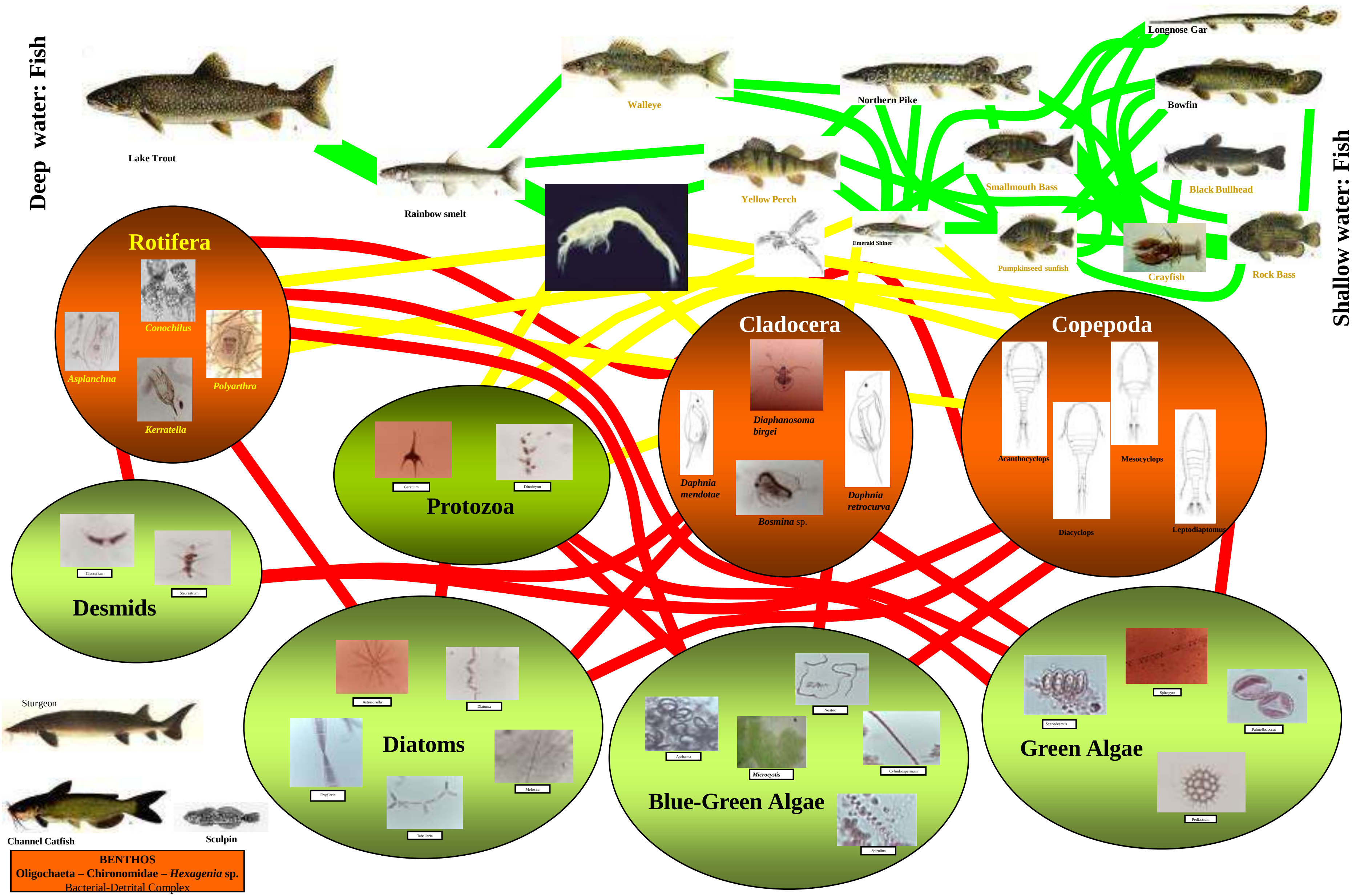
ADVENTURES OF CAPTAIN FISHHOOK WATERFLEA



THE INVASION OF LAKE CHAMPLAIN

By Alexandra Mihalek, Carrianne Pershyn and Casey Binggeli (Edited by Dr. Timothy B. Mihuc)

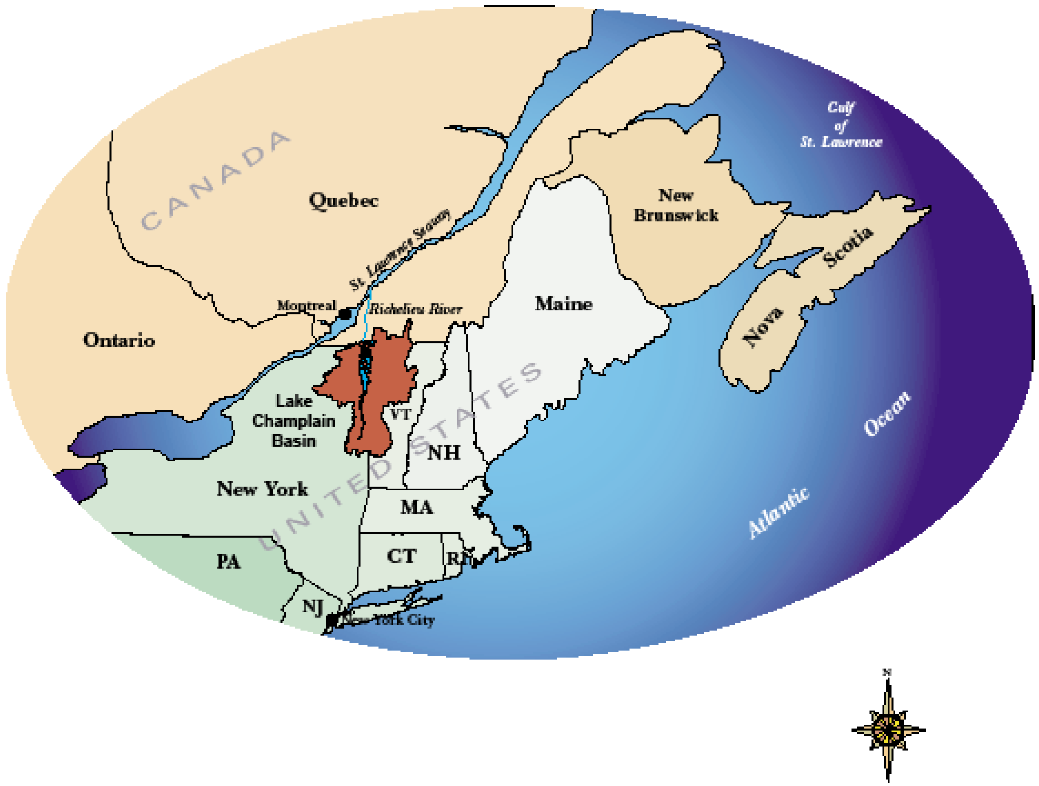
Lake Champlain Food Web



Alewife

- Marine member of herring family
- Discovered in Lake St. Catherine in 1997
- Compete with native fish for food
- Preys directly on eggs and young native fish species
- Interferes with trout & salmon reproduction
- Unstable forage base, periodic die-offs
- Quebec – Aug 2003
- Vermont – July 2004
- Management options?

Lake Champlain Region



Map by Northern Cartographic.