Microzooplankton Grazing & Windows of Opportunity for Dinoflagellate Blooms

Diane K. Stoecker
(contributions from Mike Roman, Bill Boicourt, Dan Gustafson, Matt Reaugh, Anne Thessen, Matt Johnson)

IAN 11/18/05
FACTORS THAT INCREASE (+) or DECREASE (-) PLANKTONIC HAB POPULATIONS

+ Excystment or recruitment from benthos
+ Cell division (regulated by light, macro and micro nutrients, feeding, turbulence etc)
+ or - Advection
- Mortality due to grazing
- Mortality due to disease (viruses, bacteria, parasites)
- Encystment
Why emphasis on microzooplankton grazing?

• Microzooplankton usually have > impact on phytoplankton than mesozooplankton.
• Microzooplankton grazing often limits phytoplankton net growth.

Are the interactions between dinoflagellates and microzooplankton an exception?
Microzooplankton (<200 µm) (~Predator:Prey Size Ratio)*

- Planktonic ciliates (8:1)
- Heterotrophic and mixotrophic dinoflagellates (2:1-1:1)
- Meroplankton larvae (50:1)
- Rotifers (18:1)
- Copepod nauplii (18:1)
- Other flagellates (3:1)

Favella sp.  
~ 150 µm

Tintinnopsis  
~ 45–70 µm

Strombidium sp.  
~ 30 µm

Strombidinopsis sp.  
~ 80-100 µm

Eutintinnus sp.  
~ 20 x 110 µm
Amphidinium sp. ~ 30-65 µm

G. spirale ~ 40-200 µm*

Polykrikos sp. ~ 100-150 µm*

Oxyrrhis sp. ~ 10-20 µm

Gyrodinium sp. ~ 15-20 µm

Protoperidinium sp. ~ 70-90 µm*

Protoperidinium sp. ~ 70-90 µm*

Amphidinium sp. ~ 30-65 µm*

* www.marbot.gu.se
Algal blooms are evidence of uncoupling of predator:prey dynamics

Role of microzooplankton grazing in:

1. Preventing or allowing bloom initiation
2. Limiting bloom densities
3. Decline of blooms
Large dinoflagellates tend to be grazed by “specialized” large microzooplankton at bloom densities:

Many large cell size, bloom forming dinoflagellates (for example *Lingulodinium polyedra*, *Akashiwo sanguinea*, *Gymnodinium catenatum*, large *Alexandrium spp*).

Dinoflagellates that can be grazed by “specialized” microzooplankton at bloom densities:

Hypotheses/generalizations:

• Only blooms support high populations of “specialized” microzooplankton that eat large flagellates.
• Microzooplankton grazing may contribute to the decline of blooms but generally does not prevent blooms.
• Microzooplankton production facilitates utilization of bloom biomass by metazoa (trophic link).
• Microzooplankton may serve as a vector for toxin transfer to higher trophic levels.
Many smaller dinoflagellates are grazed by microzooplankton when at low cell densities or in mixtures:

*Fucoxanthin-containing dinoflagellate HABs:*
*Karenia brevis, K. mikimotoi, & Karlodinium micrum*
(Gustafson et al. 2002, Johnson et al. 2003)


*Pfiesteria piscicida* (Stoecker et al. 2000; Stoecker & Gustafson 2002)

Dinoflagellates which are grazed when at low cell densities or in mixtures:

Hypotheses/generalizations:

• Some have a toxic exudate or can release a toxin; detrimental effects increase with cell density.

• Initiation of blooms may be suppressed or regulated by microzooplankton grazing. However, microzooplankton grazing may have little effect on dense blooms.

• “Windows” of low grazing pressure that coincide with appropriate algal growth conditions may be necessary for bloom formation.
Net growth = Division - Mortality

\[ K = \mu - g \]
Does microzooplankton grazing have the potential to inhibit bloom initiation?

Experimental studies of potential grazing on small dinoflagellates (*Pfiesteria piscicida, Prorocentrum minimum* and *Karlodinium micrum*) that are harmful or nuisance species in the Chesapeake Bay or its tributaries
Potential grazing on *Pfiesteria* NTZ
Pocomoke River Experiments, 2000
(Stoecker & Gustafson 2003)

- Low salinity ~ 5 psu
- Medium salinity ~ 10 psu
- High salinity ~ 15 psu
- Pocomoke River site of *Pfiesteria* bloom in 1997
Potential Microzooplankton Grazing on NTZ

![Graph showing potential microzooplankton grazing on NTZ with data points for different dates and salinity levels.]

- Low salinity
- Medium salinity
- High salinity

Date: May 10, May 24, Aug 02, Aug 17, Aug 30, Sep 09, Oct 02

G d⁻¹
P-like dinoflagellates were low in abundance in all natural assemblages collected from the Pocomoke in 2000.
Comparison of potential microzooplankton grazing on NTZ, g d\(^{-1}\), among High, Medium & Low Salinity Samples.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>4.08</td>
<td>0.502</td>
</tr>
<tr>
<td>Medium</td>
<td>2.93</td>
<td>0.540</td>
</tr>
<tr>
<td>Low</td>
<td>1.46</td>
<td>0.305</td>
</tr>
</tbody>
</table>

1 Way ANOVA: p=0.001***

Pairwise Multiple Comparison (Tukey Test):
- High vs. Low P<0.05
- High vs. Medium n.s.
- Medium vs. Low n.s.
Microzooplankton grazing may be important in regulating populations of non-toxic *Pfiesteria*, but may not be effective in controlling toxic or very recently toxic populations of zoospores

(Stoecker & Gustafson 2002)
Why is potential grazing on *P.p.* (and perhaps other dinoflagellates) lower at lower salinity?

- Dinoflagellates are a major component of the phytoplankton in mesohaline waters, but not in tidal freshwaters (Marshall & Nesuis 1993). Thus, grazers of dinoflagellates are probably more common at higher salinity.
- Upstream stations may be more eutrophic than downstream stations. Eutrophic waters differ in zooplankton spp. composition from less eutrophic waters.
- Residence time at upstream locations may often be too low for grazer populations to develop.
Chesapeake Bay Experiments
summer 2000

Microzooplankton potential grazing on
*Prorocentrum minimum* and
*Karlodinium micrum*

(Johnson et al. 2003)
**Prorocentrum minimum**

- 13-25 µm long, 12-22 µm wide
- Blooms winter-spring in mesohaline waters
- Can cause mahogany tides
- In late April and May 2000, formed large bloom mid-bay, with cells densities > $10^6$/ml
- In culture, $\mu_{\text{max}} \sim 1 \text{ d}^{-1}$
**Karlinodinium micrum**

- ~10 µm in size
- Can bloom spring-fall in mesohaline waters of Chesapeake Bay (Li et al. 2000)
- Toxic activity from culture filtrates elute with polar lipids (Deeds et al. 2002)
- In culture, $\mu_{\text{max}} \sim 1/d$
Chesapeake Bay showing stations along the main stem & the Potomac River
**Prorocentrum minimum**

![Graph showing Prorocentrum minimum abundance across stations and months.](image-url)
Karlenodium micrum

- Yellow: July
- Red: August

Station

<table>
<thead>
<tr>
<th>Station</th>
<th>908</th>
<th>858</th>
<th>845</th>
<th>834</th>
<th>818</th>
<th>804</th>
<th>744</th>
<th>724</th>
<th>707</th>
</tr>
</thead>
<tbody>
<tr>
<td>g d⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Potential grazing on small dinoflagellates is very variable but often > the max. potential growth rate

• Both ciliates and heterotrophic dinoflagellates are important grazers on small dinoflagellates

• Microzooplankton grazing may prevent net growth of populations of small dinoflagellates
Blooms may depend on “windows of opportunity” when grazing pressure is low that coincide with conditions conducive to dinoflagellate growth.

What causes “windows of opportunity” in which grazing pressure is low?
Can trophic cascades create “windows of opportunity”?

- Microzooplankton community grazing coefficients on phytoplankton assemblages are often \( \sim 1-2 \text{ d}^{-1} \); mesozooplankton community grazing coefficients on phytoplankton are usually an order of magnitude lower.
- Many crustacean mesozooplankton have higher clearance rates for microzooplankton than for phytoplankton (microzooplankton populations are often controlled by copepod grazing).
- Mesozooplankton (esp. copepods) consume both microzooplankton and phytoplankton, but their grazing/predation may reduce total community grazing pressure on phytoplankton by reducing microzooplankton grazing pressure.
I - Spring Diatom Bloom

II - Decline of Spring Diatom Bloom

III - Decline of Dinoflagellate Bloom and Establishment of Summer Pico- and Nanoplankton Assemblage
Conceptual model

(Compliments of M. Reaugh)
"Window of opportunity" for the net growth of small, bloom-forming dinoflagellates after freshets or blooms?

<table>
<thead>
<tr>
<th>Oligohaline</th>
<th>&quot;Window&quot;</th>
<th>Mesohaline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Turbidity</td>
<td>Lower Turbidity</td>
<td>Lower Turbidity</td>
</tr>
<tr>
<td>Lower Light</td>
<td>Sufficient Light &amp; Nutrients</td>
<td>Higher Light</td>
</tr>
<tr>
<td>Higher Nutrients</td>
<td>Lower Nutrients</td>
<td>Lower Nutrients</td>
</tr>
<tr>
<td>Dominant Grazers:</td>
<td>Low Grazing Pressure on small Dinoflagellates</td>
<td>Dominant Grazers: Heterotrophic Dinoflagellates, Large Ciliates (including Tininnids + Oligotrichs), Rotifers, Metazoan larvae, Copepods</td>
</tr>
<tr>
<td>Heterotrophic Flagellates, Bacterivorous</td>
<td>Dinoflagellates</td>
<td></td>
</tr>
</tbody>
</table>
Windows Project-Hypotheses

• “Windows of low microzooplankton grazing pressure”, in addition to light and nutrients, are necessary for blooms of small (< 25 µm) dinoflagellates to occur.

• High nutrients, by changing food web structure, can weaken top down control of small dinoflagellates.
Investigation of effects “bottom up’ and “top down” regulation of dinoflagellate blooms in the Choptank and Paxtuxent Rivers

- Abundance of bloom-forming dinoflagellates (*Heterocapsa triquetra*, *H. rotundatum*, *Prorocentrum minimum*, *Karlodinium micrum*
- Temperature, salinity, surface irradiance, inorganic nutrients, TSS, chlorophyll
- Calculation of residence times
- Abundance and grazing impact of micro and mesozooplankton grazers
“Analysis in Progress”

• For today, address subset of data from Choptank River for 2002 (dry), 2003 (wet), 2004 (more normal?)
In the Chesapeake Bay region, 2002 was a record dry year, and 2003 was a record wet year (Flow, Choptank River, Greensboro, MD; [www.usgs.gov](http://www.usgs.gov))
Estimated residence times, Choptank River, Jan-Apr

Spring 2002: ~20 days

Spring 2003: ~4 days
Average Daily Irradiance

**2002**

<table>
<thead>
<tr>
<th>Month</th>
<th>Avg PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>24.44 E m² d⁻¹</td>
</tr>
<tr>
<td>April</td>
<td>35.59 E m² d⁻¹</td>
</tr>
<tr>
<td>May</td>
<td>44.41 E m² d⁻¹</td>
</tr>
</tbody>
</table>

**2003**

<table>
<thead>
<tr>
<th>Month</th>
<th>Avg PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>27.71 E m² d⁻¹</td>
</tr>
<tr>
<td>April</td>
<td>19.63 E m² d⁻¹</td>
</tr>
<tr>
<td>May</td>
<td>35.38 E m² d⁻¹</td>
</tr>
</tbody>
</table>
Choptank River, Middle Station, surface water temperature and salinity
Choptank River, Middle Station, inorganic N and total suspended solids (TSS)
Choptank River, Middle Station, Chl. $a$

![Graph showing Chl a concentrations from March to May with data points for 2002 and 2003.](image)
Choptank River, Middle Station, Photosynthetic Dinoflagellates Abundance

- In 2002, no blooms (no data shown).
- Was the May bloom proceeded by low grazing coefficients for *Prorocentrum*?
Estimated copepod community grazing on phytoplankton, Choptank 2003
(3 experimental stations)

- Copepod grazing may have contributed to the demise of the *Heterocapsa* bloom in late winter/early spring.
- Copepod grazing probably had little direct affect on dinoflagellate populations in late spring.
- Did a “window of low grazing” allow blooms to develop?
Micro-zooplankton potential grazing & *K. micrum*

- Did µzoo grazing prevent a *K. micrum* bloom in early May?
Micro-zooplankton potential grazing & *Prorocentrum*

- Grazing pressure & dinoflagellate density were very variable (both spatially patchy).
- Average µzoo potential g/d and average ciliate densities were high during early May when the bloom was developing.
Why did a *P. minimum* bloom occur although average microzooplankton grazing was high?

- Recruitment from pycnocline? Advection?

- *In situ* growth rates *P. cordatum* are HIGHER than expected?

- Vertical and horizontal patchiness of *Prorocentrum minimum* and microzooplankton grazing?
Does “top-down” control of microzooplankton by copepods during wet (more eutrophic) years reduce over-all grazing control of phytoplankton blooms?
### Dry Year 2002

- **Copepods**: 0.9 µg C L⁻¹
- **Microzooplankton**: 118 µg C L⁻¹
- **Phytoplankton**: 216 µg C L⁻¹

### Wet Year 2003

- **Copepods**: 40 µg C L⁻¹
- **Microzooplankton**: 229 µg C L⁻¹
- **Phytoplankton**: 1785 µg C L⁻¹

### 2004

- **Copepods**: 19 µg C L⁻¹
- **Microzooplankton**: 230 µg C L⁻¹
- **Phytoplankton**: 432 µg C L⁻¹

---

**Graphs:**

- **X-axis**: % Change in Biomass (Dry year - Normal year)
- **Y-axis**: % Change in Biomass (Wet year - Normal year)

**Legend:**

- **Copepods**
- **Microzooplankton**
- **Phytoplankton**
• Micro-zooplankton biomass stays about the same!

• Is grazing limited by top-down control (copepod grazing of microzooplankton)? (But would this be true in a year when ctenophores control copepods? When jellyfish control ctenophores and copepods released from grazing pressure?)

• In wet years, phytoplankton biomass is probably less limited by microzooplankton grazing since biomass of microzooplankton does not go up proportionally with phytoplankton biomass?
Ciliates ml⁻¹

March April May

- tintinnids 2002
- oligotrichs 2002
- tintinnids 2003
- oligotrichs 2003
SUMMARY

• **GRAZING MORTALITY** is **IMPORTANT** for small dinoflagellates and perhaps many other HAB species.

• Patchiness may permit small blooms even when average grazing pressure is high.

• Interactions between bottom up perturbations and and top down regulation may be synergistic (ex., freshwater flow and eutrophication may increase resources for dinoflagellates and also weaken top down control).