Optimizing methods to estimate zooplankton concentration based on generalized patterns of patchiness inside ballast tanks and ballast water discharges

Sarah Bailey and Harshana Rajakaruna
Zooplankton populations can be spatially heterogeneous and stratified in ship ballast tanks and ballast discharge.

Sampling protocols for monitoring Regulation D-2 should be “representative of the whole discharge of ballast water from any single/combination of tanks being discharged.”

Sampling methods should therefore take heterogeneity into account, for accurate estimation of tank average.
• Very limited data on spatial structure of plankton in ballast tanks – some evidence for trends by depth for some taxa (Murphy et al. 2002)
• Recent inline sampling studies report zooplankton concentration varies depending on timing/sequence of sample collection (Gollasch & David 2013)
• If there are trends and patchiness in-tank and during inline discharge, estimates ignoring depth/sequence may lead to large errors (uncertainty)
Research Objectives

- to examine spatial heterogeneity of zooplankton in ballast water
- to model and estimate the average concentration of zooplankton across the entire ballast tank
- to determine under which contexts different sampling methods are most representative (yield the most accurate estimate of the tank average)
Analytical Methods

- Data from 5 trips (different ballast sources, age, season, etc.)
- Modeled data to look for trends by volume-discharged and tank depth
- Combined all data (net, pump, inline) to generate tank average
- Modeled standardized errors in each sample estimate w.r.t. tank averages
- Estimated bias, variance of errors and their MSE
  - bias - over or underestimations;
  - variance - variability;
  - MSE – accuracy (lower MSE = better estimate of tank average)
Trends by sequence / depth

By trip

Across trips

95% CI

C = 23861e^{0.2X_1}
R^2 = 0.89, p-value < 0.01

C = 75358e^{-0.001X_2}
R^2 = 0.91, p-value = 0.07

Concentration (ind.m^{-3})

Volume discharged (m^3)

Depth (m) above tank bottom
Pooling data to generate tank average

- **(A)** $R^2=0.31, p=0.1$
- **(B)** $R^2=0.75, p<0.05$
- **(C)** $R^2=0.45, p>0.1$
- **(D)** $R^2=0.45, p=0.1$
- **(E)**
- **(F)** $R^2=0.85, p<0.02$

- **inline**
- **Δ pump**
- **● Net haul**

- **Mean trend**
- **--- 95% CI**
- **Tank Average**
- **--- 95% CI**

-Concentration (ind.m$^{-3}$)

-W (m)
Sampling Error

Estimated bias$^2$, variance and MSE ($m^6$)

$X_2$ (m) or $X_1$ (m$^3$)
Sample representativeness, as compared to the tank average, varied depending on the depth or sequence sampled.

In-line discharge samples provided the least biased and most precise estimate of average tank abundance (having lowest MSE) when collected during the time frame of 20-60% of the tank volume being discharged.

As net-haul estimates show positive bias, a net-haul estimate meeting D-2 standard appears to be a robust “pass”, while a failure would be uncertain.
Results were consistent across trips despite differences in ballast water source, season, and age...

Additional research examining sample representativeness would be beneficial to confirm the trends we observed are generally applicable across different types of ballast tanks, different sizes of ships, a broader selection of zooplankton communities, and treated ballast water.

Next Steps
Acknowledgements

Algoma Central Corporation; crew M/V TIM S. DOOL; R.D. Linley, J. Kydd, and J. Vanden Byllaardt

Read the full publication in *Ecology and Evolution*; DOI: 10.1002/ece3.3498