JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, C05S01, doi:10.1029/2006JC003598, 2006

Introduction to special section on Analysis of Zooplankton Distributions Using the Optical Plankton Counter

Henry A. Vanderploeg[1] and Michael R. Roman[2]

Received 20 March 2006; accepted 4 April 2006; published 24 May 2006.

[1] We briefly introduce the optical plankton counters (OPCs) currently in use and summarize major themes and conclusions of papers from this special section. These collected papers demonstrate that the OPC and the new laser OPC (LOPC) are useful tools for mapping fine-scale distributions of zooplankton over broad expanses of space and for examining patterns in the size structure of zooplankton communities, which give insights into the top-down and bottom-up forces affecting them. The LOPC or OPC are particularly valuable sensors when used in conjunction with an array of other sensors on a tow body so that investigators can synoptically measure physical and biotic variables. Caution must be exercised in using the OPC or LOPC because there are times when nonzooplankton particles comprise a significant portion of the particles counted. The contribution of nonzooplankton particles to the total seston varies with system and conditions.

Citation: Vanderploeg, H. A., and M. R. Roman (2006), Introduction to special section on Analysis of Zooplankton Distributions Using the Optical Plankton Counter, *J. Geophys. Res.*, *111*, C05S01, doi:10.1029/2006JC003598.

1. Introduction

[2] Since their development in the late 1980s and early 1990s [*Herman*, 1988, 1992] there has been increasing use of optical plankton counters (OPCs) to describe spatial distributions, biomass spectra, and production of zooplankton in large lakes, estuaries, coastal and marine systems. Yet there have been no special sessions at major oceanographic or limnological meetings that have discussed recent advances and applications of OPCs. In recognition of this need we held a special session entitled "Analysis of Zooplankton Distributions Using the Optical Plankton Counter" at the American Society of Limnology and Oceanography/The Oceanography Society Ocean Research Conference in Honolulu, Hawaii, 15–20 February 2004. This special session brought together experts to discuss the application of OPCs to determine spatial distributions, biomass spectra, and production of zooplankton in a wide variety of estuarine, coastal, and offshore environments. Presenters discussed the strengths, limitations and advances in understanding zooplankton abundance and distribution from the OPC measurements. Here we introduce major themes of the papers and make some broad conclusions concerning the use of OPCs.

2. Optical Plankton Counters in Use

[3] The towed OPC (Model OPC-1T, Focal Technologies) developed by *Herman* [1988, 1992] was designed as a remotely towed sensor providing real-time information on zooplankton number, size, and biomass. It has a sampling tunnel 25 cm wide by 2 cm high by 51 cm long; and a collimated light beam 4 mm thick × 2 cm high traverses the tunnel width at the midpoint of its length [*Herman*, 1992]. The OPC measures the cross-sectional area of particles in the size range 250–1500 μm equivalent spherical diameter (ESD) as they traverse the 4-mm-thick beam of light, and data are transmitted at 0.5 s intervals to an onboard computer. The beam dimensions provided a relatively large sensing zone (volume = 20 cm^3) that led to coincidence problems (two more particles occupying the sensing zone) at ~10,000 counts m^{-3}, a concentration typically exceeded in coastal environments. To deal with potential coincidence problems in particle-rich environments, acrylic flow inserts have be used to effectively reduce the tunnel width to as little as 6 cm [*Sprules et al.*, 1998] and a compact OPC, the mini-OPC (Model OPC-2T), with tunnel opening dimensions of 2 × 10 cm (sensing zone volume of 8 cm^3) was developed; however, there are many lake and coastal situations where zooplankton are so abundant as to cause coincidence problems even with the smaller OPC or the OPC with acrylic inserts [*Herman et al.*, 2004]. It is not possible to use an insert that restricts tunnel width further, because flow through the tunnel is compromised (H. Vanderploeg, unpublished data, 2005).

[4] It is the simplicity of the principle of operation, ease of deployment and signal processing that have made OPCs a popular alternative to video imaging techniques or acous-

---

[1] Great Lake Environmental Research Laboratory, NOAA, Ann Arbor, Michigan, USA.

[2] Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, Maryland, USA.

Copyright 2006 by the American Geophysical Union.
0148-0227/06/2006JC003598$09.00

tics. As noted by *Herman et al.* [2004] the OPC and LOPC have been deployed on a variety of towed vehicles and placed in the mouths of plankton nets. This simplicity has allowed the OPC data stream to be combined with the data streams from other sensors such as CTDs, fluorometers, oxygen probes on towed vehicles that undulate through the whole water column (or part of it). Such tows give 2-D information on how zooplankton-sized particles covary with other environmental variables at fine-scale spatial scales over great expanses of lakes or oceans.

[5] A laboratory OPC (Model OPC-1L, Focal Technologies) having a 2 × 2 cm opening (again with 4-mm-thick beam) was developed to sense zooplankton pumped through the system [*Herman*, 1988]. This design was used in conjunction with shipboard sampling through a hose and for counting and sizing preserved zooplankton by circulating water containing samples through the OPC. The most common application of the lab model has been for sizing and counting zooplankton collected in net tows. Because of the ease of use for pumping different particle types through the lab OPC, it has been used to deduce how the towed OPC would count and size different particle types [*Wieland et al.*, 1997; *Sprules et al.*, 1998].

[6] The LOPC [*Herman et al.*, 2004] was designed to resolve the limitations, particularly coincidence counting, of the original towed OPC and to allow determination of particle shapes >1.5 mm ESD. The standard LOPC also consists of a long tunnel, but has a 7 × 7 cm tunnel opening. A 1-mm-thick by 7-cm-high beam traverses the midpoint of the tunnel. The detector at the end of the beam path is broken into separate 1-mm × 1-mm detector elements, thereby further reducing coincidence counting and allowing determination of shape of particles that straddle 3 or more detector elements [*Herman et al.*, 2004]. This array results in an 80-fold reduction in coincidence, allowing it to count and size particles in concentrations up to $\sim 10^6$ m^{-3}, and the ability to determine shapes of particles larger than 1.5 mm [*Herman et al.*, 2004]. The new design allows sizing particles between 100 μm and 35 mm, and time of transit across the beam of the LOPC is used to calculate flow rate through the tunnel.

3. Special Section Themes and Broad Conclusions

[7] The papers in the special section can be grouped into two major theme areas: the first five papers focus on OPC methodological concerns while the second five papers present results that demonstrate the value of the OPC for describing community structure from biomass structure and for describing spatial coupling between zooplankton and environmental variables. The methodological papers in this section raise important issues as to what particles the OPC or LOPC are sensing in nature and their limitations as a tool for measuring zooplankton abundance and biomass.

[8] One major theme of the methodological papers might be encapsulated in the observation that the OPC is not an optical zooplankton (or even plankton) counter, but is instead an optical particle counter, and that there are other particles in the water column other than plankton that can be counted by OPC. Another theme is how to interpret size of the zooplankter measured by OPC. *Liebig et al.* [2006] show that mini-OPC estimates of zooplankton biomass in Lake Michigan were often higher than that observed in nets especially when total suspended matter (TSM) was high. Experiments with model particles and zooplankton pumped through a lab OPC showed that this discrepancy was not related the OPC overestimating individual zooplankton volume or to coincidence, but was related instead to resuspended bottom materials and detrital aggregates associated with the high TSM. During periods of water column quiescence, the OPC and net tows agreed fairly well. *Hernández-León and Montero* [2006] show that projected area from digitized images of zooplankton is more useful for developing regression estimates of biomass than using particle lengths.

[9] *Moore and Suthers* [2006] demonstrate that abundant subresolved (smaller than OPC size limit of detection) particles hampered the interpretation of data from a towed mini-OPC in turbid estuarine waters of Australia because coincidence from these particles resulted in high counts in the OPC detection range. No correlation between light attenuance and subresolved particles could be made to correct for this effect and lab measurements of screened water were not useful for correcting towed mini-OPC results. To obtain meaningful counts, size and normalized biomass size spectra (NBSS) for zooplankton from such turbid environments, they recommend analyzing net collections of zooplankton with the lab OPC. The NBSS obtained from the lab OPC agreed with expected results from the productivity of the estuaries examined.

[10] *Herman and Harvey* [2006] made extensive comparisons of zooplankton counts and size obtained from vertical tows of a zooplankton net and the LOPC mounted in the mouth of the net in the St. Lawrence estuary. They used the slope of the NBSS, normally a measure of community size structure, to identify regions where abundant nonzooplankton particles were counted by the LOPC but not collected in the net. High negative slopes were associated with the abundance of diatom aggregates or gelatinous material showing up in the small size categories (<900 μm) during or immediately following, a diatom bloom. These particles were too fragile to be sampled by the net. In blue water regions or during nonbloom periods, nonzooplankton particles did not significantly contribute to the LOPC counts. The authors also demonstrate how the shape of the larger zooplankton determined from the LOPC output could be used to separate different taxa.

[11] *González-Quirós and Checkley* [2006] examine the contribution of fragile detrital particles counted by an OPC but not sampled with nets in the California Current. They were able infer occurrence of fragile particles by comparing the abundance and size of particles from a net-mounted OPC with analyses of preserved net contents with a lab OPC. The fragile particles occurred in the size range of 1.26- to 6.35-mm ESD and were hypothesized to be remains of larvacean houses.

[12] In the papers which focus on the application of OPCs, *Currie and Roff* [2006] demonstrate the usefulness of spectral analyses of OPC transects to show that plankton are not passive tracers of water movement in the relatively turbulent environment of the near shore of the Gulf of St. Lawrence. They found that biological variables scale differently from temperature and that zooplankton scaled

differently than phytoplankton. The different scaling suggests that zooplankton grazing is affecting phytoplankton distributions.

[13] The major conclusion of *Yurista et al.* [2006] is that the NBSS, which are reflective of top-down and bottom forces, can be used to discriminate zooplankton communities among the Great Lakes and between nearshore and offshore and epilimnetic and hypolimnetic environments. Because of the ability of the OPC to efficiently examine changes of zooplankton abundance and size at relatively small spatial scales over broad regions of space, they argue the OPC-determined NBSS is a useful management tool for measuring zooplankton community condition in these large lakes.

[14] *Sourisseau and Carlotti* [2006] use analyses of net tows with a lab OPC to describe the patterns in NBSS along a coastal-offshore gradient on the French continental shelf that reflected abundance of small zooplankton near shore. Further, they showed that nonlinearity in size distributions revealed that the zooplankton community was not in an equilibrium state. Interestingly, the offshore-onshore pattern in NBSS parameters parallels those observed by *Yurista et al.* [2006] for some of the Great Lakes.

[15] *Huntley et al.* [2006] used seasonal data on mesozooplankton biomass from a towed OPC at the Hawaiian Ocean Time series Station (HOT) and applied known physiological relationships for zooplankton to predict the impact of zooplankton egestion on carbon and nitrogen flux from the mixed layer. They found significant correlations between net tows and OPC results.

[16] *Zhang et al.* [2006] use a towed OPC combined with other sensors to map fine-scale distributions of zooplankton and related variables along an axial transect throughout the whole length of Chesapeake Bay. Such transects are of great interest because of the large hydrographic, nutrient, and biotic gradients from inner to outer bay and the vertical structure associated with hypoxia of the bottom waters. Axial distributions were primarily affected by freshwater input, and the OPC results were important for obtaining realistic assessment of the zooplankton forage base in this highly spatially variable system.

[17] The overall conclusion of this set of papers is that the OPC and particularly the LOPC are useful tools for mapping the fine-scale structure of zooplankton over broad expanses of space. These OPC measurements are particularly valuable when the OPC is used in combination with of other sensors. Caution has to be exercised when interpreting results of the OPC or LOPC, because there can be times when nonzooplankton particles comprise a significant proportion of particles counted.

[18] **Acknowledgments.** We thank Hans Dam for encouraging us to develop the ASLO/TOS 2004 Ocean Research Conference special session papers on the optical plankton counter into this special journal section in JGR-Oceans. This is GLERL contribution 1383 and University of Maryland Center for Environmental Science contribution 3959.

References

Beaulieu, S. E., M. M. Mullin, V. T. Tang, S. M. Pyne, A. L. King, and B. S. Twining (1999), Using an optical plankton counter to determine the size distributions of preserved zooplankton samples, *J. Plankton Res.*, *21*, 1939–1956.

Currie, W. J. S., and J. C. Roff (2006), Plankton are not passive tracers: Plankton in a turbulent environment, *J. Geophys. Res.*, *111*, C05S07, doi:10.1029/2005JC002967.

González-Quirós, R., and D. M. Checkley Jr. (2006), Occurrence fragile particles inferred from optical plankton counters used in situ and to analyze net samples collected simultaneously, *J. Geophys. Res.*, doi:10.1029/2005JC003084, in press.

Herman, A. W. (1988), Simultaneous measurements of zooplankton and light attenuance with a new optical plankton counter, *Cont. Shelf Res.*, *8*, 205–221.

Herman, A. W. (1992), Design and calibration of a new optical plankton counter capable of sizing small zooplankton, *Deep Sea Res.*, *39*, 395–415.

Herman, A. W., and M. Harvey (2006), Application of normalized biomass size spectra to laser optical plankton counter net intercomparisons of zooplankton distributions, *J. Geophys. Res.*, *111*, C05S05, doi:10.1029/2005JC002948.

Herman, A. W., B. Beanlands, and E. F. Phillips (2004), The next generation optical plankton counter: The laser-OPC, *J. Plankton Res.*, *25*, 1135–1145.

Hernández-León, S., and I. Montero (2006), Zooplankton biomass estimated from digitized images in Antarctic waters: A calibration exercise, *J. Geophys. Res.*, doi:10.1029/2005JC002887, in press.

Huntley, M. E., M. D. G. Lopez, M. Zhou, and M. R. Landry (2006), Seasonal dynamics and ecosystem impact of mesozooplankton at station ALOHA based on optical plankton counter measurements, *J. Geophys. Res.*, *111*, C05S10, doi:10.1029/2005JC002892.

Liebig, J. R., H. A. Vanderploeg, and S. A. Ruberg (2006), Factors affecting the performance of the optical plankton counter in large lakes: Insights from Lake Michigan and laboratory studies, *J. Geophys. Res.*, *111*, C05S02, doi:10.1029/2005JC003087.

Moore, S. K., and I. M. Suthers (2006), Evaluation and correction of subresolved particles by the optical plankton counter in three Australian estuaries with pristine to highly modified catchments, *J. Geophys. Res.*, *111*, C05S04, doi:10.1029/2005JC002920.

Sourisseau, M., and F. Carlotti (2006), Spatial distribution of zooplankton size spectra on the French continental shelf of the Bay of Biscay during spring 2000 and 2001, *J. Geophys. Res.*, doi:10.1029/2005JC003063, in press.

Sprules, W. G., E. H. Jin, A. W. Herman, and J. D. Stockwell (1998), Calibration of an optical plankton counter for use in fresh water, *Limnol. Oceanogr.*, *43*, 726–733.

Yurista, P. M., J. R. Kelly, and S. E. Miller (2006), Comparisons of zooplankton community size structure in the Great Lakes, *J. Geophys. Res.*, *111*, C05S08, doi:10.1029/2005JC002971.

Wieland, K., D. Peterson, and D. Schnack (1997), Estimates of zooplankton abundance and size distribution with the Optical Plankton Counter (OPC), *Arch. Fish. Mar. Res.*, *45*, 271–280.

Zhang, X., M. Roman, D. Kimmel, C. McGilliard, and W. Boicourt (2006), Spatial variability in plankton biomass and hydrographic variables along and axial transect in Chesapeake Bay, *J. Geophys. Res.*, doi:10.1029/2005JC003085, in press.

M. R. Roman, Horn Point Laboratory, University of Maryland Center for Environmental Science, 2020 Horn Point Road, Cambridge, MD 21613, USA.

H. A. Vanderploeg, Great Lake Environmental Research Laboratory, NOAA, 2205 Commonwealth Blvd., Ann Arbor, MI 48105-2945, USA. (henry.vanderploeg@noaa.gov)