From single cells to ecosystems: quantifying the role of marine viruses in carbon transport models —A paired proposal for an OCB Scoping Workshop and Working Group—

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1. SUMMARY

Viruses are an integral component of marine microbial communities and mediate carbon cycling and export processes. Despite their known prevalence and activity in marine systems, fundamental knowledge gaps prevent the inclusion of viruses in current carbon cycling models. We propose to convene a 2.5-day scoping workshop, and subsequently create a working group, uniting microbiologists, viral ecologists, geochemists, and ecosystem and geochemical modelers with the common goal of advancing understanding of marine carbon transport via viruses. The workshop and working group would facilitate collaborations to address critical knowledge gaps and develop a community strategy to inform models of viral impacts on ocean ecosystem function under different climate scenarios including the creation and publication of a synthesis paper and standardized protocols for laboratory and field experiments. This is a resubmission of a previous proposal (2023) which, while unfunded, led to an OCB-sponsored webinar series and a plenary session at the OCB2024 Summer Workshop. These community engagement activities combined with recent technological advances galvanized interest in incorporating marine viruses in predictive ecosystem and geochemical models.

2. BACKGROUND & RATIONALE

Viruses are considered the most abundant biological entities on our planet, surpassing their host abundance by at least one order of magnitude[1]. Every second, approximately 10^{23} microorganisms (e.g., bacteria, archaea, and phytoplankton) are infected by viruses in the world's ocean[2], causing the lysis of their hosts, releasing dissolved organic matter (DOM) and generating carbon-enriched sinking particulate matter[2]. This phenomenon, called the viral shunt, positions viruses as major players in the microbial loop[3,4] (the marine trophic pathway that incorporates dissolved organic carbon into the food chain) (Fig. 1) and the biological carbon pump[5,6]. In addition, viral infections alter host cell metabolisms, including central carbon pathways[7], in some cases inducing secretion of extracellular polysaccharides, cellular aggregation, and sinking[8,9], termed the viral shuttle[10]. Finally, virus particles serve as a nitrogen and phosphorus rich food source for marine protists[11] and viral infection of prey photoautotrophs alters the grazing behaviors of protists[12,13] and copepods[14].

Early virus-specific modeling efforts have focused on estimating the transport of organic matter from lysis through the microbial food chain[15,16]. However, despite these early efforts and the crucial role of viral infections in the carbon cycle, most geochemical models still omit viruses[17]. Viral infections are biologically non-trivial and geochemical modelers have lacked appropriate data to parameterize them. Furthermore, the fate of viral lysate to pools of DOM versus particulate organic matter (POM) is mediated by complicated organic chemistry and physics. Biogeochemical modelers overcome these issues by parameterizing the portioning of carbon and other elements between DOM and POM using ad hoc assumptions that lead to model predictions that are consistent with bulk measurements of organic and inorganic material. **Being devoid of underlying mechanisms regulating these pathways may lead models to make incorrect projections of future ocean states.** Fortunately, recent

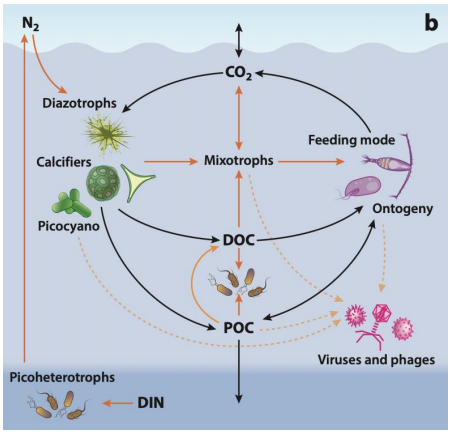

Figure 1. Food-web diagram illustrating biological carbon pump flux pathways. Despite their potential to mediate DOC and POC fluxes, viruses are generally omitted from biogeochemical models. Figure from Levine et al., (2025)[17].

advances combining laboratory-based measurements of virus-host life history traits[18,19] and molecular and chemical markers of infection[20,21] with highly sensitive field-based measurements[22,23] have opened the door to field-validated mechanistically grounded representation of viral infection in models.

The **overall goal** of the proposed scoping workshop is to determine how we can fill the "*black box*" that is viruses in global geochemical models. We will unite (i) microbiologists working on cultivated virus-host models, (ii) viral ecologists working in field systems, (iii) organic geochemists, and (iv) ecosystem and biogeochemical modelers. Initial discussions will focus on current and emerging methodologies to study carbon exchange mediated by viruses. This will be followed by discussions about current uncertainties in ecosystem models, the impact of excluding viruses, and the research required for robust integration of marine viruses into geochemical models. Following the workshop, we will form a working group, with the goal of developing and disseminating community-supported standard procedures to collect data essential for viral inclusion in carbon transport models.

2.1 Advancing OCB Priorities. The proposed scoping workshop and working group directly address OCB research priorities regarding "*marine organism-mediated carbon cycling and export via the biological pump*" and "*carbon cycling and associated biogeochemical fluxes and exchanges along the aquatic continuum*". Virus–host interactions are predicted to change with increasing global temperatures[24–27], potentially leading to alterations in virus-mediated carbon fluxes and high potential for current model predictions to diverge from observations. Through this work we will advance understanding of viral impacts on carbon transport in a changing ocean and address the OCB research priority "*marine organism response to environmental change, including molecular, physiological, ecological, and evolutionary processes*."

3. PROPOSED OCB ACTIVITY

3.1 Workshop Details. We propose an in-person workshop for ~50 persons, drawing from early, middle, and late-career stage individuals, to be held in October 2026. The workshop will be held for 2.5 days at Texas A&M University at Galveston (TAMUG). We will engage with TAMUG freshman Marine Biology, Marine Sciences, and Ocean and One Health undergraduates enrolled in the course "*Succeeding in Science*". The students will be invited to attend one session and join in small roundtable discussions with workshop participants focusing on career advising and networking.

We plan to invite four speakers, including experts in marine bacteriophage and eukaryotic virus physiology and ecology, marine biogeochemistry, and ecosystem and geochemical modeling. In addition, we will implement an open application for workshop participants and include direct outreach to various institutions and professional societies as well as publicize the workshop via social media platforms. Applicants will be asked to identify their career stage, research area, and describe their motivation for attending the workshop and how they plan to contribute to workshop goals in the future. We plan to support all participants to be inclusive of all career stages, background, and college/university size. We aim to have approximately equal numbers of participants from the four research areas identified above and will utilize a selection rubric designed with input from OCB staff.

3.2 Working Group Details. We propose to form a 12-person working group drawing from virology, microbial ecology, geochemistry and modeling expertise to transform workshop discussions into a perspective paper and determine best practices for future empirical and modeling approaches to be compiled and shared in a second edition of the Manual of Aquatic Viral Ecology[28] (MAVE, Association for the Sciences of Limnology and Oceanography (ASLO)) ebook.

3.3. Why now? Despite initial advances made by the NIMBioS Ocean Viral Dynamics Working Group (2012–2014), progress integrating viruses into ecosystem and geochemical models has largely stagnated in the past decade. **However, due to recent technological advances there is reignited interest and funding into viral modeling research, and the time is right for a synthesizing workshop and working group both to unite individual efforts and engage the broader community.**

4. PLANNED OUTCOMES & BENEFITS TO BROADER COMMUNITY

The first outcome of the workshop will be a **perspective paper** highlighting the gaps of knowledge with regards to viral infections, metabolic reprogramming, aggregation and export, and food-web impacts, and how these impact global geochemical cycles, with a focus on the carbon cycle. The second outcome will be the **formation of an interdisciplinary working group** to define standardized protocols for the generation of data from various environments and laboratories that can be directly applied to geochemical models and to engage the broader ocean sciences community via a series of webinars and scientific sessions at international conferences. Another outcome of the workshop will be to build knowledge about the impact of viruses to **overcome the current disconnect between the marine virology scientific community and the larger ocean carbon cycling community**.

This workshop will lead to **new collaborations** that would significantly advance our understanding of carbon transport via viruses. By targeting key questions identified above, as well as those emerging from discussion groups, the workshop will illuminate the "*black box*" of the role, magnitude, and importance of viruses in marine ecosystems. Exchanging knowledge across disciplines will lead to a community strategy for assessing viral impacts on ocean ecosystem function under different climate scenarios.

The subsequent working group will continue building and training a community of scientists eager to execute the proposed strategy. One outcome of the working group will be a **series of open webinars** and discussions on topics identified at workshop. Working group meetings will lead to the **creation and publication of standardized protocols** in the Manual of Aquatic Viral Ecology (MAVE) to address critical knowledge gaps with respect to incorporating marine viruses in ecosystem and global geochemical models. Protocols will be deposited to the Ocean Best Practices System (OBPS) Repository[29] which currently does not contain protocols regarding virus-mediated carbon flux. Finally, the working group will work towards **a community action plan to address research priorities** identified at the workshop and in subsequent working group discussions.

5. TIMELINE OF PROPOSED ACTIVITIES

	Activity	Target Date	2026				2027			
			1	2	3	4	1	2	3	4
Workshop	Planning	March - April 2026	■	■						
	Speaker invitations	May - June 2026		■						
	Registration open	June - July 2026		■	■					
	Application review and participant invitations	August 2026			■					
	Workshop	October 2026				■				
	Follow up with participants	October 2026				■				
	Workshop report	November - December 2026				■				
Working Group	Working group formation	November 2026				■				
	Virtual meeting	January 2027, bimonthly thereafter					■	■	■	■
	Public webinars	February 2027, quarterly thereafter					■	■	■	■
	Develop community action plan	February 2027 - June 2027					■	■		
	Coordinate 2nd edition of Manual of Aquatic Viral Ecology (MAVE)	February 2027 - October 2027					■	■	■	■
	2027 OCB Summary Workshop - in-person meeting & community input	June 2027						■		
	Finalize community action plan	July - October 2027							■	■
	Perspective paper describing future directions and best practices	December 2027							■	■
	Publish MAVE, 2nd edition	December 2027								■

6. LOGISTICAL NEEDS

For the workshop, we request funds for participant travel support, lodging, meals, room reservation, A/V assistance and publication fees. **For the working group**, we request funds for publication fees.

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