2023 SCOR WG proposal

Title: Monitoring Ocean Health: Assessing the global state and trend in phytoplankton biomass and biodiversity.

Acronym: MOHealth 2024

Summary/Abstract

During the Anthropocene our biosphere has been increasingly impacted by humans including significant impacts on ocean ecology (Bindoff et al., 2019). The cumulative impacts of these changes are not well predicted by even our most sophisticated models. There is a fundamental need for a monitoring program that allows these impacts to be observed. We require the data and tools to assess the impacts of these changes and guide responses including efforts to ameliorate, mitigate and manage. Wide consultation within the oceanic community has developed the essential ocean variables (EOVs) needed to underpin global oceanic monitoring (Miloslavich et al., 2018) including some for phytoplankton (Muller-Karger and Kudela 2016). The current monitoring methods need a systematic review to ensure they are fit for purpose. This proposal is for a SCOR WG to review, further develop, test, and refine a set of plankton measurements that are a robust, reliable, and quantitative description of the state and trends in the ecological health of our oceans.

Scientific Background

Humans are causing global impacts to the ocean ecosystem that require appropriate monitoring to develop strategic, rather than reactive, marine resource management strategies. The UN's Environment Program's Biodiversity COP15 is an important achievement designed is to "halt and reverse" biodiversity loss in the ocean by the end of this decade. The dominant flora and fauna of the ocean (phytoplankton and zooplankton), however, are listed as complementary indicators with no plan for their monitoring. Observations and modelling suggest oceanic temperatures and stratification are rising while across most of our oceans phytoplankton biomass and ocean oxygen content (Fig. 1) are declining. In the tropics, phytoplankton communities are predicted to lose 50% of their biodiversity over the coming decades (Thomas et al, 2012). If this is correct the loss of plankton biomass and biodiversity will jeopardise food security for billions of people that increasingly rely on protein derived from the sea; particularly subsistence and indigenous fishers (FAO). Changes in phytoplankton will also affect oceanic absorption of carbon, harmful algal blooms, water quality, and carbon export to the deep ocean. We suggest the fundamental goal of COP15 cannot be assessed without the monitoring of plankton across our oceans.

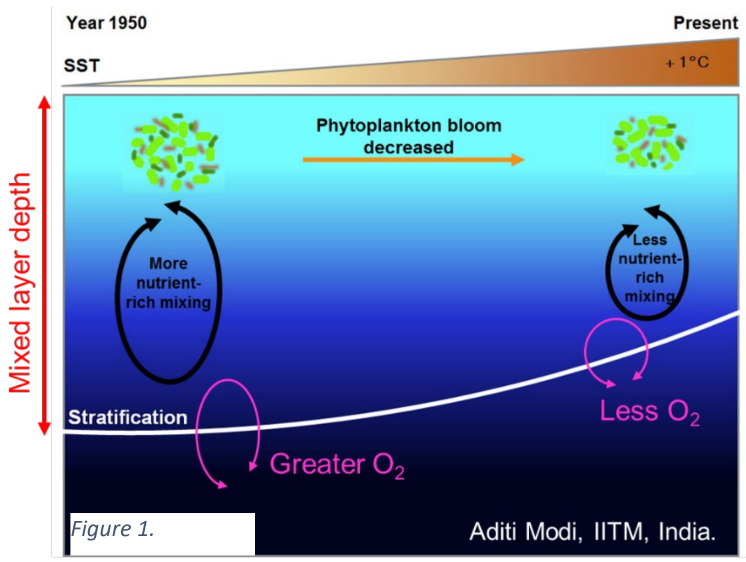

Figure 1.

The existing data for phytoplankton and zooplankton species from which to estimate biomass and biodiversity cover ~ 1/3 (Thompson and Carstensen 2023, Batten et al., 2019) of the oceanic bioregions

(Longhurst 1998). There is a need to monitor more of the ocean in a manner that allows for long term global changes in biomass and biodiversity to be quantitatively assessed. There are, however, significant scientific challenges to be overcome to achieve these goals at a reasonable cost. In particular, the short term spatial and temporal variation (noise) of phytoplankton can make assessment of biomass and biodiversity trends (the signal) challenging and thereby limiting the assessment, or modelling, of climate change impacts (Henson et al., 2010). Global assessments of phytoplankton rely on a long series of observations using both towed and fixed site observations (e.g. O'Brien et al., 2018) and satellite data. Unfortunately, we have little clarity on whether these observations provide a signal to noise ratio sufficient to observe the potential impacts of climate change at a global scale within a time frame that would allow mitigation (McDonald et al., 2018).

Spatial challenges include the statistical noise from small scale horizontal and vertical variation in phytoplankton biodiversity and biomass (Henson et al., 2010). Data from the continuous plankton recorder (CPR), the longest running phytoplankton and zooplankton time series, can be used to investigate spatial noise. The CPR data are averaged over ~ 18.5-km sections across some very long transects. The variability can be calculated at different spatial scales potentially allowing for general and location specific improvements in the spatial sampling or analytical methods.

Spatial variability in the ocean is ~ 1000 times more pronounced in the vertical than in the horizontal dimension (Harris 1978). The ideal sampling and analytical methods would be designed to maximize the accurate measure of a long-term temporal trend at every site. Long tubes, multiple bottle samples (e.g. HELCOM [https://helcom.fi/helcom-at-work/projects/peg/]) or a pumped sample (Beers 1978) may be a solution. We propose to review the existing phytoplankton data to provide recommendations on the best sampling and analytical methods to minimize small scale variability across a range of habitats.

There are also a wide variety of methods currently used to sample phytoplankton, each with their own strengths and weaknesses. For example, most open ocean plankton species monitoring uses the CPR with a 270 µm net yet the predominant phytoplankton taxa are often less than 2µm. We will compare the CPR data to bottle samples in the few locations where a CPR transect passes near fixed sampling station to better understand the strengths and weakness of each sampling method and to assess state and trend in phytoplankton biomass and biodiversity.

Temporal challenges occur in bioregions with highly seasonable phytoplankton communities (e.g. polar regions), large interannual variability, or strong mixing. Samples from individual sites are most often collected monthly, occasionally weekly or biweekly and every few minutes at sites with optical phytoplankton instruments (e.g., Imaging FlowCytobot (IFCB), FlowCAM). We will use these data to assess the impacts of sampling different volumes and temporal periods on the estimated biodiversity and biomass. Where feasible we will compare the temporal stability of estimated population characteristics across a range of physical dynamics. The results will help resolve the complex issue of the ideal temporal frequency of sampling in different environments. These results will provide the basis for improved sampling methods including at any new location.

Genomics (i.e., DNA metabarcoding) provides a broad measure of biodiversity across all life forms that has great potential to deliver a comprehensive assessment of both the state and trend of oceanic biodiversity. Taking advantage of the rapid progress and a vibrant community of experts we will assess how genomics can be better integrated into ongoing measures of the ocean's plankton biodiversity.

We anticipate that data derived from ocean color satellites will be an integral part of any oceanic phytoplankton monitoring plan because of their global spatial coverage and the potential for new hyperspectral sensors to provide information on phytoplankton biomass & diversity. Phytoplankton biomass can be quantitatively estimated as chl*a* from ocean color satellites (Dierssen 2010) however the amount of chl*a* per unit of cellular carbon (ϴ) is highly dependent upon environmental conditions. For example, phytoplankton will synthesize more, or less, chl*a* on time scales of minutes to days (Post et al., 1984) depending upon irradiance. Modelling suggests most of the observed long-term declines in oceanic chl*a* may be due to cells synthesizing less chl*a* (Behrenfeld et al. 2016). This is certainly a plausible explanation for the changes in oceanic chl*a* observed by satellites (Henson et al. 2010, Gregg and Rousseaux 2014). The results are consistent with *in situ* observations (Jackobsen and Markager 2016) suggesting further development of phytoplankton biomass indicators are highly desirable.

Carbon has fundamental roles in food chains and as a parameter in most biogeochemical and ecological models making it a better measure of phytoplankton biomass than chl*a.* Therefore, we propose a greater effort to estimate it via satellites. Almost all the particulate organic carbon (POC) found in the open ocean is derived from phytoplankton (Stramski et al., 2022). The phytoplankton carbon biomass is generally estimated by satellites using particulate backscattering coefficients (b_{bp}). More recent approaches have been developed to estimate the carbon of specific phytoplankton groups. Chase et al. (2002) for example integrates chl*a* from satellites as well as other environmental variables to estimate the content of carbon in diatoms. Kramer et al. (2022) developed an approach to derive 13 different phytoplankton pigments from ocean color data using optimized principal components regression modelling. We propose to compare these and other methods (e.g. AI, ESM) for their capability to reliably estimate the state and long-term trend in biomass and biodiversity including filling data gaps.

Finally, there have been rapid developments in hyperspectral sensors (Dierssen et al. 2020, Kramer et al., 2022) with global coverage anticipated soon from a range of satellites (e.g., TROPOMI, PRISMA, EnMAP, PACE, CHIME, SBG). These, like HPLC pigment data (Hirata et al., 2011; Moisan et al., 2017), can be used to determine phytoplankton biodiversity. We propose to use existing GOOS sites that have phytoplankton cell counts, HPLC data and satellite coverage to commence the process of comparing these three methods of estimating phytoplankton biodiversity.

Terms of Reference

Assess a range of available global satellite products for their ability to estimate long-term temporal trends in phytoplankton biomass. This will be achieved by:

TOR 1. Assess existing products that can estimate the biomass of phytoplankton as a pigment (e.g., chl*a*). For example, assess the signal to noise ratio, correct for possible physiological variation in chla, use of statistical methods to reduce noise, synthetic chla that corrects for physiological variation in chla:carbon (ϴ) and expected time span to detect a long-term signal in different oceanic regions.

TOR 2. Assess existing products and methods that can estimate the biomass of phytoplankton as carbon.

TOR 3. Review, test and evaluate methods available (ASI, ESM etc) to fill gaps in remotely sensed products.

Examine the sources of spatial and temporal variability (e.g., seasonal and interannual) in phytoplankton biodiversity.

TOR 4. Determining whether long-term trends in species abundance are present within the representative bioregion (tropical, subtropical, temperate, polar) for both common and rare species including HABS.

TOR 5. Determining how many years of observations are required to detect a climate signal for measures of biodiversity across these bioregions.

TOR 6. Assessing the potential benefits of different sampling and analytical methods to eliminate high frequency noise in phytoplankton species abundance data from different environments.

TOR 7. Assessing the ability of remotely sensed hyperspectral ocean colour methods to assess temporal trends in phytoplankton biodiversity.

TOR 8. Assessing how genomics can be better included into ongoing monitoring of planktonic biodiversity.

Working Plan

The WG proposes to have ~ 4 to 6 weekly virtual meetings averaging ~ 8 to 10 per year. Meetings are expected to be ~ 2h each. The following are proposed topics for each meeting. The work between meetings is implied by the progression of topics. The WG is constructed to have expertise on the TORs but we may need to invite other experts to assist our deliberations. Additional meetings may be scheduled as decided by the WG.

We propose to hold several 'town halls' at international conferences to engage with the broader community on how to reach our objectives of improved monitoring methods with strong international support.

Year	Meeting #	Topic
1	1	The initial meeting will provide an opportunity for all WG members to briefly introduce themselves and their work relevant to the TORs.
1	2	We will invite a representative of the GOOS Bio Eco panel (possibly co-chair Anya Waite) to address the WG and describe the monitoring challenges they are currently addressing particularly where we may be able to assist. Discuss options for a first town hall meeting.
1	3	Presentation and discussion of the existing global satellite products that estimate long-term temporal trends in phytoplankton biomass as chla.
1	4	Identify and discuss regions and data sets to be used for the testing of methods related to assessing and managing temporal variability in phytoplankton biodiversity. For example, replicate sites across tropical, subtropical, temperate and polar latitudes plus coastal and open ocean.
1	5	Discussion leading to a WG decision on one (or more) chla product for our investigation of techniques to improve the signal to noise ratio and expected time span to detect a long-term signal in different oceanic regions. (1h)
1	6	Initial discussion of methods to reduce the physiological variation in chla's impacts on long term trend assessments of phytoplankton biomass as chla.

1	7	Preliminary reporting to the WG on biodiversity trend assessments from sites identified in meeting #4.
1	8	Initial discussion on better integration of genomics into global plankton monitoring, what can we gain? How can it be integrated?
1	9	Special meeting on the monitoring of harmful algae (HA). Discuss our approach to status assessment and trend detection. Identify any specific issues that we need to address such as data access. Consider alternative methods of assessing trends such as harvest closures or events from OBIS data base. Agree on a way forward.
1	10	Review of progress to date on TORs. Potentially agree some outputs for year 2.
2	11	Planning for first 'town hall' meeting and first WG face to face meeting.
2	12	Review progress on options to correct for physiological variation in chla using data (e.g. cell size converted to carbon and compared with chla directly measured or via satellite) or modelling (e.g. Behrenfeld et al. 2016).
2	13	Initial discussion on sampling methods that may reduce small scale spatial or temporal variability in biodiversity estimates. Agree on next steps.
2	14	Initial discussion of methods that can be used to fill gaps in remotely sensed data. Agree on a work plan for assessment of methods across the range from little affected to badly impacted bioregions. Review progress on genomics in global monitoring.
2	15	TOWN HALL 1 + face to face meeting. Collective writing on one or more outputs by WG. Consider options for a second town hall.
2	16	Initial report on the time scales required to detect temporal trends in chla products for various bioregion without gap filling.
2	17	Initial assessment of remotely sensed hyperspectral ocean colour methods to assess temporal trends in phytoplankton biodiversity. Agree work plan.
2	18	Final report to WG on estimating biodiversity trends in phytoplankton species data, move to writing phase.
2	19	Update on estimating the biomass of phytoplankton as carbon via satellites including estimating from chla, backscatter, etc. Finalize work plan.
2	20	Review progress for year, identify and agree outputs for year 3.
3	21	Plan for second town hall meeting and second WG face to face meeting.
3	22	Update on genomics and monitoring. A plan for the future?
3	23	Report to WG on methods for estimating phytoplankton carbon. Move to writing phase.
3	24	Second meeting on hyperspectral methods, discussion of testing and validation.
3	25	TOWN HALL 2 + face to face meeting. Collective writing on one or more outputs by WG. Consider options for a third town hall.
3	26	Second meeting on methods of filling spatial and temporal gaps in satellite data. Consider moving to writing phase.
3	27	Second meeting on HA, discussion to refine potential outputs.
3	28	Planning for final town hall meeting.
3	29	Final report to WG on satellite estimation of phytoplankton carbon. Discussion of potential recommendations and outputs.
3	30	Final report to WG on the options for sampling methods that reduce noise (small scale variability over time or space) in biodiversity measures. Develop a plan for output.
4	31	Review progress.
4	32	TOWN HALL 3 + face to face meeting. Final collective effort on writing of outputs.

4	33	Penultimate meeting to reassess progress and discuss any remaining tasks.
4	34	Wrap up meeting.

Deliverables

Each TOR is a potential publication. At a minimum we anticipate 1 publication from TORs 1-3 and a second publication from TORs 4-8. Manuscripts will be submitted to Open access journals; or we seek institutional support to fund open access.

In addition to published papers, we will make recommendations to GOOS regarding the Global Ocean Observing System's essential ocean variables for phytoplankton.

We also propose to produce a manual of best practices for sampling phytoplankton across a range of environments.

Capacity Building

Within the first 6 months each of the 4 ECRs will be asked to identify several potential mentors from the WG and we will pair them with one of these. The mentor and mentee are expected to develop an individualized plan for the mentee that will help shape their contribution to the WG. The mentor is expected to support the mentee development throughout the WG's life.

Initially we will spend some time reviewing the current state of knowledge for these quite diverse topics (as summarized in the 'Scientific Background' and TOR). All Full members, including 3 ECRs, will be expected to present to the WG a summary of their research that is pertinent to one or more of the TORs. Associate members, including the remaining ECR, will be offered the same opportunity. For the ECRs we feel this may be the first time they will have actively considered how their science may be aligned with the range of challenges that need to be overcome to create a global observing program that will observe climate impacts before it is completely impossible to mitigate significant negative effects.

The WG will prioritize the attendance of its 2 ECRs from developing economies plus our other 2 ECRs at the international conferences where we propose to hold 'town hall' style events. We would ensure that at least one senior member of the WG is available to facilitate introductions and opportunities for each ECR at these events. Any ECR that desires it will be given the opportunity to conduct part of the town hall meeting. This should be a good opportunity to develop greater confidence in their public speaking in a less structured situation (e.g., not a simple presentation).

We will encourage all WG members to attend regional scientific meetings to act as ambassadors for the WG. We expect this will encourage more ECRs to think globally and join the effort to improve the ocean observing system. Some members are already actively engaged in capability development around the Indian Ocean, Indonesia and the South Pacific. For example, one member met individually with all the ECRs attending the 2023 Indian Ocean Expedition 2 meeting and will repeat this at the IIOE2 meeting in Indonesia in 2024.

The WG will seek opportunities within international and regional GOOS offices for our ECRs to engage directly with the people already delivering the global observing system. Most regional alliances have annual meetings that our ECRs could attend; potentially presenting our evolving ideas.

We anticipate that a greater awareness of the existing observing program(s) could be beneficial to these young academics.

We will promote the SCOR Visiting Scholars Program within our WG and already have strong indications that members will be applying.

Working Group Composition

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1.Cecile Rousseaux (co-chair)	F	NASA, USA	Satellite oceanography
2. Karlie MacDonald (co-chair)	F	University of Tasmania, Australia.	Phytoplankton ecology
3. Peter Thompson	M	CSIRO, Australia.	Phytoplankton
4. Kalle Olli	M	Estonian University of Life Sciences, Estonia.	Phytoplankton
5. Aditi Modi	F (ECR)	Indian Institute of Tropical Meteorology, India.	Satellite oceanography
6. Chris Bowler	M	Institut de Biologie de l'Ecole Normale Supérieure (IBENS) Ecole Normale Supérieure, France.	Genomics
7. Elodie Martinez	F	LOPS, France.	Phytoplankton dynamics
8. Priscila Lange	F (ECR)	University of Sao Paulo, Brazil.	Satellite Oceanography.
9. Aimee Neely	F (ECR)	SCIENCE SYSTEMS AND APPLICATIONS INC, USA	Phytoplankton, field sampling, validation
10. Pierre Hélaouët	M	Continuous Plankton Recorder Survey, UK.	Phytoplankton

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1. Adriana Zingone	F	Stazione Zoologica Anton Dohrn, Italy.	Phytoplankton
2. Hans Jakobsen	M	Aarhus University, Denmark.	Phytoplankton and carbon
3. Alice Newton	F	Universidade do Algarve, Portugal.	Phytoplankton HABS
4. Dongyan Liu	F	East China Normal University, China.	Phytoplankton

5. Masami Nonaka	M	Japan Agency for Marine-Earth Science Technology	Climate Modelling
6 Sylke Wohlrab	F	Alfred Wegner Institute	Genomics and phytoplankton
7. Joan Llort	M (ECR)	Barcelona Supercomputing Centre (BSC)	Phytoplankton modelling.

Working Group contributions

Cecile Rousseaux completed her PhD in oceanography and has built a career developing and using satellite products to investigate phytoplankton in a changing world.

Karlie MacDonald is a phytoplankton ecologist with a strong interest in the sustainable management of our oceans.

Peter Thompson has spent 45 years studying phytoplankton physiology and ecology and a strong desire to advance this field some more.

Kalle Olli uses large data sets to study fundamental properties of phytoplankton ecosystems.

Aditi Modi is a young ECR (just submitted her PhD) with considerable skills in the use of satellite data for ecological research.

Chris Bowler is a world leading marine scientist and geneticist.

Elodie Martinez is using multi-mode convolutional neural networks to reconstruct satellite-derived chlorophyll-a time series in the global ocean, skills we need in this working goup.

Priscila Lange is an ECR using satellites, modelling and in situ observations to study phytoplankton ecology.

Aimee Neely is the ideal scientist to lead the development of method to extract a consistent measure of biomass from satellite measurements of chla; noting that the chla content of phytoplankton fluctuates on time scale of minutes to months.

Pierre Hélaouët is a leading developer of analytical and statistical methods to extract the greatest possible value from CPR data.

Relationship to other international programs and SCOR Working groups.

We anticipate potential relationships with the Bio Eco Panel of GOOS, the IOC working groups TrendsPO, the IPHAB Task Team Harmful Algal Information System (HAIS) & Global HAB Status Report (GHSR). In addition, there are connections within the proposed WG to rapidly developing capabilities in remote sensing currently being undertaken in Europe and US (e.g. PACE).

Appendix

Rousseaux

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