OCB Fish, Fisheries and Carbon workshop:

An emerging research direction in the ocean biological carbon sink

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1. Scientific Summary

The biological pump transports carbon to the deep ocean, and our understanding of this process has greatly improved over the last decade, from a traditional view focused exclusively on plankton sinking, to a more holistic view which includes mixed layer pumps, seasonal lipid pumps and the contribution of fish to carbon transport (Boyd *et al.*, 2019). The biological pump is represented in Earth System Models and thus has a role in climate projections. It can remove carbon from the surface ocean, whilst also recycling carbon and other nutrients throughout the ocean depths, which eventually feeds back to surface ocean productivity. A lack of research on trophic levels beyond plankton means we do not have the data to parameterise higher trophic levels in high resolution, global biogeochemical models. Yet a paper published this year by the '*Towards a better understanding of fish contribution to carbon flux*' OCB working group led by Grace Saba (Saba *et al.*, 2021) found that fish contribute 16 % (1.5 Gt C yr^{-1}) to total gravitational carbon sink, via faecal pellets and deep respiration (Fig. 1). Clearly fish and other trophic levels beyond plankton (e.g. krill, salps, jellyfish) could having important feedback on the climate. But data and thus our understanding of the complex feedbacks and their temporal and spatial variation is sparse.

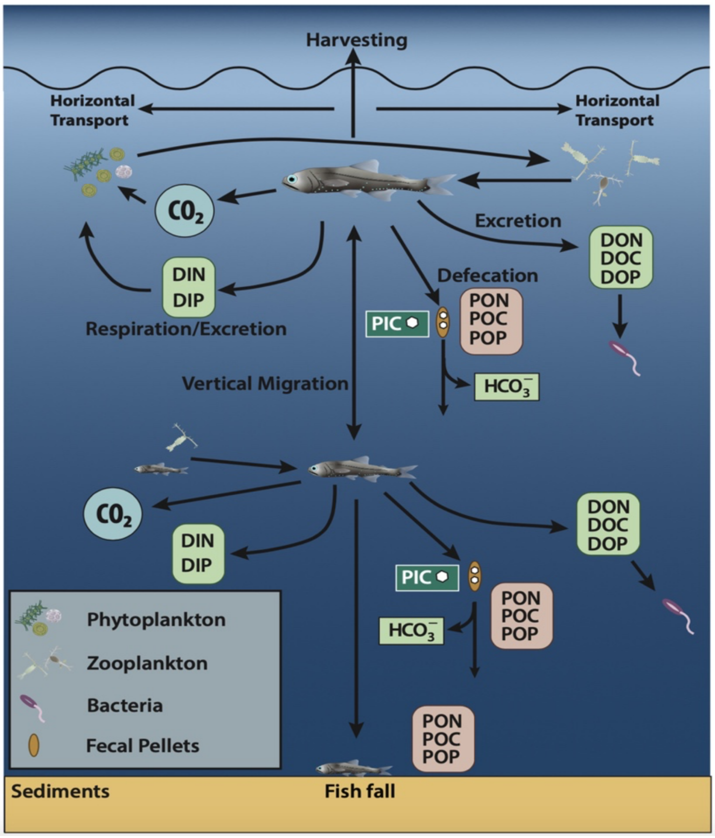

Fig. 1. Conceptual diagram highlighting the mechanisms by which fishes contribute to the biological carbon pump and nutrient cycling. Arrows between different types of organisms infer predation from a prey item to a predator (arrow pointing to the predator; e.g., zooplankton feeding on phytoplankton in the upper water column, myctophids feeding on zooplankton in the upper water column, myctophid feeding on zooplankton and small fishes in mid-water). From Saba et al. (2021).

Industrial fishing and whaling has been changing the composition of ecosystems for decades and causing the collapse of some fish stocks. Much of the research on fishing impacts focuses on the harvested species themselves, although trophic cascades caused by fishing can affect the entire foodweb, including plankton (Fig. 2). This means fishing is likely to impact the carbon sink by causing 1) changes to the plankton gravitational sink, and 2) a loss of sinking carbon from harvested fish (Cavan and Hill, in review). The loss of sinking fish carcasses due to harvesting and the CO2 emitted by fishing vessels alone has released 0.73 Gt CO_2 since the 1950s (Mariani *et al.*, 2020), whilst industrial exploitation of fish stocks is thought to have halved fish biogeochemical cycling with impacts on primary production and the carbon sink (Bianchi *et al.*, 2021) (Fig. 3). Given our lack of knowledge on fish contribution to the carbon sink as described above and the complexity in predicting trophic cascades, quantifying the total potential consequence of industrial fishing on the biological pump is not trivial. Nonetheless progress has been made on understanding the contribution of a non-fished group, the mesopelagic fish to the carbon sink.

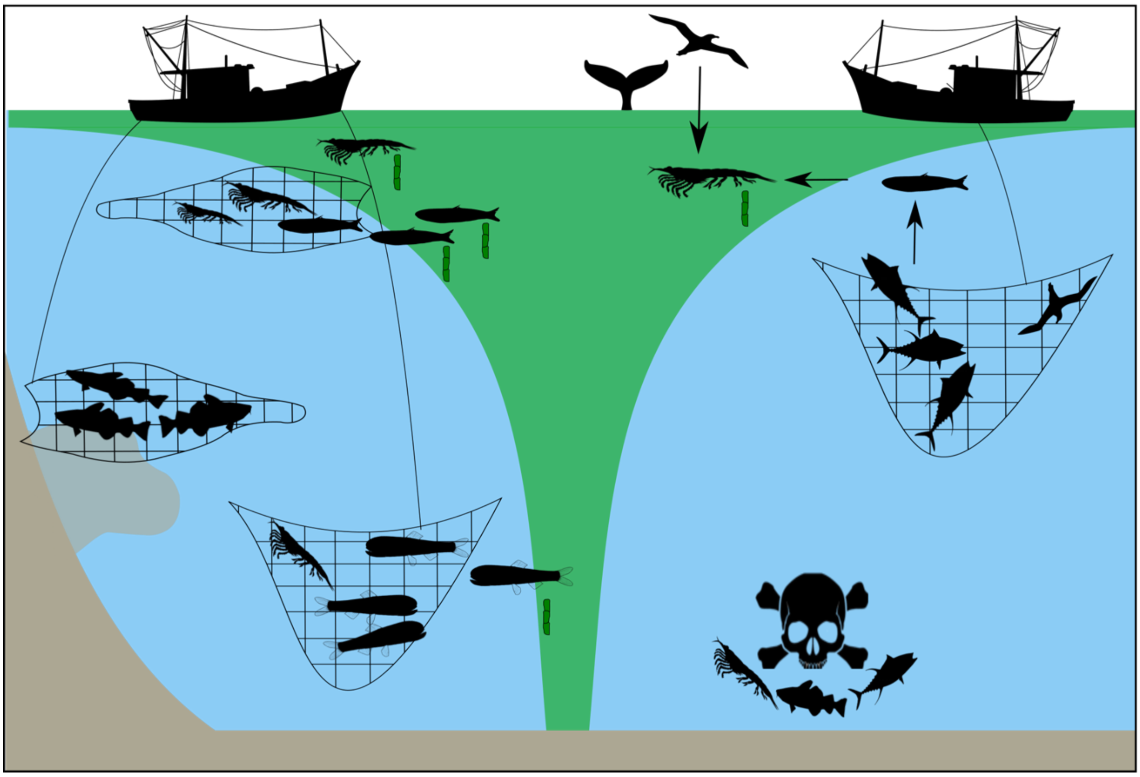

Fig. 2. **Direct and indirect impacts of fishing to the carbon sink**. Phytoplankton (green shading in the surface) stimulate fish biomass production and the export of carbon out of the upper ocean, of which ~ 1 % sinks to the deep ocean. The carbon sink is enhanced by fertilising species and those egesting fast-sinking carbon-rich faecal pellets. Direct impacts of fishing (left) include harvesting pellet-producing species, removing species living near the seabed, sediment disturbance from groundfish harvesting, removing mesopelagic species and finally reducing large falls of dead organic matter to the deep sea and sediment. Indirect impacts (right) include causing trophic cascades impacting communities that sink carbon, removing prey items for fertilizing species (e.g. mackerel or krill that feed seabirds), killing predators (e.g. seabirds) that may otherwise fertilise the oceans and help to maintain a balanced food web, and finally the release of discards which could cause localized dead zones.

Ideally if we are able to quantify how fishing changes the biological pump, and come up with monitoring solutions to keep track of fishing impacts, then the protection of the biological pump could be implemented into fisheries policy. This is a delicate task though, as aquatic food sources could be key in ending world hunger (Golden *et al.*, 2021), and there are a myriad of social and economical factors to consider as fishing supports the livelihoods of millions of people worldwide. The integrative topic of fish, fisheries, and carbon has been gaining wide interest quite rapidly over the past few years, but the diverse range of experts have not yet convened to comprehensively discuss and address the effect of fishing on potential carbon sequestration, policy considerations, and potential repercussions on socioeconomics. This proposed workshop aims to do just that.

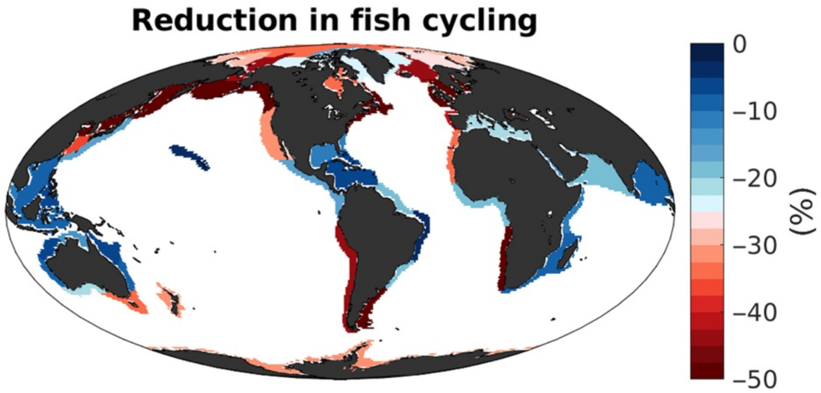

Fig. 3. Reduction (%) of the biomass cycling rate by targeted fish at the time of the global peak catch, averaged over Large Marine Ecosystems (Bianchi et al. 2021)

2. Workshop Aims:

The specific aims of this international, virtual workshop (three half-days) are split into three major themes:

1. **Fish contribution to carbon sink**. We aim to showcase the latest research on fish and fisheries in sinking carbon, and discover which academics, policy makers, NGOs and institutes are invested in this (Day 1)
2. **Fishery disturbance to carbon sink**. We will identify the knowledge and data gaps that need filling to work with higher trophic levels in biogeochemical models, and to write in the protection of the carbon sink in fishery policy (Day 2)
3. **Socioeconomic impacts**. Considering the numerous stakeholders in fisheries and sinking carbon, we will identify what the socio-economic outcomes might be of editing fishery policies to include protection and monitoring of the carbon sink (Day 3).

We intend to recruit participants that encompass diverse range of scientists and non-academics including: Fishery scientists, Biogeochemists, Deep-sea biologists, Earth System Modellers, Physical Oceanographers, Economists, coastal/benthic ecologists, Policy/knowledge exchange marine scientists and food supply scientists. From the past OCB Fish Carbon Working Group and our current collaboration with the NGO Our Fish, we have already compiled a database of ~ 40 academics working on this topic who we will invite to workshop plus the authors of papers cited in this proposal. This includes academic working groups such as ICES, IMBER, JETZON, EXPORTS, FISHMIP, the IPCC and the UN Ocean Decade. All post-graduate career stages will be encouraged to participate. Non-academics we will target includes NGOs such as Our Fish, WWF and the Pew Trusts whom we already have contacts with. We will also invite fishery management to attend and representatives from the relevant departments of national governments. We may also extend the invite to engaged fishers, which will be particularly relevant when discussing how to best engage with fishers and even use their vessels as 'ships of opportunity' to collect samples and data.

3. Outcomes and Products

The intention is that this workshop will identify the priority research and methodology gaps in this field and provide a venue to build interdisciplinary, international collaborative groups to stimulate further research. The specific products that will be developed as an outcome of this workshop include:

i. Webinars and blogs leading up to the workshop
ii. Workshop summary - openly accessible
iii. Skeleton of a future funding bid
iv. Extended database of ongoing research related to this workshop
v. Holistic review paper, physics - carbon - fish - society, on how fish and fishing contribute or alter the biological carbon sink
vi. Chair session at Ocean Sciences Meeting 2024
vii. Future working groups e.g. SCOR

4. Relation to OCB priorities

These efforts build off the recent OCB Fish Carbon working group that estimated the significant role fish play in global carbon export (Saba *et al.*, 2021), by expanding these implications to evaluate the relevance of the loss of this flux through fishing. Our proposed workshop addresses two broad OCB research themes including *Biological Pump* and *Ocean Carbon Uptake and Storage*. Specifically, within these broad topics our proposed workshop will highlight *Marine organism-mediated carbon cycling and export via the biological pump*, *Benthic carbon cycle feedbacks, from shallow to deep-sea marine habitats*, and *Marine organism response to environmental change, including molecular, physiological, ecological, and evolutionary processes*. We would also be addressing OCB's current research priority on *Carbon cycling and associated biogeochemical fluxes and exchanges along the aquatic continuum, from rivers to the coastal ocean*. The other academics engaged in this research topic and cited in this proposal are also part of the OCB community. We will encourage participants to contribute to the OCB summer seminar series in the lead up to our event. Also note, all citations in this proposal are from 2019 or later, because the topic is so new.

5. Workshop logistics

The workshop will be online to 1) prevent CO_2 emissions from long-distance travel, 2) allow participation from across the globe and 3) increase participant diversity as it will be free to attend with no travel costs. With our diverse co-chair group leading the workshop, emcompassing different genders, ethnicities and career stages, we aim to attract a similarly diverse audience.

We anticipate to hold the workshop in early 2023 to avoid key holidays and peak work months for academic staff. This also allows us time to create a workshop logo to advertise the event, and hold webinars and encourage blogs to be written on the website in the lead up to the event. We will run the workshop over three half-days, with half-days preferred to try and encourage devoted attendance during the 4-hours of each session whilst allowing participants to still achieve other important tasks during their working days. The times will be scheduled to accommodate the four organisers whilst also making sure participants from all continents are able to engage with the workshop, even if not live.

The workshop will be hosted online by e-posterboards who ran the OCB summer workshop online, and whom we have had an online demonstration of their services. The platform allows an interactive online workshop, with the use of Miro to allow breakout groups to create annotated white boards. There is also a polling option so participants can vote on important topics for funding bids. We will customise the online facility with a workshop logo.

The schedule for each planned 4-hour session is broken down below and includes:

- A 20-minute introduction to workshop and the session topic by moderator (a co-chair)
- 50 minutes of presentations (4 x 10 minutes) selected by the co-chairs from an abstract submission process prior to the workshop
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- 15-minute Break
- 1 hour in breakout room - topics and focus set by co-chairs ahead of schedule, produce output live on whiteboard function to identify key data gaps and methods.
- 30 minute feedback in lecture hall, moderator's assistant (in background) makes an online poll to vote on key topics or biggest knowledge gap, then close

6. Funding requested

We request a total of USD $30,000 for this workshop. This covers the online platform to host the event ($21,000), a scientific graphic designer (www.visualknowledge.design) to produce a workshop logo and engaging graphics for the website and publication ($5,000), and open-access publishing fees ($4,000).

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