BRICS: Biology's Role In ocean Carbon Storage – a gap analysis

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BIO CARBON

Natural Environment Research Council

National Oceanography Centre

BRICS’ goals

The Bio-Carbon gap analysis project was tasked with:

- Analysing existing global models and observations to identify major knowledge gaps (in relation to biological processes that impact ocean C storage across the 3 Bio-Carbon Challenges)
- Ranking the knowledge gaps by their influence in determining the future biologically-mediated storage of C in the ocean
- Gathering input from a wide range of experts
- Identifying significant knowledge gaps likely to be tractable by the fieldwork programme
- Identifying limitations in how current models represent the carbon system
- Informing the development of future fieldwork and modelling proposals
- Providing evidence at this workshop to inform the geographic and seasonal focus of the programme’s North Atlantic cruise plan

Gap analysis process

- Initial identification & grouping of significant processes
- Shortlist agreed by BRICS team
- Literature review (models, observations & lab studies)
- Population of evidence tables
- Expert assessment by BRICS team of evidence to rank processes
- Community-wide survey to rank processes
- In parallel: Model structure interrogation & CMIP6 trend analysis
- Biogeography, seasonality and observational tractability noted

Biological contributions to Alkalinity	Net Primary Production	Interior Respiration
High level understanding of calcium carbonate production	Resource limitation of growth	Biotic fragmentation
Mineralogy of calcium carbonate production	Phytoplankton physiology	Abiotic fragmentation
Rain ratio	Phytoplankton loss processes	Aggregation
Physiology of CaCO3 production	N2 fixation	Preferential Remineralisation
Plankton community	Phytoplankton adaptation, acclimation	Mineral ballasting
Fish derived carbonates	Zooplankton processes	Zooplankton vertical migration
Biotically mediated dissolution	Plankton metabolism	Fish-mediated processes
Abiotic dissolution	Organic matter cycling	Ontogenetic migration
Primary production and remineralisation	External nutrient inputs	Organic matter lability
Nutrient cycling	Food web complexity	Ectoenzymatic hydrolosis
Organic alkalinity	Mixotrophy	Microbial solubilisation
Sedimentary processes	Microbial loop	Viral infection
Riverine supply of alkalinity	Micronutrients	Particle characteristics
Calcium carbonate within sea ice	Response to thermal stress	Particle type
		Zooplankton processes

Evidence tables

- Total of 227 papers reviewed, generating 90 pages of evidence tables

Published studies are classified as baseline (B), future (F), observational (O), experimental (E), model (M) or review (R).

Process	Short definition	Evidence for this process' impact on C storage
Biotic Fragmentation	Fragmentation of particles into smaller pieces by the action of zooplankton flux feeding or swimming	**Briggs et al. (2020; O, B)** 'In this work, using robotic observations, we quantified total mesopelagic fragmentation during 34 high-flux events across multiple ocean regions and found that fragmentation accounted for 49 ± 22% of the observed flux loss.' * *cannot determine whether it is biotic or abiotic fragmentation and focused on high-flux events **Dilling and Alldredge, (2000; O, B)** 'At the abundances observed in this study, swimming E. pacixca would have sufficiently disturbed 3-33% of the water column each night to disrupt the aggregates contained therein. This is the first evidence for the fragmentation of large particles by the swimming activities of zooplankton and suggests that macrozooplankton and micronekton play a significant role in the particle dynamics of the water column regardless of whether they consume particles or not.' **Iversen and Poulsen, (2007; E, B)** 'Actual ingestion of captured pellets was rare (<37% for C. helgolandicus and <24% for P. elongatus), and only small pellet fragments were ingested unintentionally along with alternative food. We therefore suggest coprorhexy (fragmentation of pellets) to be the main effect of copepods on the vertical flux of fecal pellets.' **Cavan et al. (2020; E, B)** 'Using aquaria-reared Antarctic krill fecal pellets, we showed fragmentation increased microbial particulate organic carbon (POC) turnover by 1.9×, but only on brown fecal pellets, formed from the consumption of other pellets. Microbial POC turnover on un- and fragmented green fecal pellets, formed from consuming fresh phytoplankton, was equal. Thus, POC content, fragmentation, and potentially nutritional value together drive POC turnover rates.' **Stemmann et al. (2004, O, M, B)**

BRICS team expert assessment

Basis for Importance ranking		Basis for Uncertainty ranking	
High importance	Has a substantial influence on determining the future biologically-mediated storage of C in the ocean	High uncertainty	Minimal supporting evidence and/or contrasting evidence with no consensus reached by the scientific community.
Medium importance	Has a moderate influence on determining the future biologically-mediated storage of C in the ocean	Medium uncertainty	Some supporting evidence with gaps in research or no clear consensus reached by the scientific community.
Low importance	Has a weak influence on determining the future biologically-mediated storage of C in the ocean	Low uncertainty	Strong supporting evidence from a range of studies. Consensus has been reached by the scientific community.

https://bio-carbon.ac.uk/bio-carbon/sites/bio-carbon/files/documents/BRIC-stables4biocarbon.pdf

BRICS team expert assessment – an example

Process	Definition	Importance	Uncertainty
Biotic fragmentation	Fragmentation of particles into smaller pieces by the action of zooplankton flux feeding or swimming.	High	Medium
Aggregation	Formation of larger particles by the aggregation of smaller particles. Transparent Exopolymer Particles (TEP) and other sticky exudates may increase the success rate of collisions.	High	Medium
Preferential remineralisation	Preferential remineralisation of elements relative to carbon of dissolved organic matter (DOM) and particulate organic matter (POM)	High	Medium
Microbial solubilisation	Microbial respiration of dissolved and particulate organic material. The rate of solubilisation may be impacted by the microbial community and metabolic rates and growth efficiencies. Pressure, temperature and oxygen concentration, and other factors will impact these rates.	High	Medium
Particle characteristics	The size, morphology, porosity and density of particles which can affect their sinking speed and susceptibility to remineralisation, fragmentation or (dis)aggregation (excluding the role of ballast).	High	Medium
Particle type	The type of particle (e.g. fecal pellet, aggregate, single cell, carcass, mucus web) will affect the sinking speed and susceptibility to remineralisation or fragmentation/aggregation.	High	Medium
Zooplankton vertical migration	Daily vertical migration of zooplankton between euphotic and mesopelagic depths. Also referred to as active flux, with excretion, egestion, respiration and mortality occurring in the mesopelagic.	Medium	High
Fish-mediated processes	Daily vertical migration of fish and their contribution to flux via fecal pellet production.	Medium	High
Ontogenetic migration	Seasonal migration of zooplankton to mesopelagic depths where they remain over winter (also referred to as the lipid pump).	Medium	High
Mineral ballasting	Biomineral (biogenic silica, calcium carbonate) or lithogenic (dust) material which increases the specific density and sinking speed of particles.	Medium	Medium
Organic matter lability	Particulate organic matter and dissolved organic matter is composed of compounds of varying lability, with some more readily remineralised than others.	Medium	Medium
Zooplankton processes	Zooplankton particle interactions (e.g. grazing, fecal pellet production, coprophagy) excluding biotic fragmentation and diel vertical migration.	Medium	Medium
Ectoenzymatic hydrolosis	Microbial excretion of extracellular enzymes to degrade complex organic compounds.	Low	High
Viral infection	Viral infection of cells can lead to cell lysis. This may lead to the viral shuttle, i.e. increased secretion of sticky material promoting aggregation, or to the viral shunt, i.e. increased DOC production and a reduction in transfer of carbon to higher trophic levels.	Low	High
Abiotic fragmentation	Fragmentation of particles into smaller pieces by turbulence or shear.	Low	Medium

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Expert assessment examples:

- Biotic fragmentation: Fragmentation accounts for 49 ± 22% of the observed flux loss (Briggs et al., 2020) → high importance
- Mechanism = prokaryotes or zooplankton? biotic or abiotic? Zooplankton might interact with anywhere from ~ 3-100% of particles (Dilling & Aldredge, 2000; Goldthwait et al., 2004) → medium uncertainty

Expert assessment examples:

- Zooplankton vertical migration: Including DVM in global model increases flux by 14% (Archibald et al., 2019) → medium importance
- Estimates of importance range span 5 orders of magnitude (Bollens et al., 2011) → high uncertainty

Expert assessment examples:

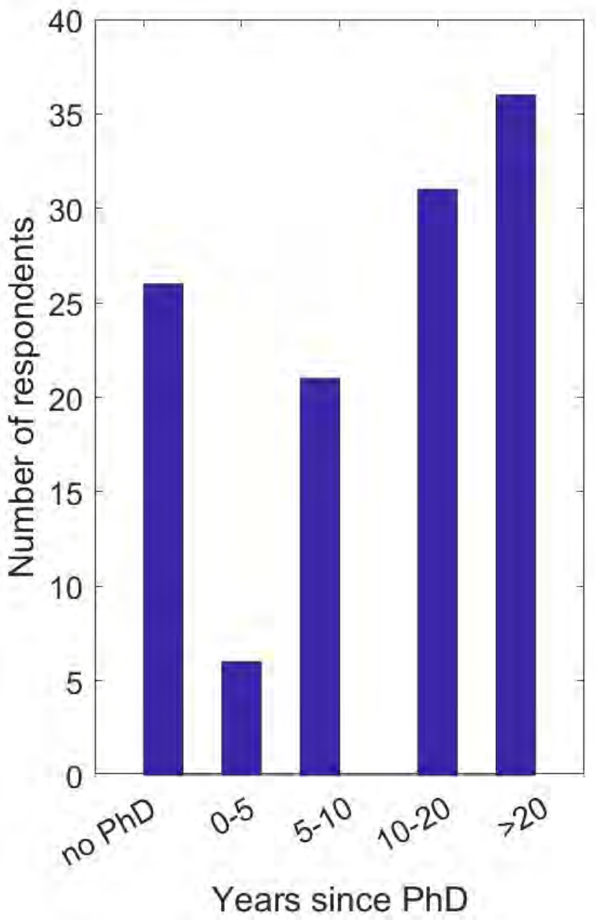
- Viral infection: Viral activity *could* be associated with higher transfer efficiency; correlation analyses, circumstantial evidence so far (Kaneko et al., 2021; Laber et al., 2015) → low importance, but high uncertainty

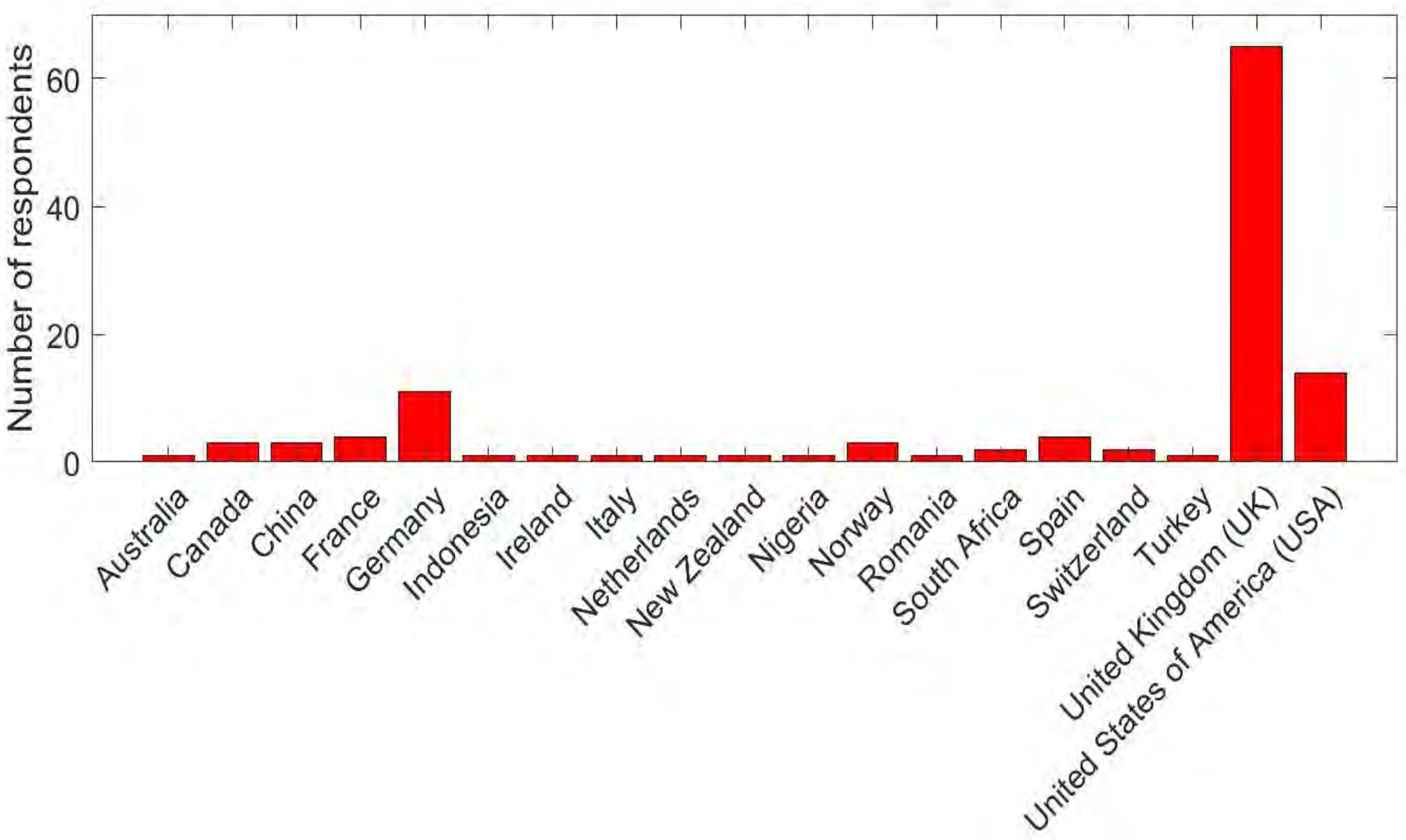
Community survey

- Designed by the BRICS team (which includes an expert in scientific community surveys)
- Participants were asked to rank their top 3 most important processes from the short-list for each of the 3 Challenges
- The survey question specified that "important" was how significant these processes are likely to be for determining the future biologically-mediated storage of carbon in the ocean
- The survey question also specified that the focus is on the global and centennial scales relevant to coupled climate models
- Additional questions on gender, career stage, country of origin, specialty, level of expertise etc.

Survey demographics

Total of 120 respondents



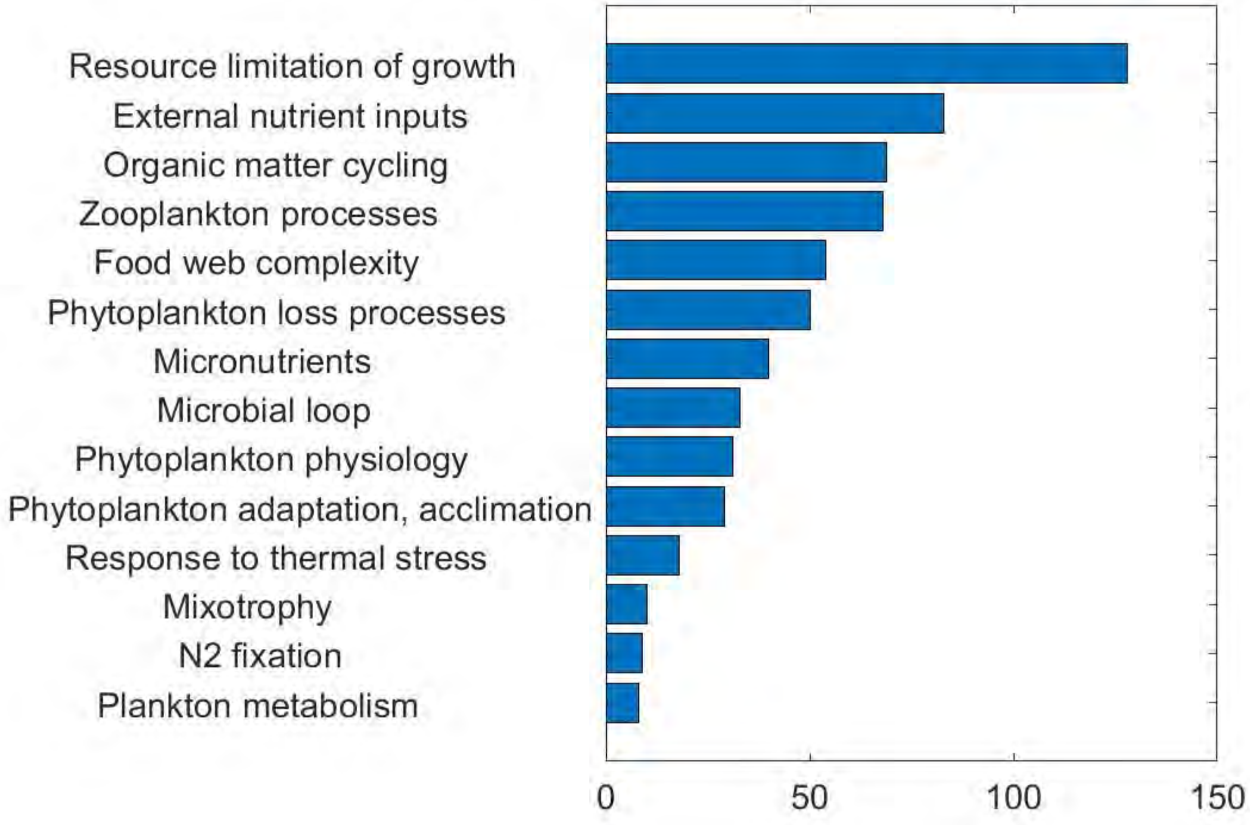


Survey results

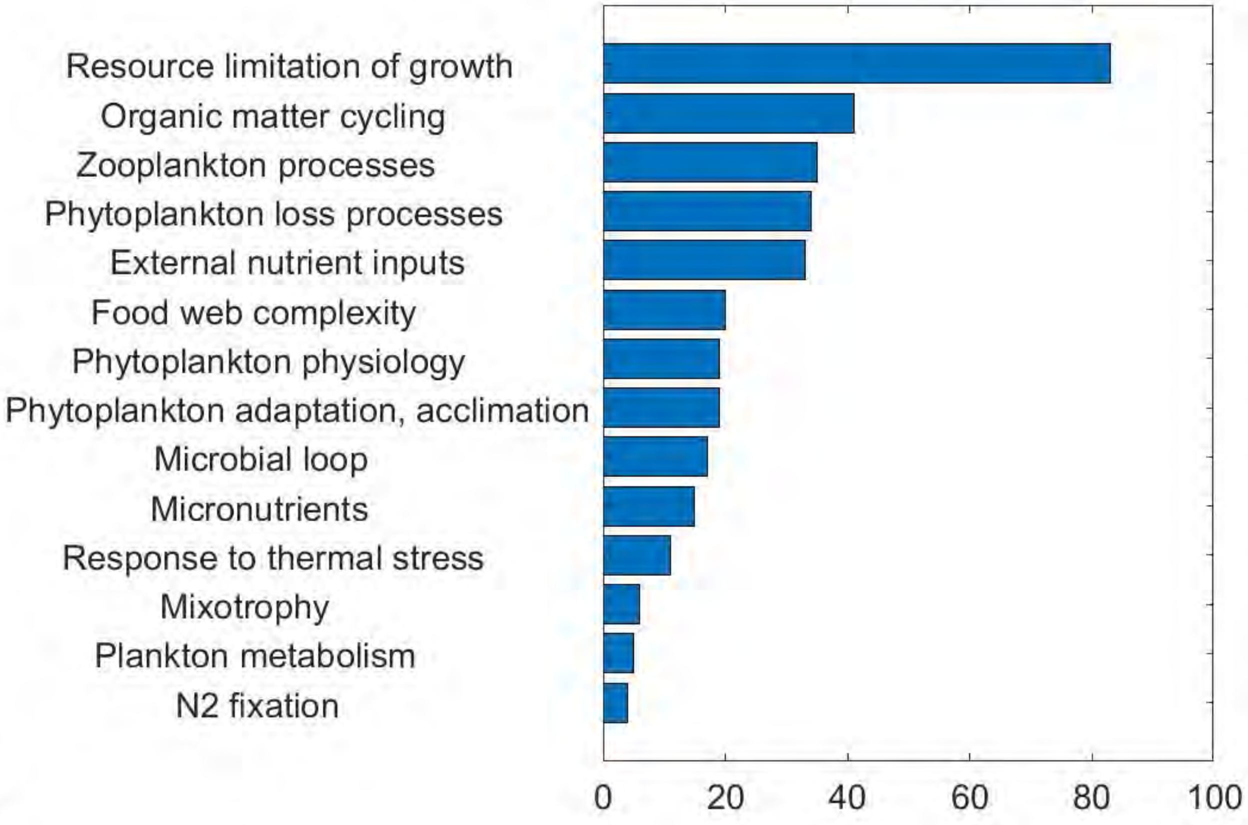
- A total of 105, 88 and 61 respondents completed the sections on net primary production, interior respiration and biological contributions to alkalinity, respectively
- Respondents were asked to rate their expertise → those with “high” or “moderate” expertise numbered 57, 40 and 23, respectively
- In the following charts responses are weighted so that the 1st ranked choice = 3 points, 2nd ranked = 2 points, and 3rd ranked = 1 point.

Net primary production

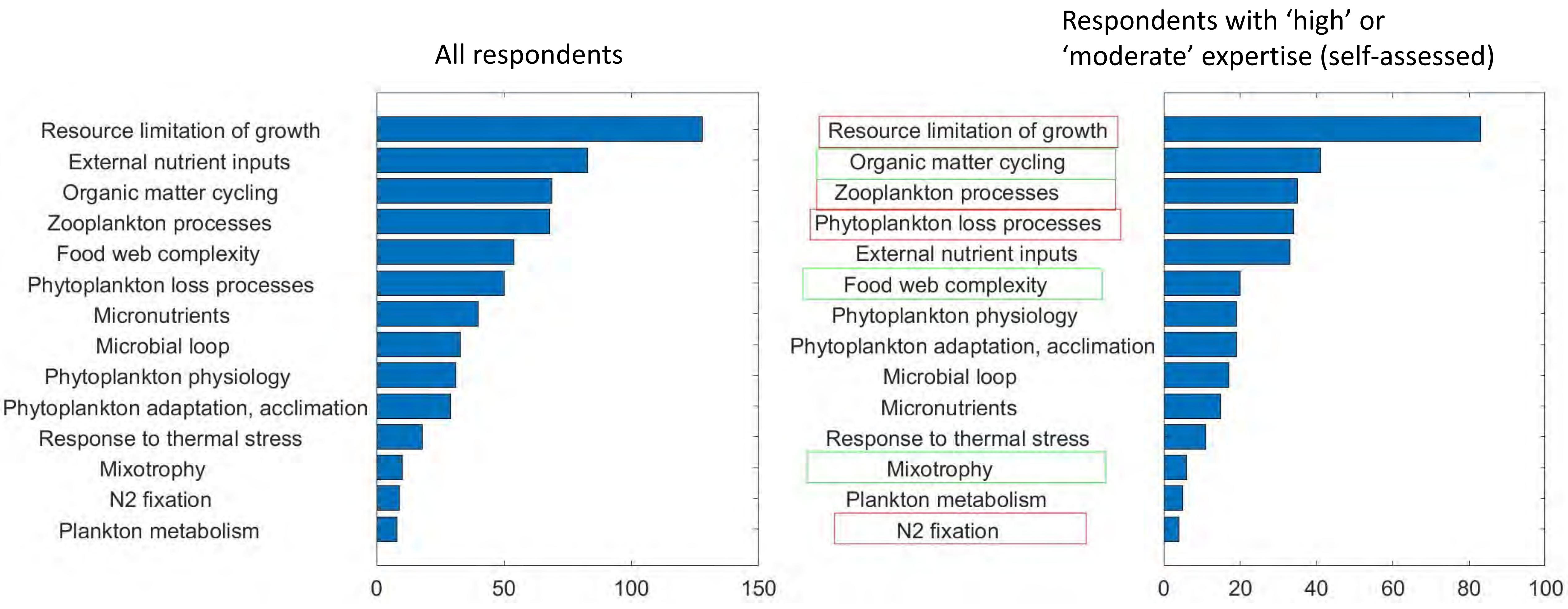
All respondents



Respondents with ‘high’ or ‘moderate’ expertise (self-assessed)



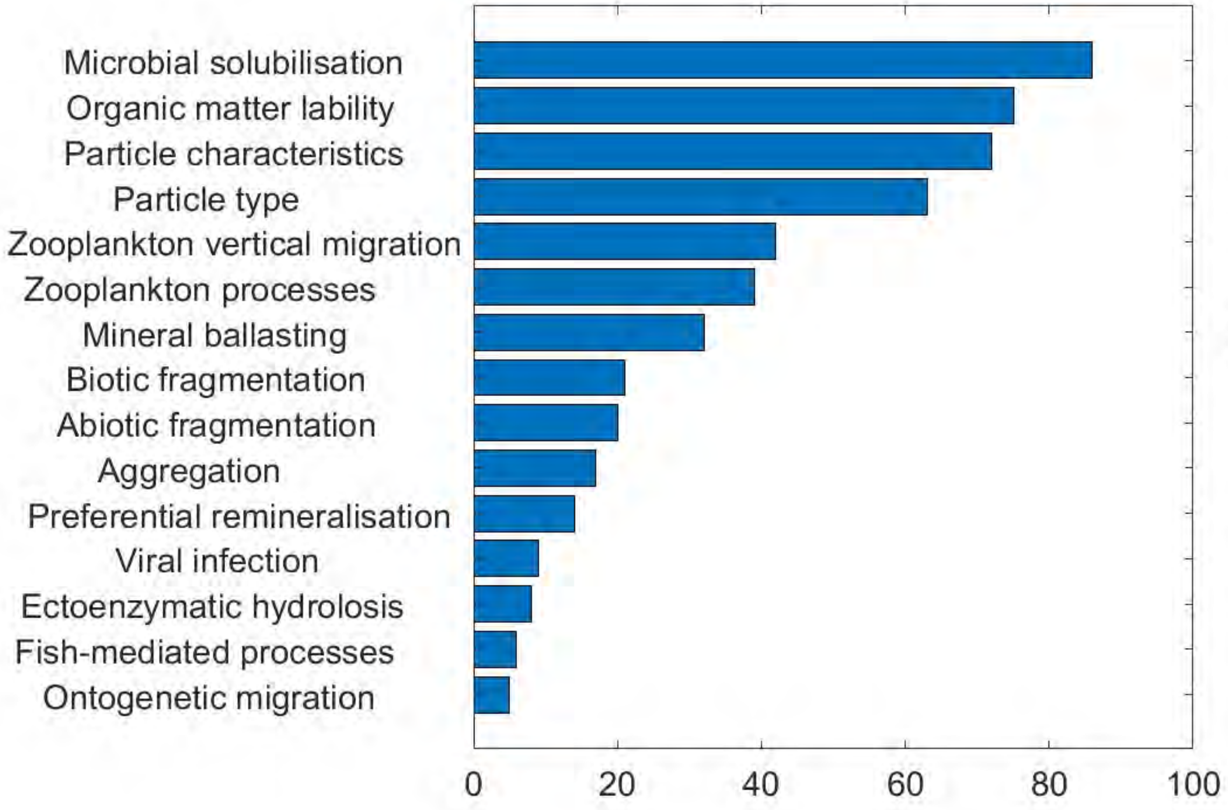
Net primary production



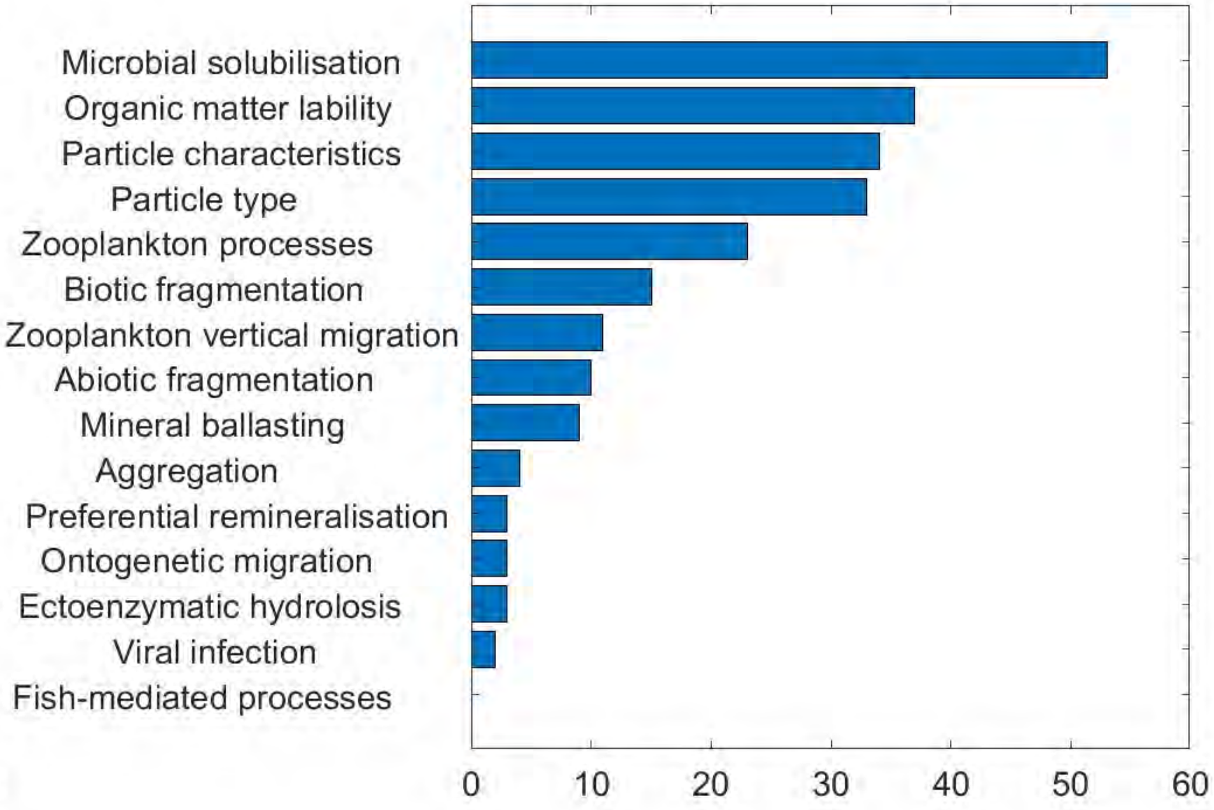
Red boxes = ranked “high” importance in expert assessment
Green boxes = ranked “low” importance in expert assessment
No box = ranked “medium” importance in expert assessment

Interior respiration

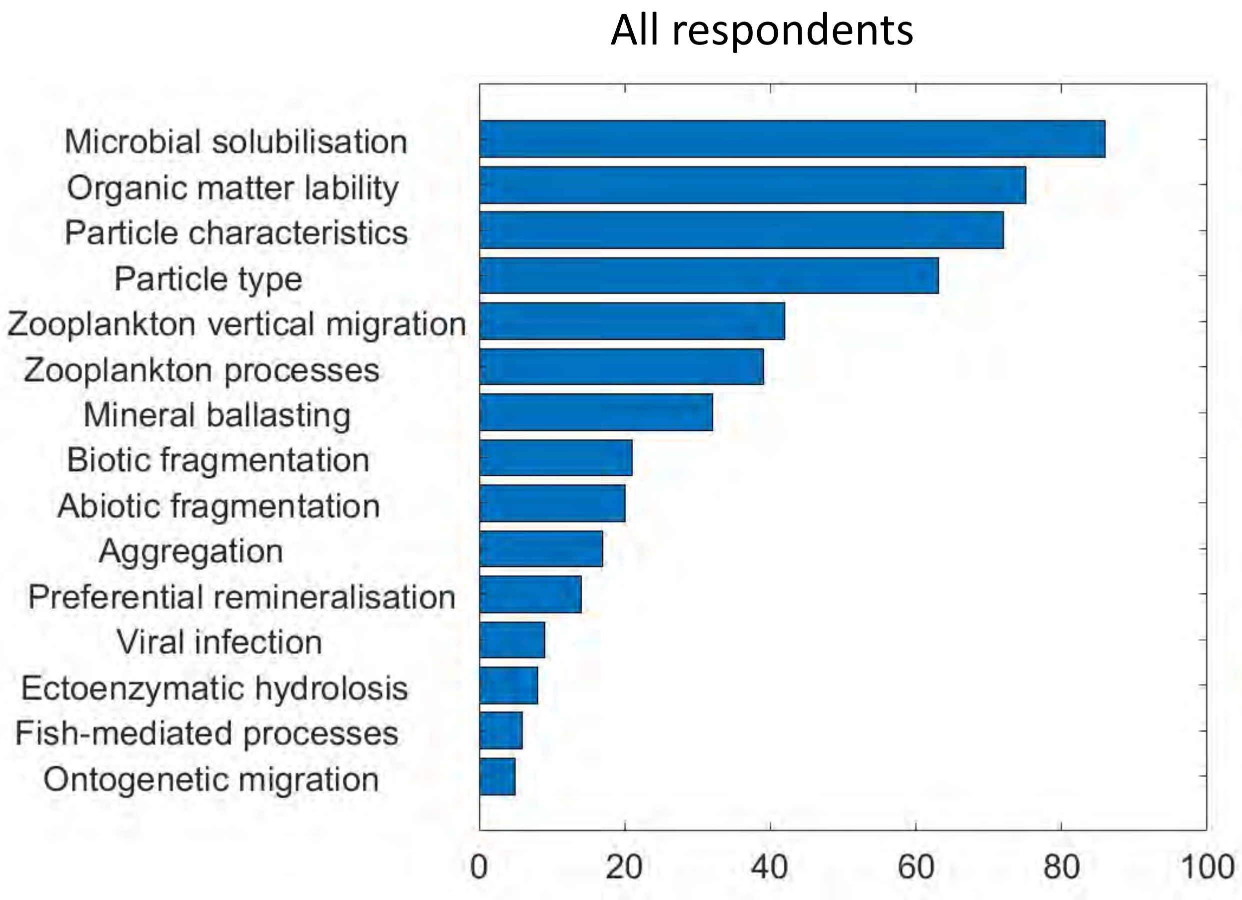
All respondents

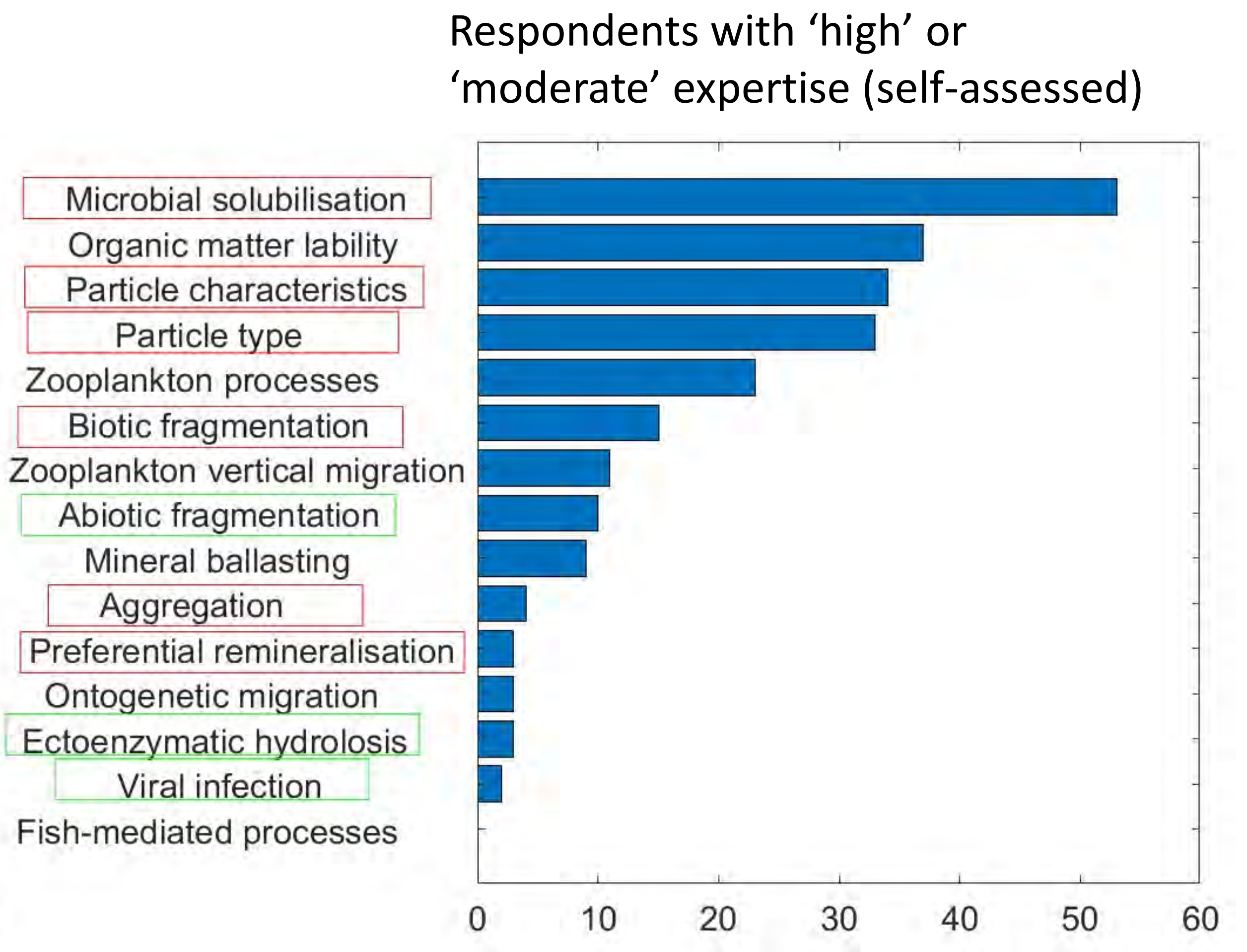


Respondents with ‘high’ or ‘moderate’ expertise (self-assessed)



Interior respiration





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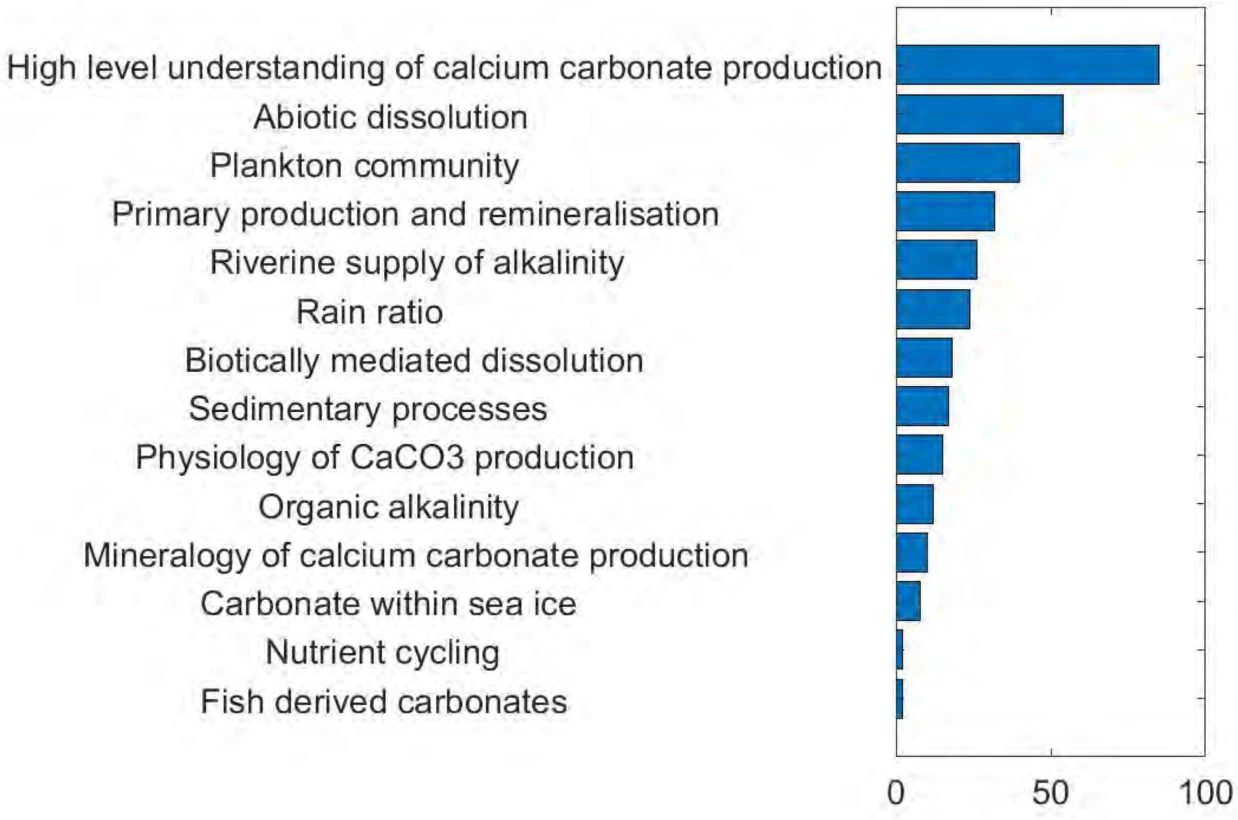
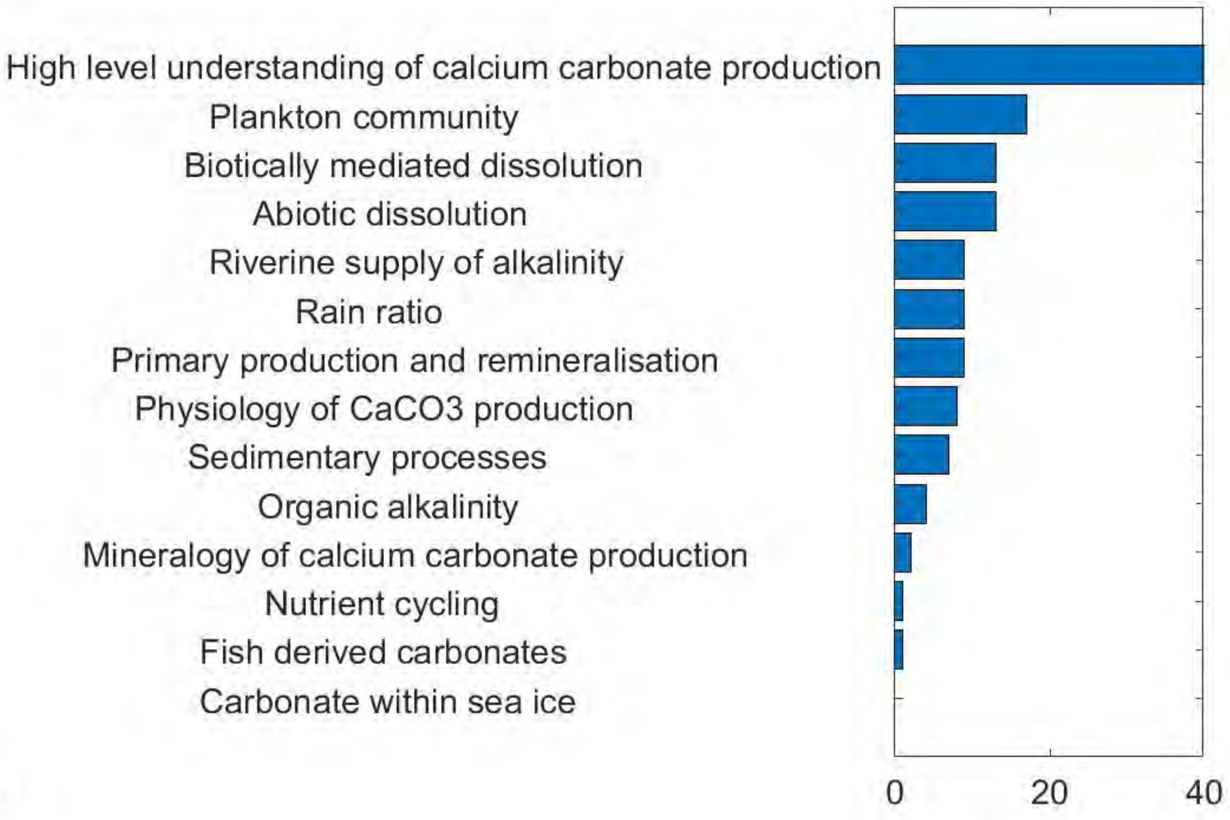
Biological contributions to alkalinity

All respondents



Respondents with ‘high’ or ‘moderate’ expertise (self-assessed)



Biological contributions to alkalinity

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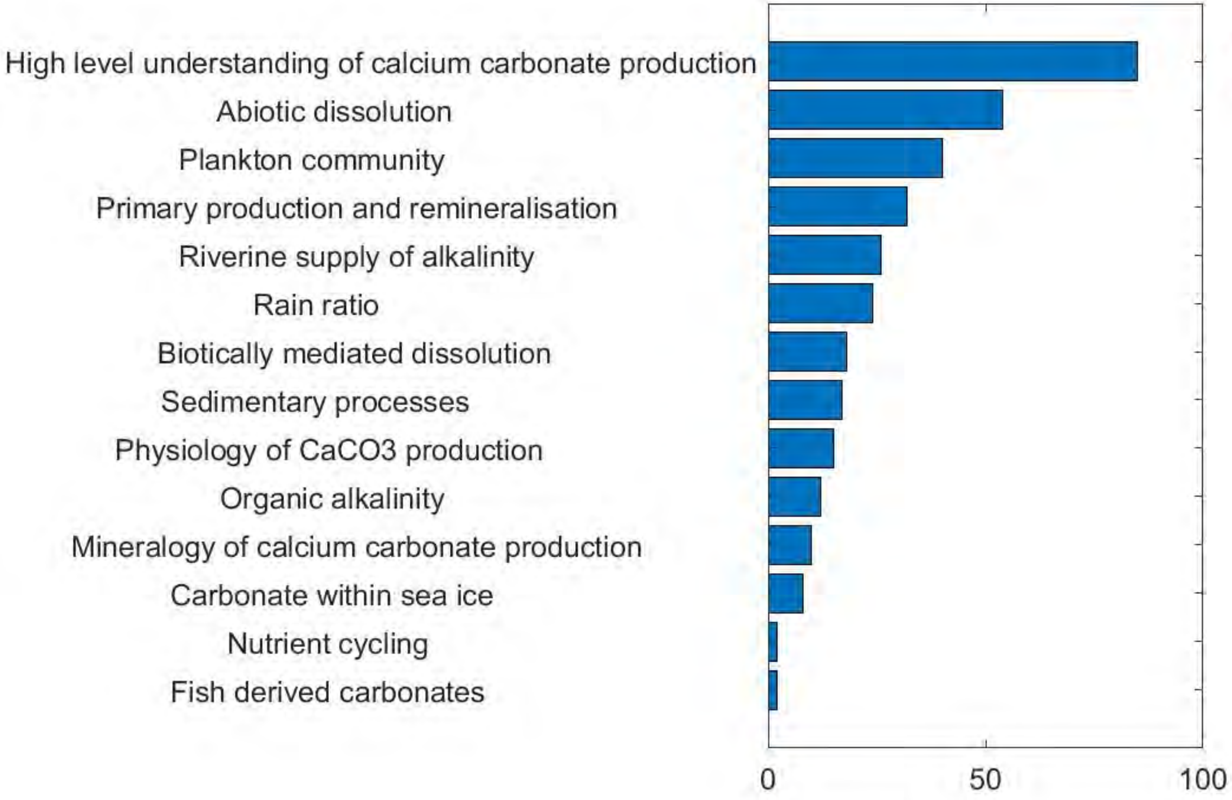

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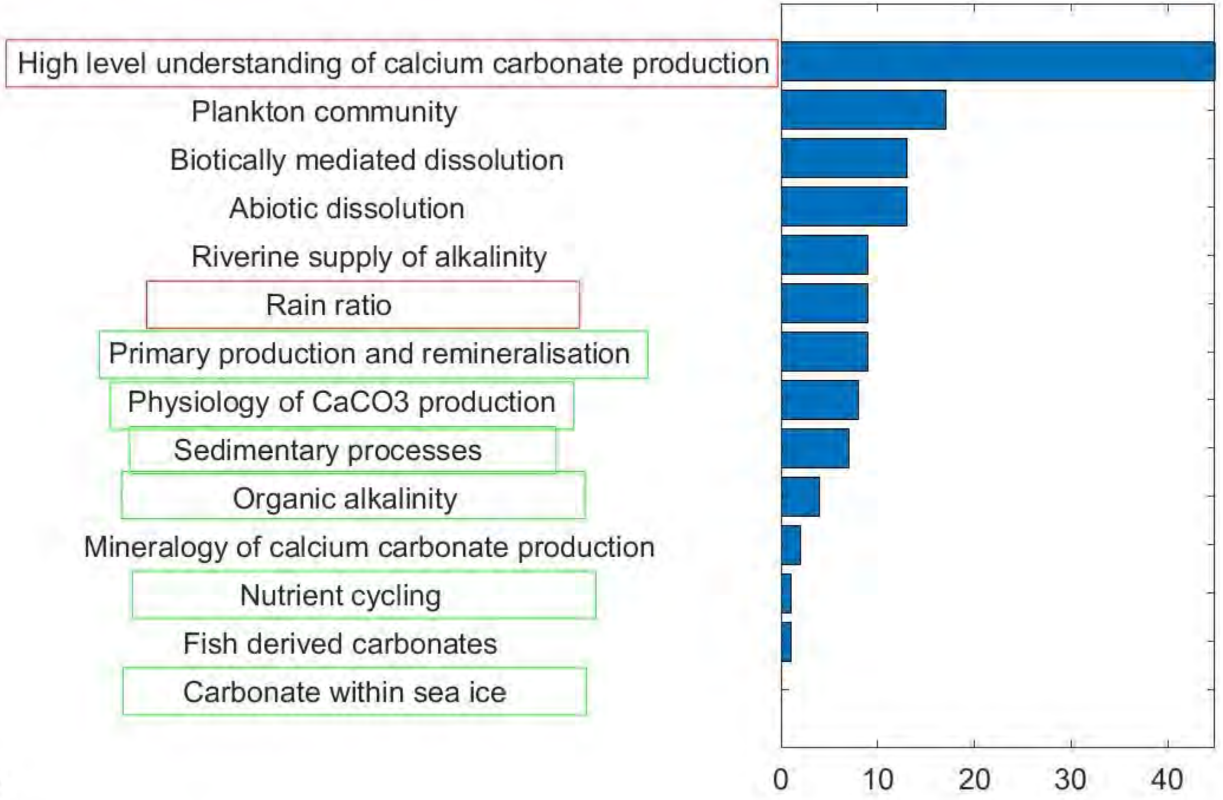

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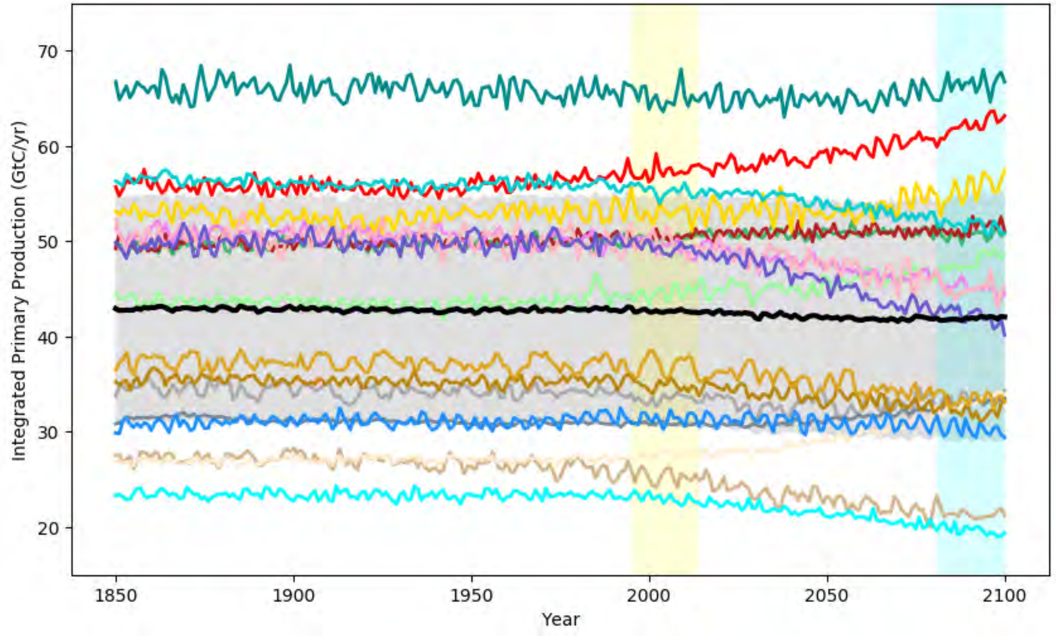
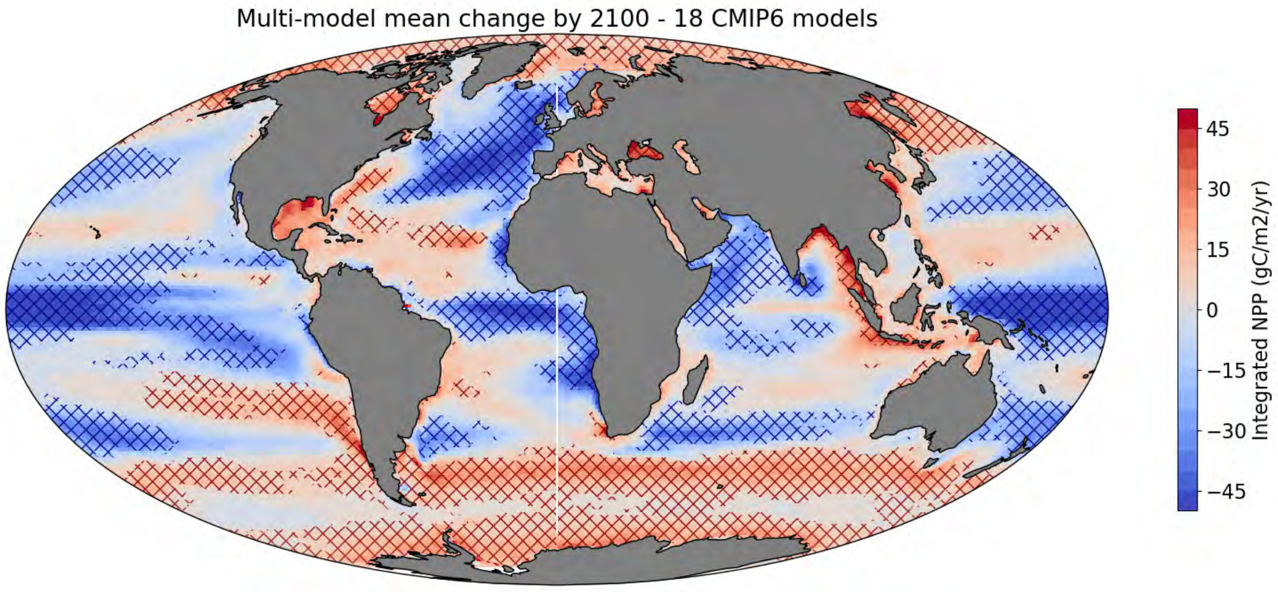
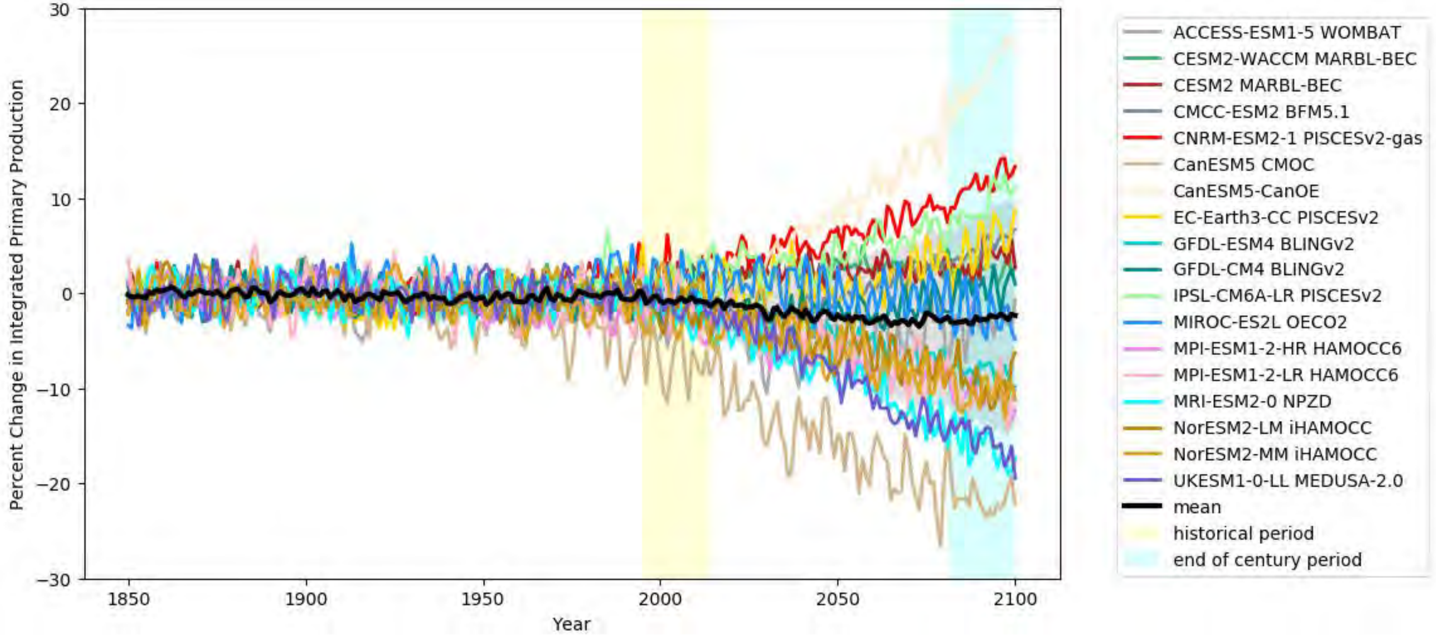
Model structure interrogation & CMIP6 trend analysis

- Purpose is to identify the consequences of inconsistent representation of processes by analysing whether models missing specific processes are likely to be biased high or low with respect to the multi-model mean

CMIP6 Analysis – net primary production

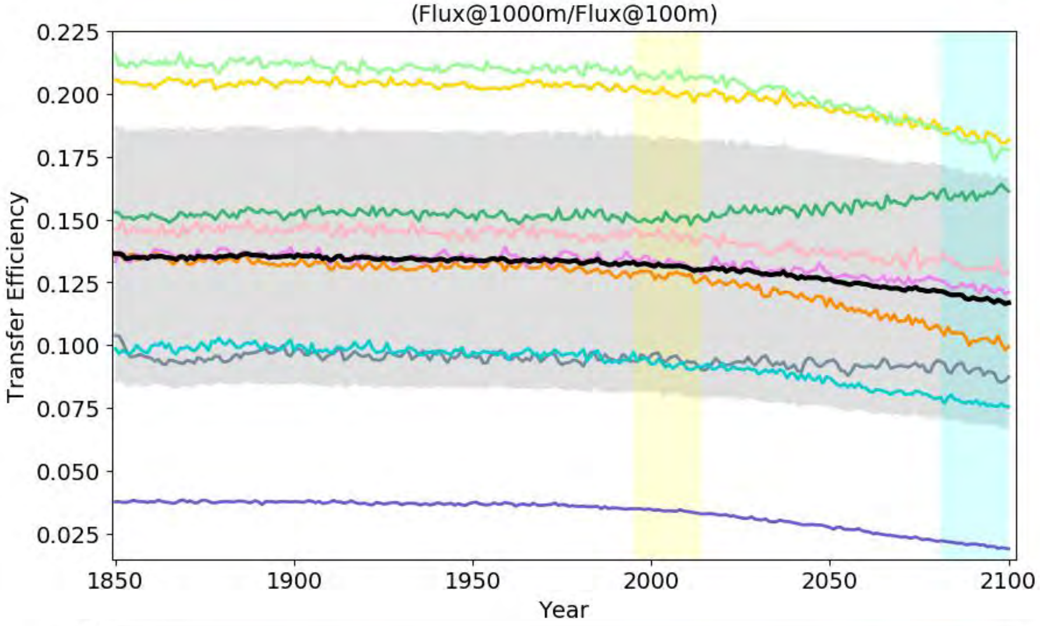


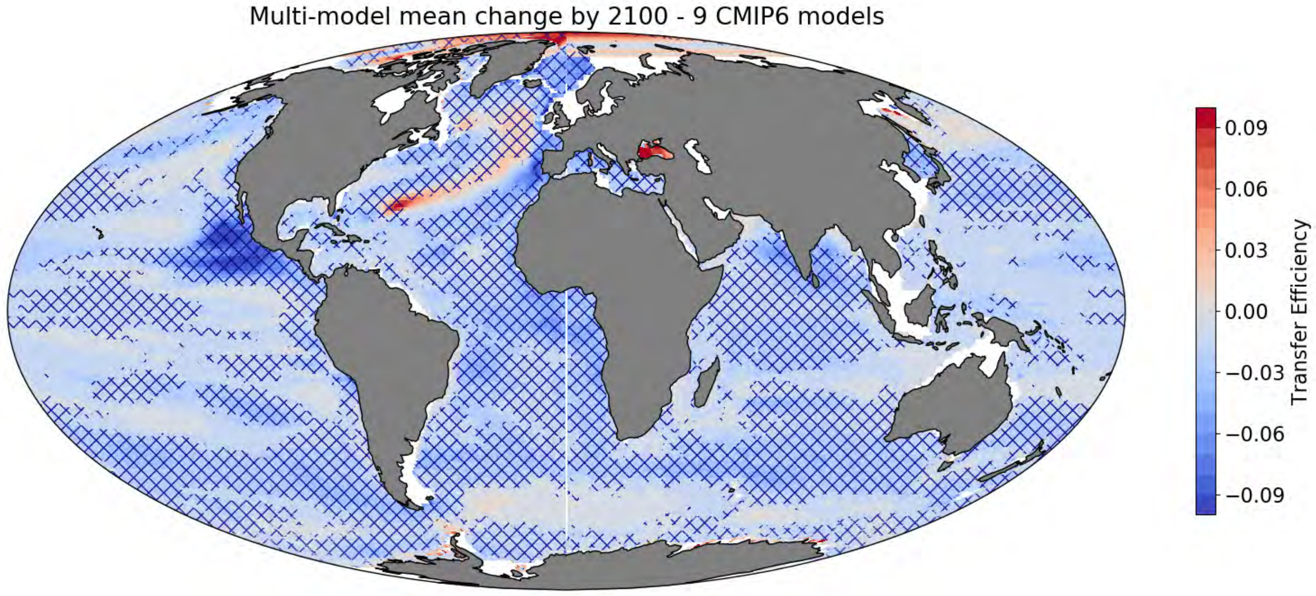


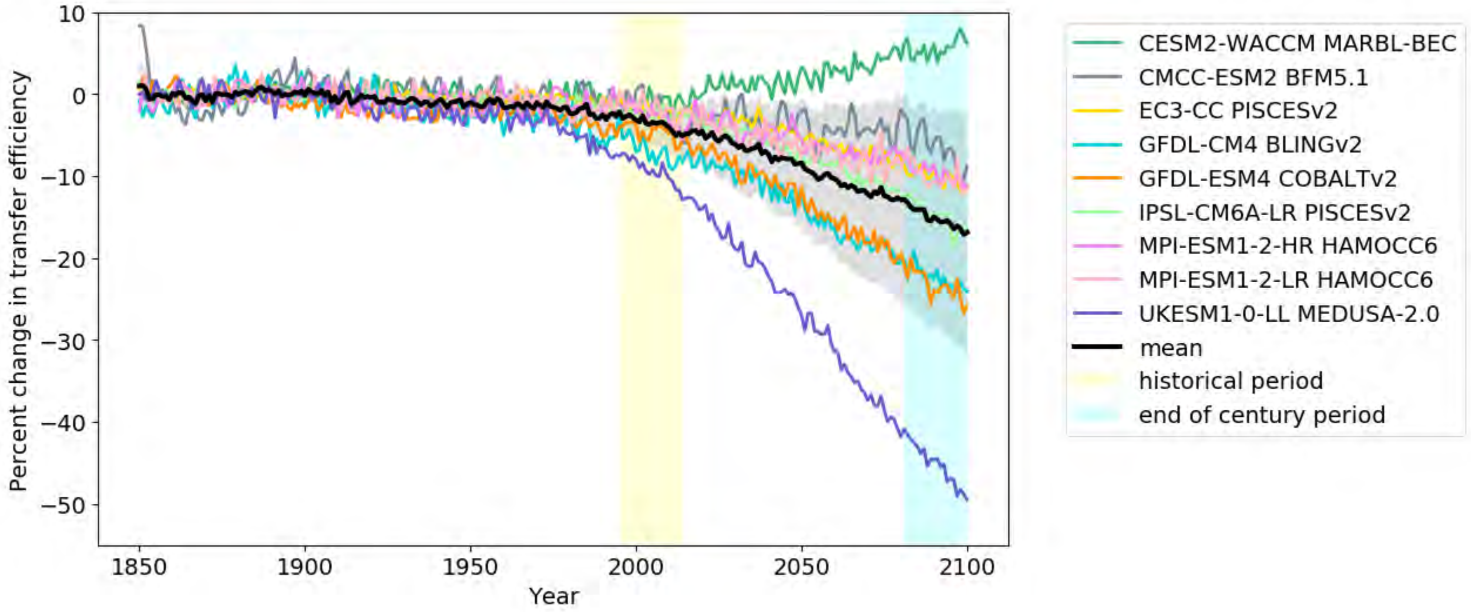


- Wide spread in global NPP magnitude
- Diverging response in trends out to 2100
- Hatching indicates where >70% of models agree on the sign on change (but magnitude of change is highly variable)
- Strong decreases in high latitude North Atlantic NPP
- Tagliabue et al. (2021); Kwiatkowski et al. (2020); Baker et al. (in prep)

CMIP6 Analysis – interior "respiration"

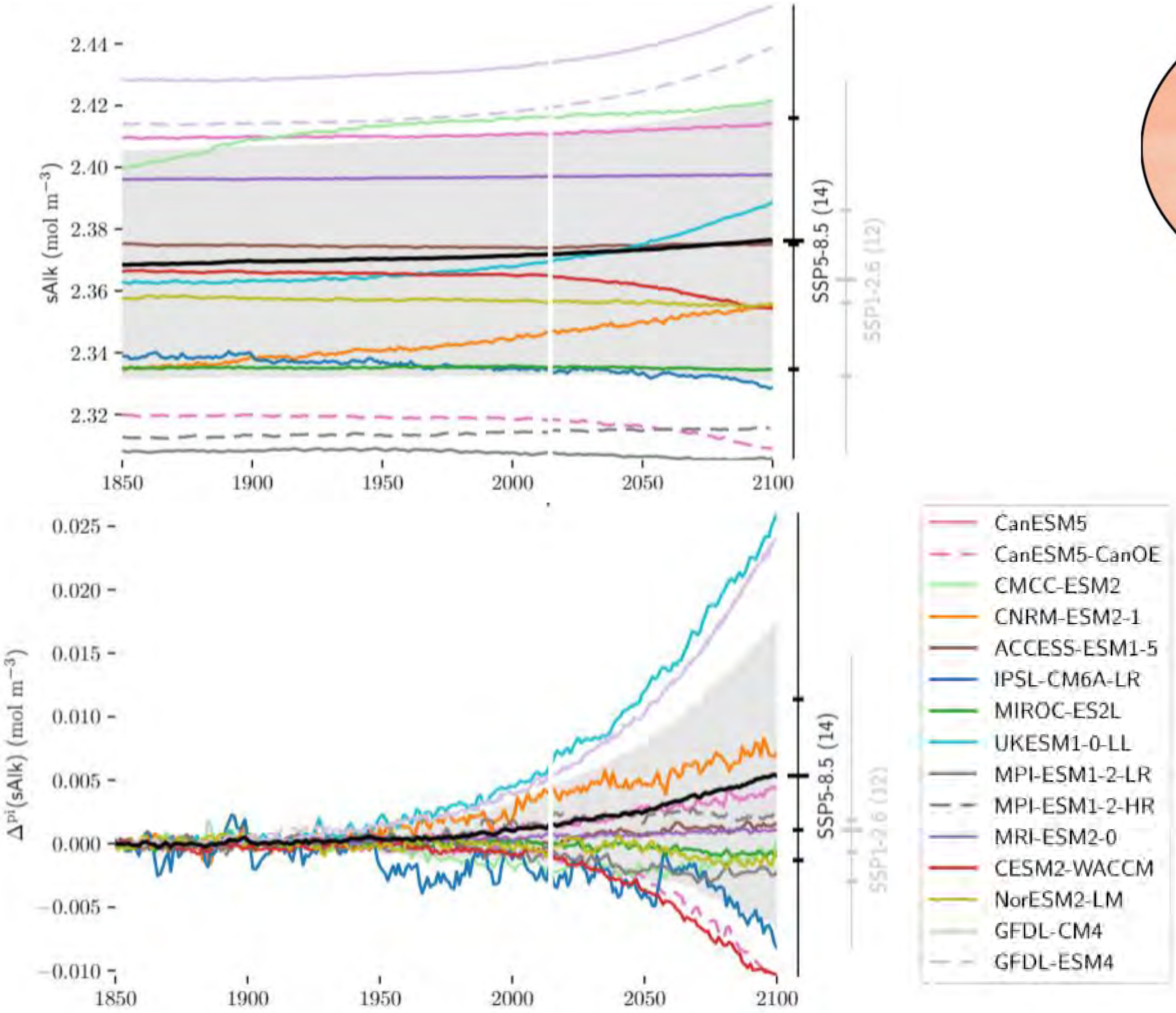


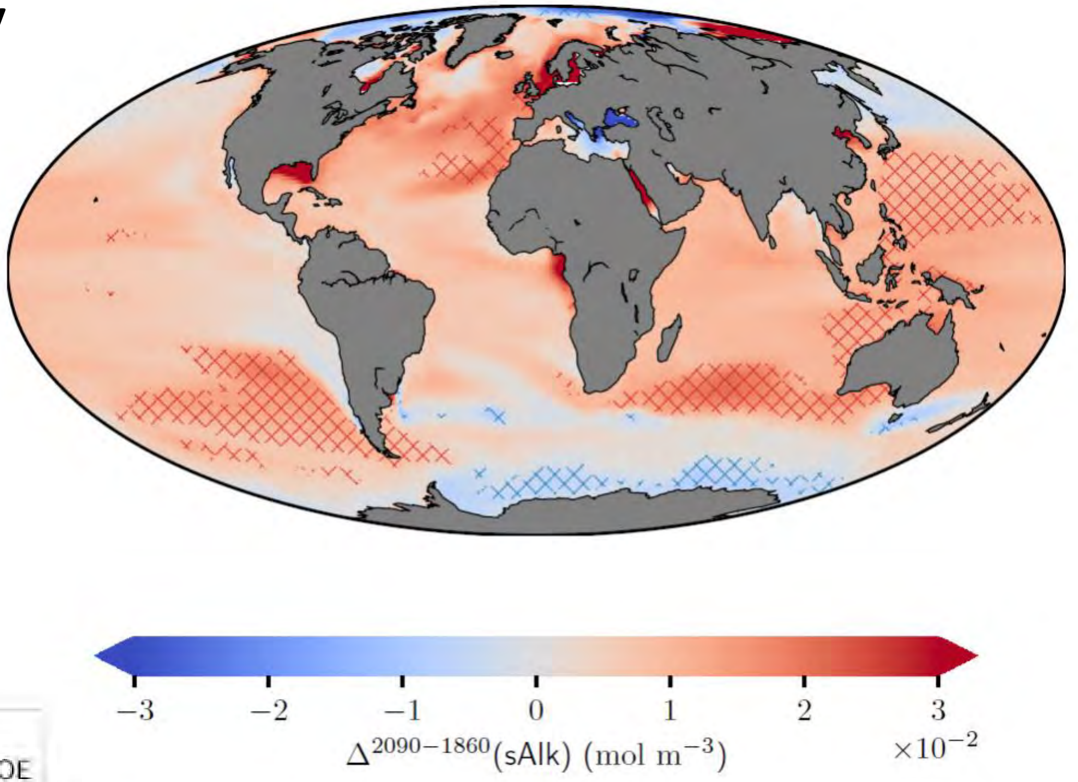




- Transfer efficiency as a proxy (ignores DOM)
- Wide spread in global T*eff* magnitude
- Majority of models show decreasing trend out to 2100
- Hatching indicates where >70% models agree on the sign on change
- Baker et al. (in prep); Baker et al. (2023, EGU conference)

CMIP6 Analysis – alkalinity





- sAlk = surface salinity normalised alkalinity
- Wide spread in global alkalinity magnitude with direct consequences for future air-sea CO2 uptake
- Diverging trend out to 2100
- Hatching indicates where >70% of models agree on the sign on change
- Few areas with good model agreement
- Planchat et al. (2023a, in press); Planchat et al. (in prep)

Geographic and seasonal focus of the cruise plan

- Targeting the North Atlantic & the timing of the cruise window already set by BIO-Carbon (i.e. the BRICS assessment is independent of this cruise plan)
- All processes are likely* to be ubiquitous, with the exception of carbonate precipitated within sea ice and ontogenetic migration
- The seasonality of the majority of processes is poorly constrained

*assessed from our literature survey and “common sense”

Summary

- Hopefully you've found the analysis useful for planning your Phase 1b projects!

- Planned publications from BRICS include:
  - A qualitative paper, which describes the expert assessment process and outcomes and the community survey results (and includes the full evidence tables)
  - Model output analyses, focusing on exploring the linkages between the flow of organic carbon from the euphotic zone to the deep ocean

- Questions and comments are welcome!