Deliverable D4.1

WP4 Implementation Plan and initial parameterisations

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About this document

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1. Abstract

This document outlines the implementation plan towards meeting the overall Objectives of WP4:

1. Quantify the role of higher trophic levels in attenuating particle flux via fragmentation and feeding
2. Quantify the contribution of higher trophic levels to the BCP via active fluxes and shunts
3. Determine ocean interior respiration and dark carbon fixation
4. Develop an internally consistent C budget in one location to test our understanding
5. Develop parameterisations linking key processes to environmental and biological parameters

2. Introduction

2.1. General description

WP4 will measure and quantify key ecological processes within the BCP related to ecosystem structure. This will involve data synthesis, fieldwork in the Arctic and across the whole Atlantic to generate new understanding of these processes and generate parameterisations to model higher trophic level behaviour, active transport by vertical migrants, and dark carbon fixation/ respiration.

Specific tasks are as follows:

T4.1 Controls over the gravitational flux (Lead: NOC; Contributors: DTU-Aqua, AMU, AWI) (M06-M42)**.** This task will establish the influence of biological processes on the attenuation of gravitational POC flux. We will generate a global database of remineralisation length scale using extant datasets and new data generated in this project. Particle fragmentation will be assessed from global in situ imaging datasets of zooplankton and particles with high vertical resolution, and new observations on vertical distributions of copepods and aggregates along a transect through the Atlantic Ocean (UK-funded AMT cruise). We will assess how key taxa affect particle size distribution, identify depth strata where zooplankton-driven changes in size and composition of particles occur. We will assess the degradation rates of particles by migrating multi-cellular organisms to estimate oxygen consumption and motion of organisms that both do, and do not, undertake diel vertical migration (DVM). Samples will be obtained through sinking particle simulation experiments and fieldwork (prokaryotic heterotrophic production as a proxy of prokaryotic mineralisation) in the NE Atlantic (France-funded ANR-APERO) between June-July 2023. Long-term moored instruments in the Arctic will be used to quantify in situ size-specific settling velocities of aggregates, vertical profiles of aggregates and zooplankton, and the role of phytoplankton aggregates versus zooplankton fecal pellets in total carbon flux.

T4.2 Higher trophic level active fluxes (Lead: DTU-Aqua; Contributors: IMR, IMAR, Exeter) (M06-42). This task will assess the effects on carbon sequestration by DVM of metazoans and fish, the lipid pump, the whale pump, and by fecal pellets and deadfall from higher trophic

levels. This task will provide spatially resolved (depth and region) global maps of nutrient injection (biomixing carbon), fecal pellet production, deadfall, carbon consumption, and respiration by vertical migrants – specifically zooplankton, fish and large megafauna (such as whales and sharks) – that will be used as DIC source terms in regional and global ocean models in WP6. Databases will be constructed for fish and whale biomass, and large scale patterns of DVM across a large class of taxa using literature reviews, existing databases and targeted field and lab studies.

T4.3 Carbon production and respiration in the interior ocean (Lead: ULPGC; Contributors: IIM-CSIC, OGS, AMU) (M06-42). We will quantify mesopelagic respiration and its relationship with environmental factors at multiple complementary spatio-temporal scales ranging from days to decades, and spatial scales covering tens to thousands of kms, by combining ecological and biogeochemical approaches: (i) respiratory electron transport system activity (ETS, days to weeks, 10 km); (ii) estimates of the consumption of organic carbon using Biogeochemical-Argo data (seasonal scale, 100 km), and (iii) oxygen utilisation rates (OUR), combining apparent oxygen utilisation and tracer-ages along isopycnal surfaces (years to decades, 1000 km). We will assess the vertical distribution of inorganic carbon fixation in the dark ocean compared with prokaryotic heterotrophic production, in free-living prokaryotes and prokaryotes attached to suspended particles versus prokaryotes attached to gravitational sinking particles, as a function of substrate quality and particle type. Compilation of existing data will be combined with new observations through ongoing projects.

T4.4. Whole Ecosystem C Budget Assessment (Lead: IIM-CSIC; Contributors: ULPGC and other partners from WP3 and WP4 interested to participate in the cruise) (M06-42). We will carry out a process study (Spain funded cruise) in 2025 from South Africa or Namibia to the Canary Islands to determine the role of different environmental drivers (oxygen, temperature, organic matter) of carbon fluxes and respiration rates to assess the balance between carbon sources and water column remineralization. This study will enhance the understanding generated by the experimental and data synthesis work carried out in T4.1 to 4.3 and give greater confidence to the parameterisations developed in T4.5. The coastal ocean transport of organic matter will be assessed using previously unpublished work from NW Africa.

T.4.5 Transfer knowledge to modeling (Lead: NOC; Contributors: All WP partners) (M06-45). This task will develop improved model parameterizations for ecosystem controls on organic carbon fluxes. This will be achieved by joint workshops with partners in WP6, and thereby directly feed into related tasks in WP6. For example, we will derive a global parameterization of respiration as a function of temperature, oxygen, and substrate quality, and a parameterisation to describe how dark inorganic carbon fixation depends on temperature, oxygen and pH.

2.2. Deliverables and milestones

Deliverable #	Deliverable Name	Lead Beneficiary	Type	Due Date (month)
D4.1	WP4 implementation plan and initial parameterisations	NOC	Report	16
D4.2	Summary V2 parameterisations	ULPGC	Report	34
D4.3	Report regarding relevance of key processes studied	NOC	Report	44
D4.4	Final report including peer-reviewed manuscripts	ULPGC	Report	54

Milestone #	Milestone Name	Lead Beneficiary	Means of verification	Due Date (month)
13	AMT cruise	UExeter	Cruise report	24
14	Data transfer #1 from WP4 to WP6	NOC	Data sets archived	21
15	Hausgarten field campaign	AWI	Cruise report	24
16	Apero cruise	AMU	Cruise report	24
17	Cape Town to Canary Islands cruise	ULPGC	Cruise report	42
18	Data transfer #2 from WP4 to WP6	NOC	Data sets archived	33

3. WP4 implementation

3.1. Task 4.1: Controls over the gravitational flux

NOC: We will examine the hypothesised particle size-remineralisation feedback, whereby a shift to smaller phytoplankton results in a shift to smaller sinking particles and hence a shallower remineralisation depth. We will collate existing databases on the slope of the phytoplankton size spectra, slope of the particle size spectra and remineralisation depth, generated from a range of sources including satellite observations, shipboard data, UVP and BGC-Argo data. We will use these data syntheses to establish empirical relationships between phytoplankton size, particle size and remineralisation depth. We will supply these parameterisations to WP6 to be tested in size-resolving models, and we will also explore whether we can develop an empirical relationship which can be applied to non-size-resolving models, e.g. via relationship with chlorophyll, temperature etc. Initial datasets and parameterisations will be shared with WP6 and the rest of the consortium as part of Milestone 14.

DTU-Aqua: We will develop a modelling framework that simulates the dynamics of aggregation, degradation, fragmentation and sinking of an entire aggregate community derived from the production of primary particles (dead cell, fecal pellets). The model will be mechanistic and describe particle aggregation as a self-similar process. In addition, we will analyse existing data for the role of two functional types of copepods on the degradation versus production of vertical flux, namely that of species that are likely to enhance the vertical flux (large calanoids that produce large fast sinking fecal pellets and perform vertical migrations) versus that of species that are likely to decrease the vertical flux (small non-calanoids that feed on sinking particles). We will both perform new observations (case studies) where ecophysiological rates such as fecal pellet production, respiration, reproduction and feeding are combined with vertical distribution and migration, and use existing data and literature on species distributions and biomasses. The focus will be on small copepods, as their behaviour and ecophysiology is less-known than that of large calanoids.

AMU: The APERO (Assessing marine biogenic matter Production, Export and Remineralisation: from the surface to the dark Ocean) campaign will take place northwest of the PAP station (16-24°W and 46-52°N) between June 3 and July 15, 2023, involving two vessels (N/O Le Pourquoi Pas and N/O Le Thalassa), as well as 3 gliders (2 equipped with UVP) and 4 BGC-Argo (equipped with UVP). Three different types of oceanic structure will be visited, cyclonic and anticyclonic eddies and the fronts between them, the latter being sampled with high-resolution sections (around 4 NM). The Pourquoi Pas will undertake five 5-day Process Studies Stations following a drifting mooring line (with 10 sediment traps between 50 and 1000m, 3 IODA, 3 RESPIRE, 3 VISU-traps) and deploying zooplankton and phytoplankton nets, marine snow catchers (4 at the same time) and CTD-rosettes with Niskin bottles and high-pressure sampler or deep-nets. The Thalassa will undertake eight 2-day stations with acoustics, nets, trawlings, molecular biology and 20 shorter (10h) mapping stations (trawling, net, molecular biology). A specific focus will be process studies done on board including microbial activities (prokaryotic heterotrophic production and dark CO2 fixation, see Task 4.3).

AWI: We will compile and analyse all measurements that we have done on in situ sampled settling organic aggregates. We have started this project as a master thesis in which we have currently compiled 1800 in situ settling aggregates including their sizes, settling velocities, aggregate type, aggregate composition, and sampling location and water properties. The next steps are to include the remaining cruises and analyse the missing data for microbial respiration and carbon content of the aggregates. The plan is to hire a postdoc on the project to help parameterize the data set for latitudinal differences and impact from environmental parameters as well as plankton communities and aggregate composition. We have secured external funding for a PhD student working on topics that are relevant for the OceanICU as well as partial funds for an additional PhD position to support the goals of OceanICU. We will supplement the latter PhD funding with funds from the OceanICU project. The next plans are to link the direct measurements on in situ collected aggregates to in situ camera profiles of aggregate size-distribution and abundance from each of the cruises and determine carbon flux and flux attenuation. We will relate these export and attenuation rates to in situ measured carbon flux using drifting sediment traps and to the directly measured microbial degradation rates, in order to identify important export and attenuation mechanisms for different seasons and regions.

3.2. Task 4.2: Higher trophic level active fluxes

DTU-Aqua: We will compile abundance, distribution and overwintering observations for 5 different copepod species around the globe, and estimate their carbon sequestration using a metabolic model and a transport matrix model. These 5 species sequester 13-35 PgC (compared to 1300 PgC for the entire biological pump). Other aspects to be investigated are sequestration driven by (i) krill fecal pellets in the Southern Ocean (about 8 PgC), and (ii) global whale distributions in the modern day compared to pre-whaling abundances. In addition, we will analyse the factors influencing the seasonal development of vertical migration of copepods in an Arctic case study.

IMR: We will estimate the following carbon fluxes associated with baleen whales in the Nordic Seas: nutrient recycling and primary production enhancement (whale pump), carbon biomass storage and export (deadfalls) and faecal carbon export to the deep ocean (faecal pellets). To achieve this, we will combine (i) field work (whale tagging to examine foraging depths) and (ii) lab experiments (carbon and nutrient concentration in faeces, diffusion rates, sinking rates, response of plankton to nutrients). Estimated carbon fluxes will be then transferred to WP6, in order to model the impact of whales on regional carbon budgets.

UExeter: We will collect vertically-resolved zooplankton samples from the upper 500m along a north-south transect of the Atlantic Ocean via participation on an AMT research expedition. The resulting samples will be used to determine the abundance and biomass of mesozooplankton, along with information on their size spectra and how this changes with increasing depth. These data will be used to examine trophic transfer efficiency across multiple, contrasting ocean biogeochemical provinces. We will also participate on additional high latitude research expeditions via collaborations to sample lipid-storing copepods from

depth. Frozen samples will be analysed to determine ETS activity rates to provide new information on their overwintering respiration rates.

IMAR: We will contribute to estimation of carbon fluxes associated with migrating/non-migrating deep scattering layers and oceanic megafauna taxa (whales, tuna, sharks) in the mid-north Atlantic around the Azores: nutrient recycling and primary production enhancement (whale pump), carbon biomass storage and export (deadfalls) and faecal carbon export to the deep ocean (faecal pellets). To achieve this, we will combine field work (whale/shark tagging to examine foraging depths, a mesopelagic cruise in summer 2024 onboard the RV METEOR for mesopelagic characterisation) with historical (tracking, mesopelagic echosounding/trawling cruises, fisheries/discards) data and bibliographic review. Estimated carbon fluxes will be then transferred to WP6, in order to model the impact of megafauna and deep scattering layers on regional carbon budgets.

3.3.1 Task 4.3: Carbon production and respiration in the interior ocean

ULPGC: We will estimate the regional variability of respiration in the interior ocean by means of the enzymatic respiratory ETS approach at temporal scales of days to weeks and spatial scales of 10^2 km. These estimates will be compared with other biogeochemical approaches of oxygen consumption at larger temporal and spatial scales. All together will contribute to derive a global parameterisation of respiration as a function of temperature, oxygen and organic matter for use in biogeochemical models (WP6).

IIM-CSIC: We will investigate long-term (years to decades) basin-scale (10^3 -10^4 km) oxygen utilisation rates (OUR) in the water masses of the mesopelagic ocean. This will be achieved by i) gathering previous OUR estimates from the literature by means of an extensive review of previous works and ii) estimating new OUR values across the global ocean through the combination of apparent oxygen utilisation (AOU) and tracer-ages derived from available public databases. We will also address the potential relationship between OUR estimates and temperature, dissolved oxygen and organic matter during water mass ageing, and exploring how local dissolved organic carbon concentrations and vertical carbon sinking fluxes are related to OUR. Results will be compared with respiration estimates by ETS (ULPGC) and Argo buoys (OGS) and transferred to WP6.

OGS: We will exploit the global BGC-Argo dataset to derive estimates of mesopelagic respiration at the seasonal scale. Simultaneously, we will extract environmental parameters corresponding to the respiration estimates that will be used to investigate existing parameterizations of mesopelagic respiration and, if needed, to derive new ones. The environmental parameters that we will target are temperature, salinity, oxygen, and organic matter concentrations. Results will be compared to those based on ETS and OUR, and results transferred to WP6.

AMU: In the framework of the APERO cruise (see task 3.1) prokaryotic heterotrophic production (using 3H-Leucine) and dark CO2 fixation (using 14C-bicarbonate) rates will be measured using marine snow catchers as well as sediment traps from drifting mooring lines in order to characterize activities of microbial communities attached to particles versus their

free-living counterparts. Microbial activities will be compared to the organic carbon export fluxes. These results will be complemented by metabarcoding data.

3.4 Task 4.4: Whole ecosystem carbon budget assessment

IIM-CSIC and ULPGC: We will carry out a process study (Spain-funded cruise) from South Africa to the Canary Islands, crossing regions of high/low oxygen, temperature and productivity, to assess the balance between carbon sources (productivity and vertical carbon fluxes) and sinks (water column respiration), and to establish empirical relationships between oxygen, temperature and organic matter with ocean interior respiration.

3.5 Task 4.5: Transfer knowledge to modelling

NOC & All WP partners: The transfer of datasets and novel parameterisations to be tested in various modelling frameworks will be shared with WP6 (and other WPs). We will coordinate with WP6 modelling teams to ensure that the data and parameterisations we develop are fit-for-purpose for model validation and development. The transfer of knowledge will occur in 2 tranches - one early in the project (Milestone 14, month 21) and one towards the end of the project (Milestone 18, month 33). In addition, our data syntheses and parameterisations will be documented in Deliverables 4.1 (month 16) and 4.2 (month 34).

3.6 Critical risks for implementation

Risk number	Description	Proposed mitigation measures	Likelihood	Severity	Specific partners exposed
1	Cruise programme fails to occur due to COVID or increases in fuel prices (Low risk, low severity). Impact is no new information regarding how key processes operate. Low severity as multiple datasets exist already, low risk as cruises mainly postponed not cancelled and	Fallback position of using extant data sets identified in plan, risk spread by operating on multiple vessels from different nations.	Low	Low	IIM-CSIC ULPGC AMU UExeter AWI IMR

Risk number	Description	Proposed mitigation measures	Likelihood	Severity	Specific partners exposed
	we are not reliant on a single campaign.				
2	Transfer of Information between WPs breaks down (low risk, high severity) due to COVID induced lockdowns preventing face to face meetings. Severity is high, efficient comms between experimentalists, modellers and data scientists is key to delivering the complex workflow Low risk as project partners have worked together before and we will manage the transfer of information very carefully and monitor it very strongly.	Devote considerable resource in WP1 to monitoring the interactions between WPs. Staged approach to data transfer between WPs to ensure that there is some flex in the system and it is resilient to a milestone being delayed. Use VC based technologies for meetings if required.	Low	High	All

3.7 Expected results

#Identifier	Result	Partner responsible	Expected time
R1	Mathematical relationship between plankton size and particle size	NOC	July 2024
R2	Estimated carbon uptake via whale pump, faecal pellets and deadfalls (Nordic Seas)	IMR	September 2025
R3	Estimated production vs. degradation of vertical flux	DTU	January 2026

#Identifier	Result	Partner responsible	Expected time
	by different types of zooplankton communities in case study areas in North Atlantic and Arctic		
R4	Parameterisation of ETS-respiration rates as a function of temperature, oxygen and organic matter in the mesopelagic ocean	ULPGC	June 2025
R5	Vertically-resolved zooplankton size spectra along a north-south transect of the Atlantic Ocean	UExeter	TBC - depends on when
R6	ETS-respiration rates of high latitude copepods in diapause	UExeter	TBC - depends on when we can get to sea
R7	Parameterisation of OURs as a function of temperature, oxygen and organic matter in the mesopelagic ocean	CSIC	June 2025
R8	Parameterisation of BGC-Argo based mesopelagic respiration as a function of temperature, oxygen and organic matter	OGS	June 2025
R9	Estimated carbon balance between sources and sinks in the mesopelagic North East Atlantic according different physical	MIO/ULPGC/AWI	July 2026

	mesoscale structure (APERO cruise)		
R10	Estimated carbon balance between sources and sinks in the mesopelagic North and South Atlantic covered by the Spanish cruise	ULPGC/CSIC	July 2026

4 WP4 management

4.3 WP4 management structure and routines

WP4 partners will have meetings approximately to exchange updates, share administrative or logistical notices and to host short science talks by WP partners. The WP co-leads will also participate in quarterly WP lead meetings organised by the project office and PI, as well as the annual general meetings organised by the project office.

WP co-lead	NOC, S. Henson
WP co-lead	ULPGC, J. Arístegui
Task 4.1 lead	NOC, S. Henson
Task 4.1 contributors	NOC, N. Briggs, S.Clayton DTU-Aqua, A. Visser, M. Koski AMU, C. Tamburini AWI, M. Iversen
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Task 4.5 lead	NOC: S. Henson

Task 4.5 contributors	All WP4 partners

4.4 Key performance indicators (KPIs)

WP4 contributes directly to ST1 and KPIs 2, 3, 8 and 11, as well as indirectly to ST2 and ST3. WP4 may additionally contribute to KPIs 12-21 depending on involvement of partners with international efforts such as IPCC and IPBES.

5 Interactions with other WPs

WP4 will interact most closely with WPs 3 and 6, and have input to all other WPs.
In particular, WP4 will supply parameterisations and datasets to WP6 for consideration in the modelling efforts. We will communicate our work and coordinate our efforts with WP6 partners to ensure that the outputs we generate are of value to model development and validation.
We will collaborate with WP3 to understand the interplay between the influence of climatic factors and ecosystem factors on the biological cycling of carbon.