Horizon 2020

Call: ERC-2018-COG
(Call for proposals for ERC Consolidator Grant)

Topic: ERC-2018-COG
Type of action: ERC-COG
(Consolidator Grant)

Proposal number: 819586

Proposal acronym: SMART-ECOFIX

Deadline Id: ERC-2018-COG

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How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

1 - General information

Topic	ERC-2018-COG
Call Identifier	ERC-2018-COG
Type of Action	ERC-COG
Deadline Id	ERC-2018-COG

Acronym: SMART-ECOFIX

Proposal title*: SiMulating ARTificially Enhanced Coastal Ocean FertilizatIon eXperiments

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months*: *60*

Primary ERC Review Panel*: PE10 - Earth System Science

Secondary ERC Review Panel: (if applicable)

ERC Keyword 1*: *Oceanography (physical, chemical, biological, geological)*

Please select, if applicable, the ERC keyword(s) that best characterise the subject of your proposal in order of priority.

ERC Keyword 2: *Biogeochemistry, biogeochemical cycles, environmental chemistry*

ERC Keyword 3: *Not applicable*

ERC Keyword 4: *Not applicable*

Free keywords: *Diatoms, primary production, ocean fertilization, biological carbon pump, silica, geoengineering, enhanced weathering*

Proposal ID **819586** *Acronym* **SMART-ECOFIX**

Abstract*

Each day, more than fifty million tons of C in the form of CO2 are fixed into organic material by marine diatoms, silica-precipitating phytoplankton that inhabit the sunlit layer of the world's oceans. A significant fraction of this C is transferred into the deep ocean, creating a deficit of CO2 in the upper layer which is compensated by the diffusive drawdown of CO2 from the atmosphere. On geological time scales, this mechanism, referred to as the biological pump, has contributed to reduce atmospheric CO2 levels and cool the climate. SMART-ECOFIX aims to accelerate in experimental devices and computer simulations the slow natural processes through which marine diatoms contributed to CO2 removal and ancient planetary cooling. The full system consists on i) accelerating the mobilization of inorganic nutrients from the rock reservoir and ii) engineering the biological pump to maximize its C export efficiency. The former involves the spread of fine-grained silicate minerals in suitable regions, known as enhanced silicate weathering (ESW), and subsequent adjustment of seawater nutrient ratios. The latter modifies the ecology, stoichiometry and food web structure of marine plankton with the aim of increasing the magnitude of organic C export and deep ocean sequestration. The strategic plan comprises i) a set of analytical techniques and experimental devices for the study of marine microbial plankton ecology and biogeochemistry, including state-of-the-art methods for single-cell determination of elemental composition, and ii) high spatial resolution ocean model simulations in high performance supercomputers. This research action is important to advance ways of engineering the biological pump and prospect potential benefits and risks of applying ESW in marine systems.

Remaining characters 209

In order to best review your application, do you agree that the above non-confidential proposal title and abstract can be used, without disclosing your identity, when contacting potential reviewers? (•) Yes ( ) No

Declarations

In case of a Synergy grant application 'Principal Investigator' means 'corresponding Principal Investigator on behalf of all Principal Investigators', and 'Host Institution' means 'corresponding Host Institution'.

1) The Principal Investigator declares to have the written consent of all participants on their participation and on the content of this proposal, as well as of any researcher mentioned in the proposal as participating in the project (either as other PI, team member or collaborator).*	☒
2) The Principal Investigator declares that the information contained in this proposal is correct and complete.	☒
3) The Principal Investigator declares that all parts of this proposal comply with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The Principal Investigator hereby declares that *(please select one of the three options below)*:

- in case of multiple participants in the proposal, the Host Institution has carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year.Where the result was “weak” or “insufficient”, the Host Institution confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check).	◉
- in case of multiple participants in the proposal, the Host Institution is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check).	○
- in case of a sole participant in the proposal, the applicant is exempt from the financial capacity check.	○
5) The Principal Investigator hereby declares that each applicant has confirmed to have the financial and operational capacity to carry out the proposed action. Where the proposal is to be retained for EU funding, each beneficiary applicant will be required to present a formal declaration in this respect.	☒

The Principal Investigator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the Host Institution and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection

The assessment of your grant application will involve the collection and processing of personal data (such as your name, address and CV), which will be performed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the purposes and means of the processing of your personal data as well as information on how to exercise your rights are available in the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Detection and Exclusion system of the European Commission (EDES), the new system established by the Commission to reinforce the protection of the Union's financial interests and to ensure sound financial management, in accordance with the provisions of articles 105a and 108 of the revised EU Financial Regulation (FR) (Regulation (EU, EURATOM) 2015/1929 of the European Parliament and of the Council of 28 October 2015 amending Regulation (EU, EURATOM) No 966/2012) and articles 143 - 144 of the corresponding Rules of Application (RAP) (COMMISSION DELEGATED REGULATION (EU) 2015/2462 of 30 October 2015 amending Delegated Regulation (EU) No 1268/2012) for more information see the Privacy statement for the EDES Database).

List of participants

#	Participant Legal Name	Country
1	AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS	Spain
2	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	Spain

2 - Administrative data of participating organisations

Host Institution

PIC	***Legal name***
999991722	*AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS*

Short name: CSIC

Address of the organisation

Street CALLE SERRANO 117

Town MADRID

Postcode 28006

Country Spain

Webpage http://www.csic.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body .... yes

Legal person .... yes

Non-profit .... yes

International organisation .... no

International organisation of European interest .... no

Secondary or Higher education establishment .... no

Research organisation .... yes

Enterprise Data

SME self-declared status........ 2015 - no

SME self-assessment .... unknown

SME validation sme........ 2007 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Marine Biology and Oceanography	☐ not applicable
	☐ Same as organisation address	
Street	Passeig Maritim de la Barceloneta 37-49	
Town	Barcelona	
Postcode	08003	
Country	Spain	

Proposal ID **819586**	*Acronym* **SMART-ECOFIX**	*Short name* **CSIC**

Principal Investigator

The following information on the Principal Investigator is used to personalise the communications to applicants. Please make sure that your personal information is accurate and for any ERC specific question please contact the ERC using the following e-mail address:

For Consolidator Grant Applicants: ERC-2018-CoG-applicants@ec.europa.eu

The name and e-mail of contact persons including the Principal Investigator, Host Institution contact are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please save and close this form, then go back to Step 4 of the submission wizard and save the changes.

ORCID ID: 0000-0002-3902-3475

Researcher ID: D | 2416 | 2018

The maximum length of the identifier is 11 characters (ZZZ-9999-2010) and the minimum length is 9 characters (A-1001-2010).

Other ID: ResearchGate | https://www.researchgate.net/profile/Pedro_Cermeno

Last Name*	CERMENO	Last Name at Birth	CERMEMO
First Name(s)*	Pedro	Gender*	(•) Male ( ) Female
Title	Dr.	Country of residence	Spain
Nationality*	Spain	Country of Birth*	Spain
Date of Birth* (DD/MM/YYYY)	03/05/1975	Place of Birth*	Zaragoza

Contact address

Current organisation name	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFIC
Current Department/Faculty/Institute/ Laboratory name	INSTITUT DE CIENCIAS DEL MAR

☐ Same as organisation address

Street	Passeig Maritim de la Barceloneta 37-49		
Postcode/Cedex	08003	Town*	Barcelona
Phone*	+34 932 30 95 00	Country*	Spain
Phone2 / Mobile	+34 652 55 73 40		
E-mail*	pedrocermeno@icm.csic.es		

Contact address of the Host Institution and contact person

The name and e-mail of Host Institution contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Host Institution, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. Please note that the submission is blocked without a contact person and e-mail address for the Host Institution.

Organisation Legal Name **AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS**

First name* **Guillermo** Last name* **Sanjuanbenito**

E-Mail* **programas.europeos@csic.es**

Position in org. *Head of European Programmes Unit*

Department *Deputy Vice-Presidency for Scientific Programming* ☐ Same as organisation

☒ Same as organisation address

Street CALLE SERRANO 117

Town MADRID Postcode 28006

Country Spain

Phone +34915681709 Phone2/Mobile *+XXX XXXXXXXXX*

Proposal ID **819586** *Acronym* **SMART-ECOFIX** *Short name* **BSC**

Partner organisation

PIC	***Legal name***
999655520	*BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION*

Short name: BSC

Address of the organisation

Street Calle Jordi Girona 31

Town BARCELONA

Postcode 08034

Country Spain

Webpage www.bsc.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Legal person .... yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....yes

Enterprise Data

SME self-declared status..................................2011 - no

SME self-assessment .... unknown

SME validation sme.. unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Earth Sciences	☐ not applicable
	☒ Same as organisation address	
Street	Calle Jordi Girona 31	
Town	BARCELONA	
Postcode	08034	
Country	Spain	

Proposal ID **819586** *Acronym* **SMART-ECOFIX** *Short name* **BSC**

Contact address of the partner organisation and contact person

The name and e-mail of Partner Organisation contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Partner Organisation, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. The contact person needs to be added as 'Main Contact' for the Partner Organisation.

Organisation Legal Name **BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTAC**

First name* **Raffaele** Last name* **Bernardello**

E-Mail* **raffaele.bernardello@bsc.es**

Position in org. *Researcher*

Department *Earth Sciences* ☐ Same as organisation

☒ Same as organisation address

Street Calle Jordi Girona 31

Town BARCELONA Postcode 08034

Country Spain

Phone +34934137774 Phone2/Mobile *+xxx xxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Francesca	Arcara	francesca.arcara@bsc.es	+34934137774

Proposal ID **819586** *Acronym* **SMART-ECOFIX**

3 - Budget

Participant Number in this proposal	Organisation Short Name	Organisation Country	Total eligible costs/€ (including 25% indirect costs)	Requested grant/€
1	CSIC	ES	1 348 479	1 348 479
2	BSC	ES	228 750	228 750
Total			1 577 229	1 577 229

4 - Ethics

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does your research involve the use of human embryos?	◯ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	◯ Yes ◉ No	
2. HUMANS		**Page**
Does your research involve human participants?	◯ Yes ◉ No	
Does your research involve physical interventions on the study participants?	◯ Yes ◉ No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	◯ Yes ◉ No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	◯ Yes ◉ No	
5. ANIMALS		**Page**
Does your research involve animals?	◯ Yes ◉ No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	◯ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	◯ Yes ◉ No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	◯ Yes ◉ No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	◯ Yes ◉ No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	◯ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	◯ Yes ◉ No	
7. ENVIRONMENT & HEALTH and SAFETY		**Page**

Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	◯ Yes ⦿ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ⦿ No	
Does your research involve the use of elements that may cause harm to humans, including research staff?	◯ Yes ⦿ No	
8. DUAL USE		Page
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	◯ Yes ⦿ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		Page
Could your research raise concerns regarding the exclusive focus on civil applications?	◯ Yes ⦿ No	
10. MISUSE		Page
Does your research have the potential for misuse of research results?	◯ Yes ⦿ No	
11. OTHER ETHICS ISSUES		Page
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ⦿ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

How to Complete your Ethics Self-Assessment

Proposal ID **819586** *Acronym* **SMART-ECOFIX**

5 - Call specific questions

Academic Training	
Are you a medical doctor or do you hold a degree in medicine? Please note that if you have also been awarded a PhD, your medical degree may be your first eligible degree.	○ Yes ◉ No
Date of earliest award (PhD or equivalent)* - DD/MM/YYYY	22/03/2006
With respect to the earliest award (PhD or equivalent), I request an extension of the eligibility window, (indicate number of days) [see the ERC 2018 Work Programme and the Information for Applicants to the Starting and Consolidator Grant 2018 Calls].	○ Yes ◉ No
Eligibility	
Please indicate your percentage of working time in an EU Member State or Associated Country over the period of the grant: Please note that you are expected to spend a minimum of 50% of your total working time in an EU Member State or Associated Country.	100,00
I acknowledge that I am aware of the eligibility requirements for applying for this ERC call as specified in the ERC Annual Work Programme, and certify that, to the best of my knowledge my application is in compliance with all these requirements. I understand that my proposal may be declared ineligible at any point during the evaluation or granting process if it is found not to be compliant with these eligibility criteria.*	☒
Data-Related Questions and Data Protection (Consent to any question below is entirely voluntary. A positive or negative answer will not affect the evaluation of your project proposal in any form and will not be communicated to the evaluators of your project.)	
For communication purposes only, the ERC asks for your permission to publish, in whatever form and medium, your name, the proposal title, the proposal acronym, the panel, and host institution, should your proposal be retained for funding.	◉ Yes ○ No
Some national and regional public research funding authorities run schemes to fund ERC applicants that score highly in the ERC's evaluation but which can not be funded by the ERC due to its limited budget. In case your proposal could not be selected for funding by the ERC do you consent to allow the ERC to disclose the results of your evaluation (score and ranking range) together with your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such authorities?	◉ Yes ○ No
The ERC is sometimes contacted for lists of ERC funded researchers by institutions that are awarding prizes to excellent researchers. Do you consent to allow the ERC to disclose your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such institutions?	◉ Yes ○ No
For purposes related to monitoring, study and evaluating implementation of ERC actions, the ERC may need that submitted proposals and their respective evaluation data be processed by external parties. Any processing will be conducted in compliance with the requirements of Regulation 45/2001.	
Have you previously submitted a proposal to the ERC? If known, please specify your most recent ERC application details.	◉ Yes ○ No

Proposal number	724966
Other details	ERC-2016-COG / evaluated by the panel as B / this is a different proposal

Proposal ID **819586** *Acronym* **SMART-ECOFIX**

Excluded Reviewers

You can provide up to three names of persons that should not act as an evaluator in the evaluation of the proposal for potential competitive reasons.

Extended Open Research Data Pilot in Horizon 2020

If selected, all applicants will participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that **all** research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR - findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does **not** have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature), thereby freeing themselves retroactively from the associated obligations.

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

[1] According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.

SiMulating ARTificially Enhanced Coastal Ocean FertilizatIon eXperiments

SMART-ECOFIX

Cover Page:

- Name of the Principal Investigator (PI) Pedro Cermeño
- Name of the PI's host institution for the project Institut de Ciencies del Mar, CSIC, Spain
- Proposal duration in months 60

Each day, more than fifty million tons of C in the form of CO_2 are fixed into organic material by marine diatoms, silica-precipitating phytoplankton that inhabit the sunlit layer of the world's oceans. A significant fraction of this C is transferred into the deep ocean, creating a deficit of CO_2 in the upper layer which is compensated by the diffusive drawdown of CO_2 from the atmosphere. On geological time scales, this mechanism, referred to as the biological pump, has contributed to reduce atmospheric CO_2 levels and cool the climate. ***SMART-ECOFIX aims to accelerate in experimental devices and computer simulations the slow natural processes through which marine diatoms contributed to CO_2 removal and ancient planetary cooling.*** The full system consists on i) accelerating the mobilization of inorganic nutrients from the rock reservoir and ii) engineering the biological pump to maximize its C export efficiency. The former involves the spread of fine-grained silicate minerals in suitable regions, known as enhanced silicate weathering (ESW), and subsequent adjustment of seawater nutrient ratios. The latter modifies the ecology, stoichiometry and food web structure of marine plankton with the aim of increasing the magnitude of organic C export and deep ocean sequestration. The strategic plan comprises i) a set of analytical techniques and experimental devices for the study of marine microbial plankton ecology and biogeochemistry, including state-of-the-art methods for single-cell determination of elemental composition, and ii) high spatial resolution ocean model simulations in high performance supercomputers. This research action is important to advance ways of engineering the biological pump and prospect potential benefits and risks of applying ESW in marine systems.

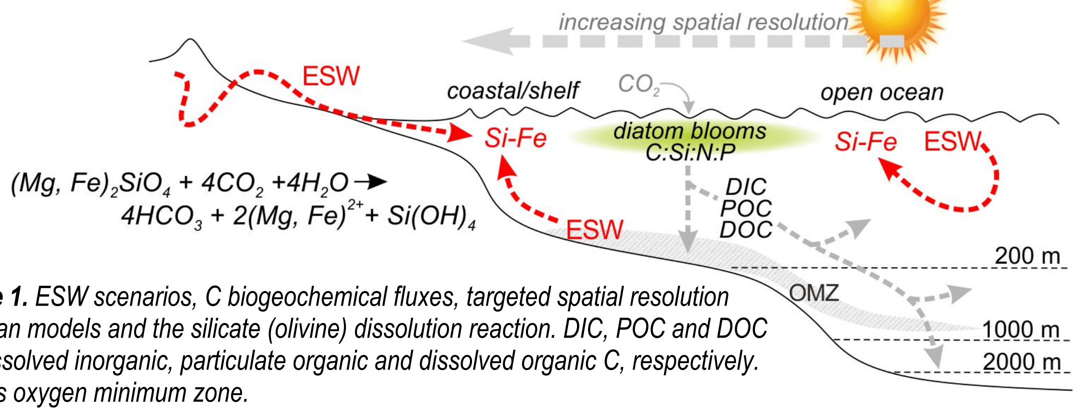

Figure 1. *ESW scenarios, C biogeochemical fluxes, targeted spatial resolution of ocean models and the silicate (olivine) dissolution reaction. DIC, POC and DOC are dissolved inorganic, particulate organic and dissolved organic C, respectively. OMZ is oxygen minimum zone.*

Section a: Extended Synopsis of the scientific proposal

Enhanced silicate weathering (ESW), the spread of crushed silicate minerals in suitable regions to accelerate the chemical weathering rates, is attracting a great deal of interest among Earth system scientists since it shows potential to remove CO_2 from the atmosphere[1-4]. When silicate minerals react with CO_2 in aqueous solution, the CO_2 turns into bicarbonate that ends up locked in the ocean basins for geological timescales (the alkalinity flux)[5,6]. Concurrently, the chemical dissolution of silicates fertilizes the surface ocean with inorganic nutrients such as silicon (Si) and iron (Fe), which spur the proliferation of diatoms, Si-precipitating phytoplankton, whose cell remains sink rapidly to the bottom of the ocean locking C away from the atmosphere (the biological pump)[7-11]. Whereas the alkalinity flux has been well quantified using Earth system models that simulate ESW scenarios[3,12,13], the effect of ESW on the biological pump remains unknown (Fig. 1).

I hypothesize that ESW will alter phytoplankton community ecology, biomass stoichiometry and food web structure, favouring the proliferation of organic C-sinkers such as diatom species with tendency to form long chains, heavy aggregates and resting spores. I also hypothesize that ESW will increase the magnitude of organic C export to the deep ocean by adjusting the rate of viral infections[14,15], predation, fragmentation, respiration and production of recalcitrant dissolved organic matter[16-18], as well as the competitive dynamics of distinct plankton functional groups such as diatoms and heterotrophic bacteria[19,20]. ***If technically viable, ESW could increase the export of organic C to the deep ocean either by itself or by supplementing other ocean fertilization schemes.*** The strategic plan uses experimental devices and super high resolution ocean model simulations to achieve the following scientific objectives: i) to accelerate the natural processes through which marine diatoms contributed to CO_2 removal and ancient planetary cooling, ii) to explore ways of engineering the biological pump and maximizing its C export efficiency, iii) to quantify organic C export under idealized ESW regional scenarios and iv) to evaluate the potential of ESW deployment schemes for climate change mitigation, marine ecosystem management and restoration.

Silicate weathering and the biological pump: a geological perspective

On geological timescales, the removal of CO_2 from the atmosphere is constrained by the rate of silicate weathering as it controls the burial of inorganic C, via alkalinity flux, and organic C, via input of dissolved nutrients to ecosystems[21-24]. C isotope mass balance analyses indicate that the former contributes 80% to C removal whereas the latter accounts for the remainder 20%; the 4:1 steady-state geochemical model[25,26]. These inorganic and organic C burial fluxes are in balance with volcanic degassing and oxidative weathering (natural CO_2 emissions), which keep atmospheric CO_2 levels and global temperature in check (global thermostat). These processes are exemplified by the idealized reactions[5,21,23],

$$CaSiO_3 + CO_2 \leftrightarrow \mathbf{CaCO_3 + SiO_2} \quad \text{(inorganic C sub-cycle)}$$

$$CO_2 + H_2O \leftrightarrow \mathbf{CH_2O + O_2} \quad \text{(organic C sub-cycle)}$$

So far, enhanced weathering proposals have focused primarily on shifting the inorganic C sub-cycle towards the right side of the reaction (i.e. mineral carbonation, e.g. *CARBFIX* project, https://www.or.is/english/carbfix-project)[27]. On the contrary, the prospect of engineering the organic C sub-cycle has received far less attention probably brought about by the false belief that biology has contributed little to the long-term regulation of atmospheric CO_2 levels[28,29].

Main hypothesis and justification

The scientific foundation of SMART-ECOFIX is built upon the main hypothesis that ESW increases the efficiency of the biological pump. Here, efficiency of the biological pump is defined as the ability of marine plankton ecosystems to accelerate the removal of CO_2 from the atmosphere either by increasing the magnitude of organic C export to the deep ocean and sediments[7] and/or the C to N to P biomass ratio of sinking fluxes[30-32]. It must be noted that organic C export to the deep ocean is an essential but insufficient condition for C sequestration, which requires that any enhanced production must lead to the settling of the material into the deeper water masses below the depth of winter mixing[33].

There are several plausible, not mutually exclusive mechanisms to establish a positive linkage between ESW and the efficiency of the biological pump all revolving around the effect of ESW on seawater chemistry, diatom ecology and biomass stoichiometry, and the subsequent effect of diatoms on the C export efficiency of the biological pump[10,11].

1) Si fertilisation spurs diatom blooms. Selective Si sequestration in the Southern Ocean constrains diatoms from forming blooms elsewhere and therefore limits the biologically-driven C sequestration potential of the entire ocean[9,34,35]. The most compelling evidence that Si availability often regulates diatom productivity[36] derives from the observation that the Si:N supply ratio to the surface waters nearly equals the Si:N ratio within diatoms[37]. On geological time scales, enhanced continental Si weathering supplies to the ocean basins rose diatoms to ecological prominence[38].

2) Si fertilisation increases the Si:C ratio of marine diatoms. The elemental Si:C ratio of diatoms is critical for quantifying the effectiveness of these organisms in the vertical transfer of C by the biological pump[39,40]. Frustule thickness and weight can greatly affect the scaling relationship between sinking velocity and cell size[41], thereby adjusting C export fluxes[40]. Understanding controls on Si:C ratio is important to better parameterizing scaling relationships between sinking velocity and diatom cell size in biogeochemical models. Silicification and frustule thickness also protect diatom integrity from mechanical destruction and grazers[42], thereby increasing organic C export fluxes.

3) Interplay between Si and Fe enhances C export. Large-scale Fe fertilization of the Si-rich Southern Ocean has been shown to add C to the sinking Si flux[43]. Conversely, Fe fertilization of Si-depleted ocean regions exhibits variable, typically low potential for C export, often attributed to the lack of fast sinking diatoms and/or the rapid recycling of standing stocks. Hence, concurrent Si-Fe fertilization of specific ocean regions via artificially ESW is expected to increase diatom abundance, frustule thickness and the vertical flux of organic C to the deep ocean.

4) The C:N:P stoichiometric ratio increases during diatom bloom progression. The C:N:P ratio of standing stocks imposes fundamental limits to the efficiency of the biological pump[31,44]. The C:N:P stoichiometric ratio may significantly deviate from a fixed Redfield ratio as a result of enhanced C consumption under nutrient-limiting conditions[31,45] and at high environmental CO_2 levels[30], or as a result of specific physiological features[46,47] such as the ability of diatom resting spores for lipid biosynthesis[48].

5) Diatom ecology and food web structure impact the magnitude of C export[10,49,50]. Field evidence shows that a large fraction of the annual C export in productive waters of the Southern Ocean, the North Atlantic or the Cape Verde Ocean Observatory is accounted for by short-term export events of diatom resting spores[51-55]. In addition to this, microbial food web structure can influence the magnitude of C export by adjusting the rate of viral infections[14,15], predation, fragmentation, respiration, preferential nutrient recycling[32] and production of recalcitrant dissolved organic matter[16-18], or by affecting the competitive dynamics for inorganic nutrients of distinct plankton functional groups such as diatoms, autotrophic flagellates and heterotrophic bacteria[19,20].

All these experimental and mechanistic evidences support the idea that ESW would impact marine phytoplankton ecology, biomass stoichiometry and food web structure in a way that enhance the efficiency of the biological pump, which, at present, transports 5 to >12 Pg C yr^{-1} from the surface waters to the ocean interior[56].

Research Gaps and Limits in the State of the Art

- Ocean fertilization, a means of climate geoengineering, refers to dumping nutrients into the ocean waters in order to stimulate phytoplankton primary productivity[8,33,57]. The resulting phytoplankton draw down atmospheric CO_2 and then die, falling to the deep ocean and sequestering C[33]. Nevertheless, the majority of large-scale ocean fertilization experiments conducted so far have been unable to convincingly prove significant potential for long-term CO_2 sequestration[57-60], largely associated with the lack of fast-sinking diatoms and with the predominance of plankton communities and microbial food webs very efficient in organic matter recycling. ***Thus, how might geoengineering improvements make phytoplankton blooms more efficient at sending C into the deep ocean?***
- Enhanced silicate weathering (ESW), the application of crushed silicate minerals in suitable regions to accelerate the weathering process, opens up the possibility of exploiting ESW schemes as a means of ocean Si (and possibly Fe) fertilization[1,61,62]. So far, most attention has been focused on land-based ESW applications, which potentially bring a number of benefits in addition to CO_2 sequestration, such as crop fertilization and soil improvement. I hypothesize that land-, coastal- and ocean-based ESW applications will alter marine phytoplankton community ecology, biomass stoichiometry and food web structure, in a way that enhance the dominance of organic C-sinkers such as diatom species with tendency to form long chains, heavy aggregates and resting spores.
- Knowing the elemental composition of phytoplankton in the field will allow us to diagnose species, life forms and environmental conditions prone to organic C export, and thus this information is instrumental to prospecting ways of engineering the biological pump. The elemental composition of phytoplankton in the field is usually obtained from bulk measurements (living plus detrital particles) or by assuming that cell quotas in the field match those measured in laboratory cultures[63-65]. More promising for analytical work are single-cell microscopy methods which base detection on the distinctive radiation absorption and fluorescence properties of individual elements. ***SMART-ECOFIX will exploit a state-of-the-art, single-cell microanalytical technique (for microplankton cells)***[46,66].
- Evidence is growing that marine diatoms are not only efficient transporters of organic C to the mesopelagic zone, but can also transport it to the deep bathypelagic ocean[10,67]. Linking diatom ecology, stoichiometry and food web structure to ocean biogeochemistry is important to improve estimates of organic C export and sequestration.
- Continental margins are poorly represented in global ocean models, which are way too coarse to capture the processes that dominate the physics of coastal and shelf seas[68]. Continental margins contain some of the most important habitats of marine diatoms and contribute substantially to organic C export to the deep open ocean. Thus, ***obtaining accurate estimates of organic C export under ESW scenarios requires a major focus on ocean modelling at very high spatial resolution.***

In sum, an ERC grant will allow me to undertake ground-breaking research by exploiting i) a multidisciplinary marine microbiology research laboratory in Barcelona agglutinating expertise in molecular tools, analytical methods and modelling skills for the study of microbial plankton and ocean biogeochemistry, and ii) current computational capabilities at the Barcelona Supercomputing Centre. From an epistemological standpoint, SMART-ECOFIX responds to calls for innovative research crossing the boundaries of Earth sciences and marine plankton ecology. It will expand our understanding of the complex interplay between abiotic and marine biotic factors that contribute to regulate the chemical composition of Earth's atmosphere and ocean environments. This is an essential step prior to any intervention such as the deployment of ESW schemes aimed at altering the ecological/biogeochemical functioning of natural systems.

Summary of Scientific Impact

i. The project will provide ***new insights into the marine phytoplankton ecology-stoichiometry-biogeochemistry link*** with implications for interpreting, understanding and modelling the functioning of the biological C pump in past, present and future ocean scenarios.

ii. The project will produce an unprecedented and highly valuable dataset of single-cell elemental composition of field phytoplankton cells. Among other things, this dataset will be important to diagnose species, life-forms, trophic structures and oceanographic conditions prone to organic C export. ***It will provide the basis for the design of new and more effective ocean fertilization strategies***.

iii. The project will quantify the extent of organic C export and sequestration under idealized ESW regional scenarios. On the management side, this achievement will provide ***the basis to evaluate the prospect of ESW as a means to enhance the efficiency of the biological pump***.

iv. ESW will contribute to the ***restoration of water column silica budgets in marine systems affected by coastal eutrophication and damming***. This is expected to alleviate these marine systems from the rising incidence of toxic blooms of harmful algal species and the progressive strengthening of oxygen minimum zones.

v. In the medium-term (coming decades), this research will be important to assess whether ESW applications in marine systems will be a valuable and viable option to contribute to CO_2 removal, ecosystem management and restoration.

Methodology

The overarching objective of SMART-ECOFIX is to accelerate in experimental devices and using high-spatial resolution ocean models, the slow natural processes through which marine diatoms contributed to CO_2 removal and ancient planetary cooling. To accomplish this scientific objective, I propose to develop a research program composed of the following two research streams (RS):

RS1. Experimental simulations in biostats and mesocosm

Motivation. Mounting evidence indicates that diatom species, forming long chains, symbiotic associations, resting spores and aggregates, contribute to organic C export more than previously thought[10,51,52,54,67]. These results open up the possibility of engineering the marine biological pump via ESW in order to maximize its C export efficiency. Estimates of plankton stoichiometry in the field and representation of the processes involved in water column vertical remineralization are two of the most critical flaws of previous studies linking plankton ecology and C biogeochemistry.

Main objectives. To accelerate in lab BIOSTATS and MESOCOSM enclosures the chemical weathering (dissolution) of forsterite olivine with the following research objectives: i) to gain knowledge on the ecological, biochemical and trophic response of marine plankton, ii) to explore the fate of photosynthetic organic matter in the aftermath of diatom blooms, and iii) to inform biogeochemical models and implement their predictive skills with particular focus on organic C export.

-BIOSTATS. To investigate the effect of ESW and dynamical nutrient supply regimes on the life cycle, cell physiology and biomass stoichiometry of selected diatom strains (e.g. Chaetoceros and Thalassiosira spp). ESW will be simulated by adding forsteritic olivine powder to artificial and/or filtered seawater media. For the purpose of ESW, the mineral olivine ($Mg_{2(1-x)}Fe_{2x}SiO_4$) has received most attention[1,2,69,70], as it combines a fast dissolution rate with a relative widespread abundance[70]. The kinetics of forsterite dissolution will be investigated following temporal changes in the concentration of Si and trace elements in seawater, and from model simulations using the software PHREEQC.

The basic experimental design utilizes "biostats" or chemostat bioreactors in which the initial Si:N ratios in the inflow media (3, 1, 0.5 mole/mole) are supplemented with forsteritic olivine powder either in a continuous way or intermittently to simulate different nutrient supply regimes. This experimental matrix yields six combinations that simulate N limiting conditions, a "neutral" condition (Si:N of 1) and Si limiting conditions in which both constant and intermittent supplements of olivine powder are provided. Phosphorus is in excess relative to N. The experimental design physically consists of distinct nutrient reservoirs connected to digitally controlled peristaltic pumps, where the desired nutrient combination can be directed to each of biostats operating in parallel under identical light and temperature[71].

-MESOCOSMS. To investigate the extent to which accelerated olivine dissolution in seawater alters phytoplankton community ecology, stoichiometry, food web structure and biomass remineralization in distinct marine environments. Again, ESW will be simulated by adding forsteritic olivine powder to seawater in mesocosms.

The experimental design consists of one Light Phase (LP) in the ocean-based mesocosm enclosures, and Dark Phases 1 and 2 (DP1&2) in opaque containers placed in temperature-controlled walking chambers (Fig. 2A). The objective of the LP is to induce diatom blooms by the addition of forsteritic olivine powder to seawater, and then to investigate changes in plankton physiology, biomass stoichiometry, food web structure and biogeochemistry. Previous experiments (unpublished) show that additions of Si to mesocosm enclosures containing natural plankton communities led to higher particulate organic C production rates per unit of phosphate consumed than same communities without Si additions (Fig. 2B). These results support the idea that additions of olivine forsterite would increase the efficiency of biomass production during the LP. On the other hand, the objective of DP1&2 is to characterize the remineralization of the photosynthetic biomass produced and processed, respectively, in the LP and DP1. To do so, the particulate organic matter (POM) produced during the LP will be concentrated using a system of decantation and inverse filtration, and transferred to dark containers containing natural seawater from 200 m depth (DP1). After ~20 day incubation, the remaining POM will be again transferred to dark containers containing seawater from 500 m depth (DP2).

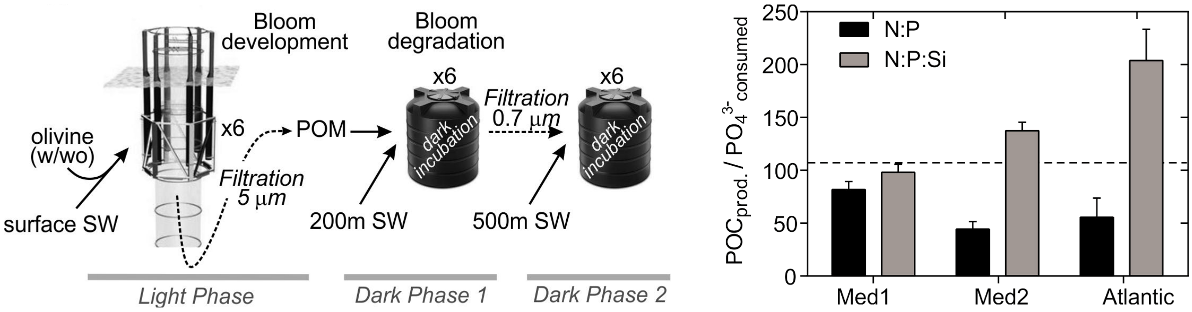

***Figure 2. A**) Experimental design depicting the three different phases (one light and two dark) involved in the MESOCOSM experiments. **B**) Particulate organic C (POC) production per unit of phosphate (PO_4^{3+}) consumed with and without Si additions to plankton communities of the western Mediterranean (Med1 & Med2) and the North Atlantic. Dashed line indicates Redfield.*

Main analytical methods. All the methods and facilities described below are implemented and currently operating in my research laboratory within the framework of previous and on-going projects (see funding ID).

- Single-cell elemental composition (XRMA): energy-dispersive X-Ray Microanalysis method using a Hitachi S-3500N Scanning Electron Microscope (SEM) equipped with an energy-dispersive spectrometer Si(Li) detector for analyzing simultaneously C, N, P, Si, and other elements in natural marine microplankton cells and detrital particles[66].
- Routine variables: inorganic nutrients in seawater (autoanalyzer), pH (colorimetric), alkalinity (pH change at acidified conditions), total organic C (TOC analyzer), particulate organic C and N (elemental analyzer), transparent exopolymer particles[72,73], chlorophyll-*a*, prokaryotes, phyto- and zooplankton abundance and size (Flow Cytometry, Optical Microscopy and an automatized FlowCam), bacterial production (^{3}H-leucine incorporation), enzymatic activity[74], physiological status of phytoplankton (Fast Repetition Rate Fluorometry), net community metabolism (Winkler method), virus mediated mortality[75,76] and zoo grazing (dilution technique[77]).

RS2. High-spatial resolution ocean model simulations

Motivation. Previous simulations of ESW using ocean biogeochemical models[61,62] i) assume that Si and Fe additions are homogeneously distributed over the entire ocean, ii) are coarse in spatial resolution, which prevents coastal and shelf seas from being adequately resolved, and iii) miss critical aspects of the phytoplankton ecology, stoichiometry and ocean biogeochemistry link. I argue that ESW schemes of ocean fertilization would be more effective and realistic if application efforts were targeted on specific ocean regions, those with the greatest potential for organic C export and sequestration. RS2 will explore in detail the following two specific scenarios:

Scenario 1: ESW in a coastal eutrophic system. Coastal eutrophication increases the occurrence of harmful algal blooms, lowers the efficiency of the biological pump and leads to the expansion of subsurface oxygen minimum zones. Decreased Si:N and Si:P ratios observed in many coastal systems over the past decades are likely responsible for these environmental changes[78]. ESW might potentially restore the water column silica budget in eutrophic systems thereby increasing the organic C export efficiency. Thus, if coastal eutrophication and ESW were properly coordinated, it could restore diatom productivity and attenuate the incidence of harmful algal blooms.

Scenario 2: ESW in a coastal upwelling system. Most proposals of ESW focus on spreading fine-grained silicate over tropical land soils, where the silicate weathering process is greatly accelerated. Yet, enhanced weathering of ultrabasic silicates such as olivine minerals (Mg_2−xFexSiO_4) is feasible in marine settings. I propose to investigate the potential of applying this method in coastal upwelling systems.

Main objectives. To scale up biogeochemical implications from experimental devices to regional scales with the following objectives: i) to explore ways of engineering the biological pump, ii) to diagnose ocean regions with greatest potential for organic C export iii) to quantify in super high resolution ocean model simulations the magnitude of organic C export and sequestration in selected ocean regions and iv) to evaluate whether ESW is a valuable option for CO_2 removal and restoration of marine systems affected by coastal eutrophication.

Modelling strategy. Ocean dynamics will be solved by the Nucleus for European Modelling of the Ocean (NEMO) (https://www.nemo-ocean.eu/)[79]. NEMO is part of the EC-Earth (http://www.ec-earth.org/) Earth System Model (ESM). The Earth Sciences department at Barcelona Supercomputing Centre (BSC-ES), partner on this proposal, is an active member of the EC-Earth consortium and contributes to its development in several aspects, among them ocean dynamics and biogeochemistry. To simulate ESW scenarios at a global scale but with enough spatial resolution to reasonably resolve coastal dynamics we will adopt a high resolution configuration of 1/12º with 75 vertical levels. The ocean circulation model will be coupled with the biogeochemical model PISCES-v2 (Pelagic Interaction Scheme for Carbon and Ecosystem Studies), which resolves the dynamics of lower trophic levels of marine ecosystems (phyto- and zooplankton) and the biogeochemistry of O_2, C and major nutrients controlling phytoplankton growth (P, N, Fe, and Si)[80].

The coupled NEMO/PISCES model simulations will be designed and performed at BSC in collaboration with Dr. F.J. Doblas-Reyes, head of the Earth Sciences Department and Dr. R. Bernardello who is responsible for ocean biogeochemical activities at BSC. Because of the high resolution and the high number of state variables in PISCES-v2 the simulations proposed are extremely expensive in terms of computational resources. We will therefore adopt an off-line strategy whereby the ocean physics are computed only once at super-high resolution, saved on hard-disk and then used as environmental forcing of the many biogeochemical simulations required to represent several scenarios. This strategy has lower computational burden than fully coupled models and so is appropriate for the high resolutions intended here. The dynamical fields required will be generated from an historical simulation performed with EC-Earth using the high resolution ocean. This simulation will be forced with observed greenhouse gases and aerosols for the period 1990-2010. Daily averaged fields will be generated to force PISCES-v2 in offline mode.

The coupling of PISCES-v2 to ocean circulation outputs will enable i) to resolve coastal and shelf seas at very high spatial resolution, ii) to account for variations in key stoichiometric ratios such as the Si/C ratio and iii) to account for the sinking of POM broken down into many distinct size classes each characterized by its own sinking rate. This is an adequate modelling scheme to face the challenges posed in this proposal. If applicable, existing biogeochemical parameterizations will be implemented using new formulations based on results derived from biostats and mesocosms. Ultimately, the combination of experimental work (RS1) and regional modelling (RS2), intended to extrapolate the biogeochemical implications of experimental results to broader spatial and temporal scales, will allow us to evaluate the feasibility, benefits and risks of deploying regional-scale ESW schemes.

Technical Feasibility

The applicant has strong conceptual understanding, technical expertise and computational skills related to the proposal's research theme. The applicant has published relevant papers related to these topics in top journals such as Science and PNAS. My expertise and skills will facilitate the implementation of the project, including:

- Cross-disciplinary training in plankton ecology/physiology and biogeochemistry. My research department at the ICM-CSIC in Barcelona agglutinates strong expertise in molecular tools and analytical methods for the study of marine plankton. ***Dr. Mariona Segura-Noguera at University of Lincoln (UK)*** will contribute expertise in single-cell elemental composition analyses. ***Prof. F.G. Figueiras at IIM-CSIC (Vigo, Spain)*** has agreed to participate in the setup, sampling and sample analyses of mesocosms and contribute with his enormous expertise in coastal plankton ecosystems.
- The research team has strong skills in ocean modelling and access to high performance computational facilities at Mare Nostrum 4, the most powerful supercomputer in Spain managed by the Barcelona Supercomputing Centre (BSC) in Barcelona. ***Dr. F.J. Doblas-Reyes, head of the Earth Sciences Department and Dr. R. Bernardello who is responsible for ocean biogeochemical activities at BSC*** will participate in technical and scientific aspects of the modelling work-package. Their strong computational skills and experience in Earth system modelling will guarantee the implementation of high spatial resolution model configurations within the timeframe of the proposal.
- Collaboration with researchers in other research institutions in Europe and US (within the framework of previous research projects), which has allowed me to acquire conceptual understanding and refine methodologies. ***Prof. Paul Falkowski, Board of Governors Professor at Rutgers University (USA), will participate as external advisor in developing strategies to engineer the production and sinking of diatoms along continental margins.***

I will be affiliated at the Institute of Marine Sciences (ICM-CSIC) in Barcelona, one of the leading European centres in environmental sciences. Infrastructures, research facilities and technical support at the ICM-CSIC and the Barcelona Supercomputing Centre (BSC), partner on this proposal, will guarantee the proper execution of the project. PhD students will be required appropriate background to conduct the proposed research. One postdoc will be selected according to his/her programming skills (FORTRAN, C/C++), modelling expertise and potential contribution to the project Each PhD will be assigned a specific theme: *PhD#1*) Impact of ESW and nutrient supply dynamics on diatom physiology, life-cycle and stoichiometry; *PhD#2*) Simulating artificially enhanced coastal ocean fertilization experiments in mesocosm enclosures. I will stimulate discussion among PhD students and other participants of the project with the aim of facilitating data exchange and synergies. The postdoctoral fellow and external collaborators will help to supervise, mentor and train students.

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Section b: Curriculum vitae (max. 2 pages)

PERSONAL INFORMATION

Family name, First name: Cermeño, Pedro
Date of birth: 03 May 1975
Nationality: Spanish
URL for web site: https://www.researchgate.net/profile/Pedro_Cermeno
ORCID: https://orcid.org/0000-0002-3902-3475

EDUCATION

2006	PhD, Biology, Department of Marine Sciences, University of Vigo, Spain. Name of PhD Supervisor: Emilio Marañón
2001	Diploma (equivalent to M.Sc.), Organic geochemistry, University of Vigo, Spain
2000	BSc, Marine Sciences, University of Vigo, Spain
1998	BSc, Biology, University of Salamanca, Spain

EMPLOYMENT RECORD AND FELLOWSHIPS

2018–	Research scientist at Institute of Marine Sciences of the Spanish National Research Council (CSIC), Barcelona, Spain
2012–2017	Ramón y Cajal Researcher (equivalent to Tenure track) Marine Biology & Oceanography, Institute of Marine Sciences (CSIC), Barcelona, Spain
2009–2012	Research Associate, Dept. of Marine Sciences, University of Vigo, Spain
2007–2009	Marie Curie Postdoctoral Fellow, Institute of Marine & Coastal Sciences, Rutgers University, NJ, USA.
2006-2007	Fulbright Postdoctoral Fellow, Institute of Marine & Coastal Sciences, Rutgers University, NJ, USA.

BRIEF RESEARCH STATEMENT AND PRELIMINARY WORK

My research group studies the interactions between marine microbial life and the environment on a range of spatial and temporal scales. I am interested in how marine microorganisms respond to shape element cycles, with special emphasis on carbon. I combine experimental work, state-of-the-art analytical methods and computer models with the aim of identifying feedbacks and synergies among the biotic and abiotic compartments of Earth.

I use experimental devices such as laboratory microcosms, chemostats (bioreactors), mesocosm enclosures and in situ experiments in the sea to gain further understanding of marine microbial plankton physiology, ecology and evolution, and their role in the regulation of global biogeochemical cycles and Earth climate. On the modelling side, I employ mathematical models of plankton cell physiology, community ecology and ocean circulation with the aim of expanding experimental learning into broader spatial and temporal scales.

RESEARCH PROJECTS (PI)

Since I assumed responsibility as PI in 2007, I have raised in excess of 1M € in competitive funding to support my research laboratories in Rutgers-USA, Vigo and Barcelona-Spain. (see next section Funding ID)

SUPERVISION OF GRADUATE STUDENTS

- Tamara Rodríguez-Ramos (PhD) Universidad de Vigo, graduated July 2014
  Currently, Research Assistant at IEO (www.ieo.es)
- Miguel Branco Vázquez (Msc) Universidad de Vigo, graduated July 2014
- Miguel Cabrera Brufau (Msc) Institut de Ciencias del Mar-CSIC, Sept 2016
- Virginia García Bernal (Msc) Institut de Ciencias del Mar-CSIC, Sept 2016
- Miguel Branco Vázquez (PhD) Universidad de Vigo, (expected 2018)
- José Luis Otero Ferrer (PhD) Universidad de Vigo, (expected 2018)
- Charlie Gaborit (PhD) Institut de Ciencias del Mar-CSIC, (expected 2018)

COMMISSIONS OF TRUST & REVIEWER DUTIES

- Reviewer (Journals): 50+ scientific manuscripts for *Nature*, *PNAS*, *PLoSone*, *L&O*, *Prog. Oceanog.*, *Glob. Chan. Biol.*, *Ecol. Letts.*, *Deep Sea Res.*, etc.
- Reviewer (Funding Agencies): CICYT (Spanish Funding Agency), ANEP (Spanish Agency for Evaluation and Prospecting), Projects EXPLORA 2015 (Spanish Ministry of Economy and Competitiveness), US National Science Foundation (NSF), Israel-US bi-national Science Foundation (BSF).

- Scientific evaluation committees: Ramón y Cajal 2014 (tenure track Spanish research call), Juan de la Cierva 2014 (Postdoc Spanish research call).
- Thesis committees (María Huete-Ortega, Daffne Lopez-Sandoval, Patricia de la Fuente)
- Co-organizer of the session 'Phytoplankton Diversity and Biogeochemistry' at the Ocean Science Meeting/ASLO, New Orleans 2016.

PARTICIPATION IN OCEANOGRAPHIC CRUISES

- ***Economic Exclusive Zone 2000*** R/V Hespérides. Galician shelf – *Cartography*.
- ***TPR 2001*** R/V Mytilus. Ría de Vigo – *Determination of primary production*.
- ***EVALUPRE 2003*** R/V Mytilus. Galician shelf– *Phyto Photosynthesis-Irradiance curves*.
- ***JR98 2003*** R/V James Clark Ross. Celtic Sea – *Determination of primary production*.
- ***CARPOS 2006*** R/V Hespérides. Azores. – *Determination of primary production* (2006).
- ***TRYNITROP 2007*** R/V Hespérides. Canarias-Argentina. – *Nutrient addition experiments.*
- ***MALASPINA 2011*** R/V Hespérides. Auckland-Hawaii – *Determination of primary production.*
- ***DISTRAL 2012*** R/V Mytilus. *Ría de Vigo.* – **Chief-scientist**.
- ***CHAOS 2013*** R/V Mytilus. Ría de Vigo. – **Chief-scientist**.

SCIENTIFIC NETWORK

Prof. P. G. Falkowski, Rutgers University, NJ, USA.

Prof. Falkowski is world leader in aquatic photosynthesis, microbial ecology and evolution, and ocean biogeochemical cycles. He is Board of Governors Professor, Bennett L. Smith Chair in Business and Natural Resources at Rutgers University and Director of the Rutgers Energy Institute. Since I joined his lab in 2006, first as Fulbright and then as Marie Curie postdoctoral fellow, I acquired enormous conceptual understanding on the interplay between marine plankton communities (taxonomic and size structure) and ocean biogeochemistry. I also acquired methodological skills dealing with the use of chemostat bioreactors. Prof. Falkowski will participate as external advisor in this ERC grant in developing strategies to engineer the production and sinking of diatoms along continental margins.

Prof. F.G. Figueiras, Institute of Marine Research (IIM-CSIC), Spain.

Prof. Figueiras is expert in phytoplankton ecophysiology and has very good knowledge of the functioning of coastal ecosystems involved in this research grant such as the Galician Rías Bajas or the western Mediterranean Sea. We have collaborated in previous projects dealing with phytoplankton diversity and its relationship to primary productivity and ecosystem functioning. Prof. Figueiras will participate in this ERC grant as external collaborator contributing to the setup, sampling and chemical/biological analyses of the mesocosm experiments.

Dr. O. Romero, MARUM-University of Bremen, Germany.

Dr. Romero is usual collaborator of the applicant in research projects aimed at investigating the response of marine diatoms to environmental stressors. Our research has implications for understanding how marine diatom communities respond to environmental variability (e.g. nutrient fluxes, ocean circulation) on a variety of temporal scales from days to thousands of years. This geological perspective on diatom ecology, physiology and biogeochemistry will contribute to interpreting the results derived from this ERC grant.

Dr. M. Follows, Ocean Modelling, MIT, USA.

Using a global ocean circulation model (MITgcm), we projected a data-driven empirical relationship between the distribution of diatoms and coccolithophores, and the depth of the oceanic nutricline from present to 2100 in order to investigate the consequences of climate warming on plankton community structure and the marine C cycle. These results and subsequent reports

Prof. M.J. Benton, University of Bristol, UK.

Prof. Benton is world leader in palaeontology and patterns of life diversification. We have applied a state-of-the-art mathematical method for causal inference that has resulted in a fascinating relationship between marine invertebrate diversification and the kinematics of plate tectonics. Prof. Benton is collaborator in the research proposal "A new evolutionary model of marine invertebrate diversification driven by plate tectonics and kinematics (INDITEK)" currently under review (see Funding ID).

Dr. Sergio Vallina, Instituto Español Oceanografía, Spain

Dr. Vallina has enormous expertise in ocean ecosystem modelling. We have actively collaborated in numerous projects aimed at gaining further understanding on the mechanisms underlying the distribution of marine planktonic microorganisms, their diversity and biogeochemical impact. Dr. Vallina has contributed with his expertise to the development of my scientific career. Currently, we have a research project SPEAD in progress (see Funding ID).

Appendix: All ongoing and submitted grants and funding of the PI (Funding ID)

Since I assumed responsibility as PI in 2007, I have raised in excess of 1M € in competitive funding to support my research laboratories in Rutgers, Vigo and Barcelona.

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
Simulating Plankton Evolution with Adaptive Dynamics in a global ocean model (SPEAD)	Spanish Science Foundation	156.000	2018-2020	PI: **P. Cermeño** Coordination, management and modelling tasks.	Providing advances in ecological/evolutionary modelling supportive to the SMART-ECOFIX's modelling work package.
Biogenic trace gases and their processes in the surface ocean (BIOGAPS)	Spanish Science Foundation	235.000	2017-2019	PI: R. Simó Nutrient additions and remineralization patterns.	Contributing to the experimental setup and implementation of methodologies.

Grant applications

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[2]
A new evolutionary model of marine invertebrate diversification driven by plate tectonics and kinematics (INDITEK)	Spanish Science Foundation (under review)	Requested: 95.000	2-years	PI: **P. Cermeño** Coordination, management and modelling tasks.	none

Funding ID (last 10 years)

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
Surface Ocean natural Fertilization and the biological pump through geological Time (SUAVE)	Spanish Science Foundation	120.000	2014-2017	PI: **Pedro Cermeño** Coordination, management and determination of organic matter remineralization, writing.	Supporting the hypotheses and providing a geological insight into the SMART-ECOFIX's rationale/objectives.
Understanding microbial plankton community assembly	Spanish Government	252.000	2012-2017	PI: **Pedro Cermeño** Coordination, management, ecological model implementation, writing.	Providing a better understanding of the mechanisms underlying phytoplankton community structure in nature.
Dispersal, neutral models and assembly of marine microbial plankton communities (DISTRAL)	Spanish Science Foundation	37.000	2012-2014	PI: **Pedro Cermeño** Coordination, management, plankton diversity, writing.	Providing a better understanding of the mechanisms underlying phytoplankton community structure in nature.
Response of marine phytoplankton	Xunta de Galicia	52.882	2010-2013	PI: **Pedro Cermeño** Coordination,	Supporting the hypotheses and providing

communities to historical climate change: effect on diversity and atmospheric CO_2 levels (REFRESCO)	Program Incite			management, data analysis, writing.	a geological insight into the SMART-ECOFIX's rationale/objectives.
Taxonomic composition and cell size of marine eukaryotic phytoplankton (TASIO)	European Union FP7	250.744	2007-2010	PI: **Pedro Cermeño** Coordination, management, plankton competition experiments, writing.	Supporting the hypotheses and contributing to the experimental setup, implementation of methodologies and conceptual understanding.
Circumnavigation of the global ocean and exploration of biodiversity (MALASPINA)	Spanish Science Foundation	239.313	2009-2013	PI: Carlos Duarte Determination of primary production (particulate and dissolved), writing.	Supporting the hypotheses
Macroecological patterns in marine phytoplankton (PERSEO)	Spanish Science Foundation	236.313	2008-2010	PI: Emilio Marañón, Co-IP: **Pedro Cermeño** Coordination, determination of phytoplankton N uptake rates, writing.	Contributing to the experimental setup and implementation of methodologies.

Section c: Early achievements track-record (max. 2 pages)

Publications summary and 10 key publications

As of January 2018, I have published 49 peer-reviewed publications, 30 of which as first and/or senior author. The citation count in Google Scholar is 1550, h-index: 23, i-10 index: 29.

1. **Cermeño P, Benton MJ, Paz O, Verard C. (2017) Trophic and tectonic limits to the global increase of marine invertebrate diversity. *Scientific Reports 7, 15969.* doi:10.1038/s41598-017-16257-w.**

   We challenge the long-standing view that ecological interactions such as resource competition and predation set upper limits to the global diversity, which, in the absence of external perturbations, is maintained indefinitely at equilibrium. Rather, we hypothesize that the apparent stability of marine invertebrate diversity through the Phanerozoic is linked to the recycling of the ocean crust, which is continuously being created and destroyed at mid-ocean ridges and subduction zones, respectively. I designed and coordinated all the work, analysed data and wrote the manuscript.

2. **Cermeño P. (2016) The geological story of marine diatoms and the last generation of fossil fuels. *Perspectives in Phycology 3(2):53-60*. doi: 10.1127/pip/2016/0050. (Invited review) # cites: 5.**

   I review the mechanisms that led marine diatoms to become one of the most prominent primary producers on earth today. The review stresses the importance of diatoms as the main source of Tertiary oils (fossil fuels) and discusses the significance of diatoms in the regulation of the global C cycle.

3. **Cermeño P, Falkowski PG, Romero O, Schaller M, Vallina S. (2015) Continental erosion and the Cenozoic rise of marine diatoms. *PNAS* 112(14):4239-4244. IF: 9.674 # cites: 30 (commented in *Nature Geosciences*)**

   Using competition models and sedimentary records, we show that the erosion of continental silicates facilitated the ecological expansion of diatoms in marine systems during the past 40 million years. Our results suggest an increase in the efficiency of the oceanic biological pump over this period. These results support the central idea of the SMART-ECOFIX proposal that enhanced silicate weathering could potentially increase diatom productivity, sinking and organic C export. I designed and coordinated all the work, analysed data and wrote the manuscript.

4. **Vallina S, Dutkiewicz S, Follows M, Montoya JM, Cermeño P, Loureau M. (2014). Global relationship between phytoplankton diversity and productivity in the ocean. *Nature Communications* 5, 4299, doi: 10.1038/ncomms5299. IF: 11.470 # cites: 45.**

   Using a global ocean ecosystem model, we provide new, based on predatory pressures, to explain the unimodal relationship between marine phytoplankton diversity and ecosystem productivity on spatial scales ranging from local to global. I contributed to the design of the research, the interpretation of results and the writing of the manuscript.

5. **Cermeño P. (2011) Marine planktonic microbes survived climatic instabilities in the past. *Proceedings of the Royal Society of London B*, 279 (1728):474-479. IF: 5.415 # cites: 6.**

   Using the marine microfossil record of diatoms and calcareous plankton, I show that the probability of species extinction is not correlated to secular changes in climate. I discuss the significance of dispersal as a potential means of buffering external contingencies.

6. **Cermeño P, Lee J-B., Wyman K., Schofield O., Falkowski PG. (2011) Competitive dynamics in two species of phytoplankton under non-equilibrium conditions. *Marine Ecology Progress Series* 429: 19–28. IF: 2.711 # cites: 34.**

   Using continuous culture systems (classical chemostats), we show that nutrient supply dynamics (i.e. the frequency of nutrient pulses) regulates the competitive dynamics between diatoms and coccolithophores. I designed the research, performed the experiments, analysed results and wrote the manuscript.

7. **Cermeño P, de Vargas C, Abrantes F, Falkowski PG. (2010) Phytoplankton biogeography and community stability in the ocean. *PLoSone* 5, e10037. Highlighted Faculty of 1000. IF: 4.411 # cites: 37.**

   Fossil records of marine diatom covering the last 200-k years in Benguela, the eastern equatorial Atlantic and the Mauritanian upwelling system, show recurrent cycles of community departure and recovery linked to concurrent changes in oceanographic/climatic conditions. I designed the research, analysed data and wrote the manuscript.

8. **Cermeño P, Falkowski PG. (2009) Controls on diatom biogeography in the ocean. *Science* 325:1539-1541. doi: 10.1126/science.1174159. IF: 29.747 # cites: 97.**

   We demonstrate that the geographical configuration of continental land masses does not impose limits to the global dispersion of marine planktonic diatoms. These results are key to understanding the patterns of species distribution, global diversity and the evolution of marine microorganisms. Since geographic isolation is an essential component of allopatric speciation, our results stress the need to consider alternative speciation models. I designed the study, analysed the data and wrote the manuscript.

9. **<u>Cermeño P</u>, Dutkiewicz S, Harris RP, Follows M, Schofield O, Falkowski PG. (2008). The role of nutricline depth in regulating the ocean carbon cycle. *PNAS* 105(51):20344-20349. doi: 10.1073/pnas.0811302106. Highlighted Faculty1000. Q1 IF: 9.38 # cites: 158.**

   A data-driven relationship between the coccolithophore to diatom biomass ratio and the nutricline depth is projected using an intermediate complexity general ocean circulation model. Our study predicts changes in the distribution of diatoms and coccolithophores by the end of this century and a decrease of 8% in the efficiency of the biological pump. I designed the study, analysed the data and wrote the manuscript.

10. **<u>Cermeño P</u>, Marañón E, Pérez V, Serret P, Fernández E, Castro CG. (2006) Phytoplankton size structure and primary production in a highly dynamic coastal ecosystem (Ría de Vigo, NW-Spain): Seasonal and short-time scale. *Estuarine, Coastal and Shelf Science* 67(1-2):251-266. IF: 7.609 # cites: 115.**

    We report a full annual cycle of phytoplankton biomass, primary production, community size structure and net community metabolism in the Ría de Vigo, a highly dynamic coastal ecosystem characterised by spring bloom, summer upwelling and winter mixing. I performed the analyses, analysed data and wrote the manuscript.

Invited Presentations (Conferences, Workshops)

Since 2010, I have been given 13 invited lectures at research institutions and conferences.

1. Interdisciplinary Centre of Marine and Environmental Research (CIIMAR), 18 January 2010, Porto, Portugal. Title: Determinants of extinction of planktonic microbes. Invited by Dr. Marcos Rubal.
2. National Laboratory of Energy & Geology seminar series (LNEG), 10 February 2010, Lisboa, Portugal. Title: Climate change and the extinction of marine planktonic microbes in the sea. Invited by Dr. Fatima Abrantes.
3. Eur-OCEANS/Europole Mer Conference, 31 May-2 June 2010, Centre de la Mer, Aber Wrach, Brittany, France. Title: Influence of meso- and sub-mesoscale ocean dynamics on the global carbon cycle and marine ecosystems. Invited by conference committee.
4. Earth, Atmospheric & Planetary Sciences, MIT, July 2011, Cambridge, USA. Invited by Dr. Mick Follows.
5. Department of Natural Resources, University of Malaga, 7 October 2011, Malaga, Spain. Title: Microbial plankton functional groups, ecology and biogeochemistry. Invited by Dr. Isabel Reche.
6. EMBO workshop, The Molecular life of diatoms, 25-28 June 2013, Paris, France. Title: Reconstructing the evolutionary history of marine diatoms. Invited by conference committee.
7. The Ramón Margalef Summer Colloquia, Physical-Biological ocean interactions: from the micro to the large scale, 1-12 July 2013, Barcelona, Spain. Title: Marine microplankton functional groups. Invited by conference committee.
8. The Ramón Margalef Summer Colloquia, What ecology can learn from natural and human-induced disturbances: A cross-system view, 7-18 July 2014, Barcelona, Spain. Title: Role of marine phytoplankton functional groups in Earth biogeochemical cycles. Invited by conference committee.
9. Conference Jacques Monod, 22-26 June 2015, Roscoff, France. Title: Continental erosion, marine diatoms and the geological C cycle. Invited by conference committee.
10. Global Changes in Marine Plankton Diversity and Productivity SDiv workshop, 30 Nov-4 Dec 2015 Leipzig, Germany. Title: Global ocean databases for biodiversity-productivity studies. Invited by Dr. Boris Worm.
11. The Marine Ecology and Climate group special seminars– Bristol University, 1 December 2015, Bristol, UK. Title: PaleOcean fertilization and Carbon sequestration. Invited by Dr. Fanny Monteiro.
12. The evolution of the Global Ocean Symposium– Rutgers University. April 2016, New Brunswick, USA. Title: Ocean fertilization during the Cenozoic era. Invited by Prof. Paul Falkowski and Prof. Oscar Schofield.
13. PALEOGENIE workshop– Bristol University, June 2016, Bristol, UK. Title: The role of marine biology in the geological carbon cycle. Invited by Dr. Andy Ridgwell.

Awards/Distinctions

- 2012 Ramón y Cajal grant – Spanish Ministry of Economy and Competitiveness (ranked #1st out of 140 candidates)
- 2009 Juan de la Cierva grant –Spanish Ministry of Science and Technology (ranked #3rd out of 200 candidates)
- 2007 Marie Skłodowska-Curie Fellowship, Research Fellowship Program – European Commission.
- 2006 Fulbright fellowship – U.S. Department of State's Bureau of Educational and Cultural Affairs (The Fulbright Program in association with the Spanish Science Agency).

Part B2: *The scientific proposal*

Section a. State-of-the-art and objectives

Enhanced silicate weathering (ESW), the spread of crushed silicate minerals in suitable regions to accelerate the chemical weathering rates, is attracting a great deal of interest among Earth system scientists since it shows potential to remove CO_2 from the atmosphere[1-4]. When silicate minerals react with CO_2 in aqueous solution, the CO_2 turns into bicarbonate that ends up locked in the ocean basins for geological timescales (the alkalinity flux)[5,6]. Concurrently, the chemical dissolution of silicates fertilizes the surface ocean with inorganic nutrients such as silicon (Si) and iron (Fe), which spur the proliferation of diatoms, Si-precipitating phytoplankton, whose cell remains sink rapidly to the bottom of the ocean locking C away from the atmosphere (the biological pump)[7-10]. Whereas the alkalinity flux has been well quantified using Earth system models that simulate ESW scenarios[3,11,12], the effect of ESW on the biological pump remains unknown (Fig. 1).

I hypothesize that ESW will alter phytoplankton community ecology, biomass stoichiometry and food web structure, favouring the proliferation of organic C-sinkers such as diatom species with tendency to form long chains, heavy aggregates and resting spores. I also hypothesize that ESW will increase the magnitude of organic C export to the deep ocean by adjusting the rate of viral infections[13,14], predation, fragmentation, respiration and production of recalcitrant dissolved organic matter[15-17], as well as the competitive dynamics of distinct plankton functional groups such as diatoms and heterotrophic bacteria[18,19]. ***If technically viable, ESW could increase the export of organic C to the deep ocean either by itself and/or by supplementing other ocean fertilization schemes.*** The strategic plan uses experimental devices and super high resolution ocean model simulations to achieve the following scientific objectives: i) to accelerate in experimental devices and using high spatial resolution ocean models, the natural processes through which marine diatoms contributed to CO_2 removal and ancient planetary cooling, ii) to explore ways of engineering the biological pump and maximizing its C export efficiency, iii) to quantify organic C export under idealized ESW regional scenarios and iv) to evaluate the potential of ESW schemes for climate change mitigation, marine ecosystem management and restoration.

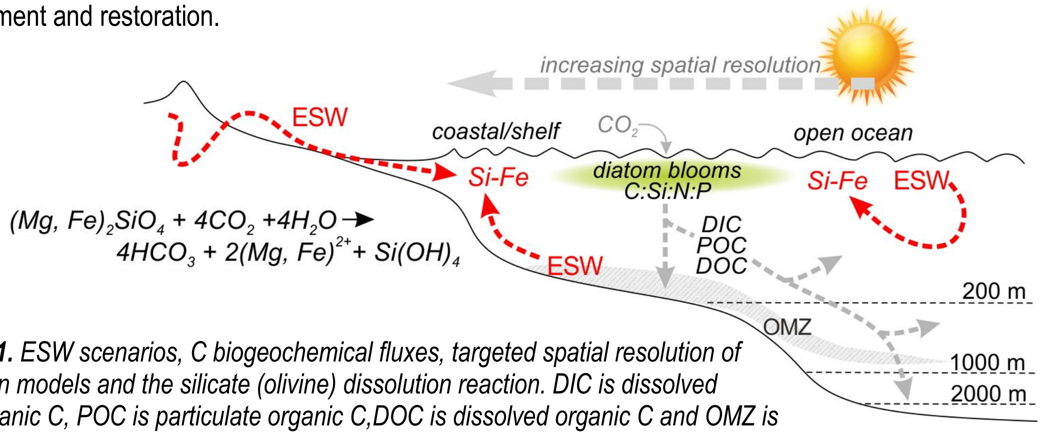


Fig. 1. *ESW scenarios, C biogeochemical fluxes, targeted spatial resolution of ocean models and the silicate (olivine) dissolution reaction. DIC is dissolved inorganic C, POC is particulate organic C,DOC is dissolved organic C and OMZ is oxygen minimum zone.*

Silicate weathering and the biological pump: a geological perspective

On geological timescales, the removal of CO_2 from the atmosphere is constrained by the rate of silicate weathering as it controls the burial of inorganic C, via alkalinity flux, and organic C, via input of dissolved nutrients to ecosystems[20-23]. C isotope mass balance analyses indicate that the former contributes 80% to C removal whereas the latter accounts for the remainder 20%; the 4:1 steady-state geochemical model[24,25]. These inorganic and organic C burial fluxes are in balance with volcanic degassing and oxidative weathering (natural CO_2 emissions), which keep atmospheric CO_2 levels and global temperature in check (global thermostat). These processes are exemplified by the idealized reactions[5,20,22],

$$CaSiO_3 + CO_2 \leftrightarrow \mathbf{CaCO_3 + SiO_2} \quad \text{(inorganic C sub-cycle)}$$
$$CO_2 + H_2O \leftrightarrow \mathbf{CH_2O + O_2} \quad \text{(organic C sub-cycle)}$$

So far, enhanced weathering proposals have focused primarily on shifting the inorganic C sub-cycle towards the right side of the reaction (i.e. mineral carbonation, e.g. *CARBFIX* project, https://www.or.is/english/carbfix-project)[26]. On the contrary, the prospect of engineering the organic C sub-cycle has received far less attention probably brought about by the false belief that biology has contributed relatively little to the long-term regulation of atmospheric CO_2 levels[27,28].

A priori the 4:1 steady-state model of inorganic to organic C burial ratio sets the relative contribution of each flux (inorganic and organic) to atmospheric CO_2 removal[21,24]. This is basically associated with the fact that, on average, continental weathering delivers, on a stoichiometric basis, far more alkalinity than inorganic nutrients. ***However, changes in the efficiency of the biological pump might potentially shift the C cycle away from geochemical***

steady-state, increasing the relative contribution of organic productivity to CO_2 drawdown. Here, efficiency of the biological pump is defined as the ability of marine plankton ecosystems to accelerate the removal of CO_2 from the atmosphere either by increasing the magnitude of organic C export to the deep ocean and sediments[7] and/or the C to N to P biomass ratio of sinking fluxes[29-31]. It must be noted that organic C export to the deep ocean is an essential but insufficient condition for C sequestration, which requires that any enhanced production must lead to the settling of the material into the deeper water masses below the depth of winter mixing[32].

In support of the organic C sub-cycle, enhanced rates of marine primary productivity (largely attributed to diatoms) and build-up of dissolved organic matter stocks in the sea during specific geological times could result in a drop of atmospheric CO_2 levels and global cooling[33-37]. One illustrative example is the Palaeocene-Eocene Thermal Maximum, an approximately 170.000-year-long period of global warming ~55.9 million years ago, that ended when >2.000 Pg of organic C were sequestered in the deep ocean and sediments over 30.000-40.000 years[36-38].

Main hypothesis and justification

The scientific foundation of SMART-ECOFIX is built upon the main hypothesis that ESW increases the efficiency of the biological pump. There are several plausible, not mutually exclusive mechanisms to establish a positive linkage between ESW and the efficiency of the biological pump all revolving around the effect of ESW on seawater chemistry, diatom ecology and biomass stoichiometry, and the subsequent effect of diatoms on the C export efficiency of the biological pump.

1) Si fertilisation spurs diatom blooms. Selective Si sequestration in the Southern Ocean constrains diatoms from forming blooms elsewhere and therefore limits the biologically-driven C sequestration potential of the entire ocean[9,39,40]. The most compelling evidence that Si availability often regulates diatom productivity[41] derives from the observation that the Si:N supply ratio to the surface waters nearly equals the Si:N ratio within diatoms[42]. On geological time scales, enhanced continental Si supply to the ocean basins rose diatoms to ecological prominence[43].

2) Si fertilisation increases the Si:C ratio of marine diatoms. The elemental Si:C ratio of diatoms is critical for quantifying the effectiveness of these organisms in the vertical transfer of C by the biological pump[44,45]. Frustule thickness and weight can greatly affect the scaling relationship between sinking velocity and cell size[46], thereby adjusting C export fluxes[45]. Understanding controls on Si:C ratio is important to better parameterizing scaling relationships between sinking velocity and diatom cell size in biogeochemical models. Silicification and frustule thickness also protect diatom integrity from mechanical destruction and grazers[47], thereby increasing organic C export fluxes.

3) Interplay between Si and Fe enhances C export. Large-scale Fe fertilization of the Si-rich Southern Ocean has been shown to add C to the sinking Si flux[48]. Conversely, Fe fertilization of Si-depleted ocean regions exhibits variable, typically low potential for C export, often attributed to the lack of fast sinking diatoms and/or the rapid recycling of standing stocks. Hence, concurrent Si-Fe fertilization of specific ocean regions via artificially ESW is expected to increase diatom abundance, frustule thickness (Si:C ratio) and the vertical flux of organic C to the deep ocean.

4) The C:N:P stoichiometric ratio increases during diatom bloom progression. The C:N:P ratio of standing stocks imposes fundamental limits to the efficiency of the biological pump[30,49]. The C:N:P stoichiometric ratio may significantly deviate from a fixed Redfield ratio as a result of enhanced C consumption under nutrient-limiting conditions[30,50] and at high environmental CO_2 levels[29], or as a result of specific physiological features[51,52] such as the ability of diatom resting spores for lipid biosynthesis[53].

5) Diatom ecology and food web structure impact the magnitude of C export[10,54,55]. Field evidence shows that a large fraction of the annual C export in productive waters of the Southern Ocean, the North Atlantic or the Cape Verde Ocean Observatory is accounted for by short-term export events of diatom resting spores[56-60]. In addition to this, microbial food web structure can influence the magnitude of C export by adjusting the rate of viral infections[13,14], predation, fragmentation, respiration, preferential nutrient recycling[31] and production of recalcitrant dissolved organic matter[15-17], or by affecting the competitive dynamics for inorganic nutrients of distinct plankton functional groups such as diatoms, autotrophic flagellates and heterotrophic bacteria[18,19].

All these experimental and mechanistic evidences support the idea that ESW would impact marine phytoplankton community ecology, biomass stoichiometry and food web structure in a way that enhance the efficiency of the biological pump, which, at present, transports in the range 5 to >12 Pg C yr^{-1} from the surface waters to the ocean interior[61].

Research Gaps and Limits in the State of the Art

- ESW, the application of crushed silicate minerals in suitable regions to accelerate chemical weathering rates, opens up the possibility of exploiting ESW schemes as a means of ocean Si (and possibly Fe) fertilization[1,62,63]. Currently, the effect of ESW on marine plankton ecosystems is uncharted terrain, but conventional wisdom suggests that it would enhance the organic C export efficiency of the biological pump. For instance, by increasing the production and sinking of diatoms along continental margins and shallow seas.

- Accurate estimates of plankton elemental composition are of critical importance to understand, model and predict marine biogeochemical cycles in past, present and future ocean scenarios. Knowing the elemental composition of phytoplankton in the field allow us to diagnose species, life forms and environmental conditions favourable for organic C export, and thus this information is key to prospecting ways of engineering the marine biological pump. The elemental composition of phytoplankton in the field is usually obtained by using size-fractionation followed by bulk measurements, or by assuming that field quotas match those measured in laboratory cultures[64-66]. More promising for analytical work are single-cell microscopy methods which base detection on the distinctive radiation absorption and fluorescence properties of individual elements. SMART-ECOFIX will exploit a state-of-the-art, single-cell microanalytical technique[51,67] (for microplankton) implemented in my research department.
- Evidence is growing that marine diatoms are not only efficient transporters of organic C to the mesopelagic zone, but can also transport it to the deep bathypelagic ocean[10,68]. Linking diatom ecology, stoichiometry and food web structure to ocean biogeochemistry is important to improve estimates of organic C export and sequestration.
- The quantity and quality of dissolved organic matter released during diatom blooms remain poorly characterized, despite refractory pools being an important component of the relatively long-term C storage in the ocean[17].
- Continental margins are poorly represented in global ocean models, which are way too coarse to capture the processes that dominate the physics of coastal and shelf seas[69]. Continental margins contain some of the most important habitats of marine diatoms and contribute substantially to organic C export to the deep open ocean. Thus, obtaining accurate estimates of organic C export under ESW scenarios requires a major focus on ocean modelling at very high spatial resolution.

Scientific novelty of the project and new horizons for science and technology

Ocean fertilization, a means of climate geoengineering, refers to dumping nutrients into the ocean waters in order to stimulate phytoplankton primary productivity[8,32,70]. The resulting phytoplankton draw down atmospheric CO_2 and then die, falling to the deep ocean and sequestering C[32]. To be efficient for C sequestration, ocean fertilization must increase the magnitude of organic C export per unit of nutrient added as well as the remineralisation length scale; the vertical distance over which organic particle flux declines 63% affected by respiration, fragmentation and sinking[32,71]. Nevertheless, the majority of large-scale ocean fertilization experiments conducted so far have been unable to convincingly prove significant potential for long-term CO_2 sequestration[70,72-74], largely associated with the lack of organic-C sinkers such as diatoms species forming aggregates and resting spores, and/or with the predominance of plankton communities and microbial food webs very efficient in organic matter recycling. ***Thus, how might geoengineering improvements make phytoplankton blooms more efficient at sending C into the deep ocean?***

Diatoms sustain roughly 20% of global primary production and contribute disproportionately to organic C export to the deep ocean and sediments[7,44]. Unlike the majority of other phytoplankton, diatoms have absolute requirements for silicon (Si), which they use to build their silica shells (frustules), and hence the availability of Si regulates diatom primary productivity in widespread ocean regions[9]. Enhanced silicate weathering (ESW), the application of crushed silicate minerals in suitable regions to accelerate the chemical weathering process, opens up the possibility of exploiting ESW schemes as a means of ocean Si (and possibly Fe) fertilization[1,62,63]. So far, most attention has been focused on land-based ESW applications, which potentially bring a number of benefits in addition to CO_2 sequestration, such as crop fertilization, soil improvement and an increased buffering of soil acidity. I hypothesize that land-, coastal- and ocean-based ESW applications will alter marine phytoplankton community ecology, biomass stoichiometry and food web structure, increasing diatom productivity and organic C export. Furthermore, coastal eutrophication and river damming decrease the Si:N and Si:P ratio of fluvial delivery to the coastal ocean[75,76]. As a consequence, the food chain in coastal areas, typically dominated by diatom-copepod interactions, is being altered[75]. I further hypothesize that ESW will contribute to the restoration of natural nutrient stoichiometry and phytoplankton community composition in marine systems influenced by coastal eutrophication and river damming.

In sum, an ERC grant will allow me to undertake ground-breaking research by exploiting i) a multidisciplinary marine microbiology research laboratory in Barcelona agglutinating expertise in molecular tools, analytical methods and modelling skills for the study of microbial plankton and ocean biogeochemistry, and ii) current computational capabilities at the Barcelona Supercomputing Centre. The proposed research will enable i) to investigate the effect of ESW on phytoplankton ecology, stoichiometry, food web structure and ocean biogeochemistry, ii) to explore ways of engineering the biological pump, maximizing its C export efficiency and designing more efficient ocean fertilization schemes, iii) to quantify organic C export under idealized ESW regional scenarios and iv) to evaluate likely environmental risks of applying this method. From an epistemological standpoint, SMART-ECOFIX responds to calls for innovative research crossing the boundaries of Earth sciences and marine plankton ecology. It will expand our understanding of the complex interplay between abiotic and marine biotic factors that contribute to regulate the chemical composition of Earth's atmosphere and ocean environments. This is an essential step forward prior to any deliberate intervention such as the deployment of ESW schemes aimed at altering the ecological and biogeochemical functioning of the natural system.

Summary of Scientific Impact

i. The project will provide ***new insights into the marine phytoplankton ecology-stoichiometry-biogeochemistry link*** with implications for interpreting, understanding and modelling the functioning of the biological C pump in past, present and future ocean scenarios.

ii. The project will produce an unprecedented and highly valuable dataset of single-cell elemental composition of field phytoplankton cells. Among other things, this dataset will be important to diagnose species, life-forms, trophic structures and oceanographic conditions prone to organic C export. ***It will provide the basis for the design of new and more effective ocean fertilization strategies***.

iii. The project will quantify the extent of organic C export and sequestration under idealized ESW regional scenarios. On the management side, this achievement will provide ***the basis to evaluate the prospect of ESW as a means to enhance the efficiency of the biological pump***.

iv. ESW will contribute to the ***restoration of water column silica budgets in marine systems affected by coastal eutrophication and damming***. This is expected to alleviate these marine systems from the rising incidence of toxic blooms of harmful algal species and the progressive strengthening of O_2 minimum zones.

v. In the medium-term (coming decades), this research will be important to assess whether ESW applications in marine systems will be a valuable and viable option to contribute to CO_2 removal, ecosystem management and restoration.

vi. Ultimately, SMART-ECOFIX will encourage the establishment of a cutting-edge research laboratory that promote learning by bridging gaps between ocean plankton ecology, biogeochemistry and geoengineering, and collaborations with other research labs in EU and abroad.

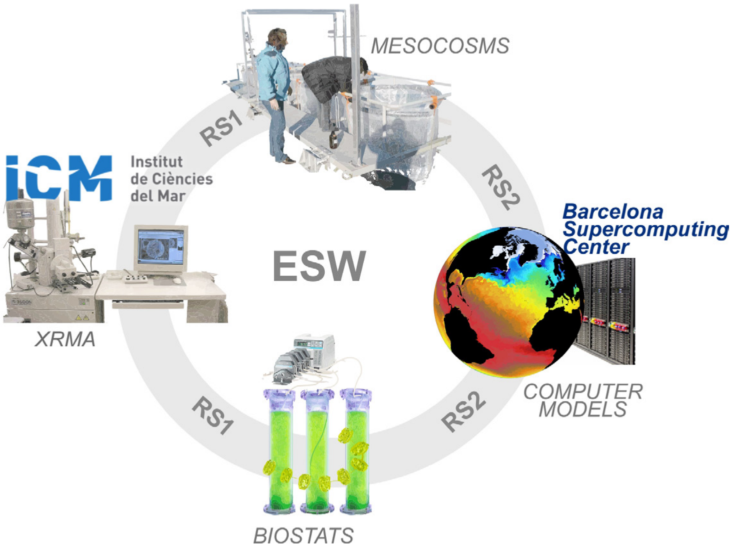
Section b. Methodology

The overarching objective of SMART-ECOFIX is to accelerate in experimental devices and using high-spatial resolution ocean models, the slow natural processes through which marine diatoms contributed to CO_2 removal and ancient planetary cooling. To accomplish this scientific objective, I propose to develop a research program composed of the following two research streams (RS) (Fig. 2):

RS1. Experimental simulations in biostats and mesocosms – to accelerate in laboratory BIOSTATS and MESOCOSM enclosures the chemical weathering of forsterite olivine; a fast weathering silicate mineral, with the aim of inducing diatom blooms, adjusting stoichiometry and altering the planktonic food web structure in a way that enhances organic C export.

RS2. High spatial resolution ocean model simulations – to scale up from experimental devices to regional spatial scales with the following objectives: i) to explore ways of engineering the biological pump, ii) to diagnose ocean regions with greatest potential for organic C export iii) to quantify in super high resolution ocean model simulations the magnitude of organic C export in selected ocean regions and iv) to evaluate whether ESW is a valuable option for CO_2 drawdown and restoration of marine systems affected by coastal eutrophication.

Fig. 2. *A diagram depicting the main methods, experimental setups and interplay among the research streams (RSs) that form the basis of the research program. Scaling up from experimental "pilot plant" recreations to regional predictions requires the implementation of very high resolution ocean models and enormous computational capabilities like those supplied at the Barcelona Supercomputing Centre.* ***Ultimately, the combination of experimental work (RS1) and modelling (RS2) will provide the qualitative and quantitative basis to evaluate the feasibility, benefits and risks of deploying regional-scale ESW schemes aimed at climate change mitigation, ecosystem management and restoration.***



RS1. Experimental simulations in biostats and mesocosm

Motivation. Mounting evidence indicates that diatom species, forming long chains, symbiotic associations, resting spores and aggregates, contribute to organic C export more than previously thought[10,56,57,59,68]. These results open up the possibility of engineering the marine biological pump via ESW in order to maximize its organic C export efficiency. Estimates of plankton stoichiometry in the field and representation of the processes involved in water column vertical remineralization are two of the most critical flaws of previous studies linking plankton ecology and C biogeochemistry.

Main objectives. To accelerate in lab BIOSTATS and MESOCOSM enclosures the chemical weathering (dissolution) of forsterite olivine with the following research objectives: i) to gain knowledge on the ecological, biochemical and trophic response of marine plankton, ii) to explore the processing and fate of photosynthetic organic matter in the aftermath of diatom blooms, and iii) to inform biogeochemical models and implement their predictive skills with particular focus on organic C export.

Analytical methods. All the methods and facilities described below are implemented and currently operating in my research laboratory within the framework of previous and on-going projects (see funding information).

- Single-cell elemental composition (XRMA): energy-dispersive X-Ray Microanalysis method using a Hitachi S-3500N Scanning Electron Microscope (SEM) equipped with an energy-dispersive spectrometer Si(Li) detector for analyzing simultaneously C, N, P, Si, and other cation and anion concentrations in single natural marine microplankton cells and detrital particles[67]. The advent of new technologies provides more powerful amenities (requested in section C of this proposal).
- Chromophoric and Fluorescent Dissolved Organic Matter (CDOM & FDOM): spectrophotometry and spectrofluorometry of filtered seawater[77].
- Transparent Exopolymer Particles (TEP) and Coomassie Stainable Particles (CSP): staining with Alcian blue and Coomassie, respectively, and spectrophotometry[78,79].
- Enzymatic activity: activity of extracellular enzymes such as leu-aminopeptidase, alkaline-phosphatase, etc[80].
- Virus mediated mortality: the rate of lysed cells will be determined following the virus-reduction approach[81,82]. Briefly, prokaryotes and phytoplankton samples will be conveniently diluted with free virus seawater. Then, the viral production originated from already infected cells will be counted by flow cytometry[83], and the rate of lysed cells will be calculated by dividing the viral production for the burst size (number of viruses per cell).
- DNA & RNA sampling and analysis for genetic diversity (DNA/RNA): quick filtration in situ using a peristaltic pump and large 3-µm and 0.2-µm polycarbonate filters. Flask freezing in Liquid N_2 and storage at -80ºC. Massive sequencing.
- Sulfur volatiles: purge and trap and gas chromatography with mass spectrometry detector using a portable Agilent 5975T system.
- Routine variables: dissolved inorganic nutrients in seawater (autoanalyzer), pH (colorimetric), alkalinity (pH change at acidified conditions), total organic C (TOC analyzer), particulate organic C and N (elemental analyzer), chlorophyll-*a* (fluorometry), prokaryotes, phyto- and zooplankton abundance and size (Flow Cytometry, Coulter Counter, Optical Microscopy and an automatized FlowCam), bacterial heterotrophic production (^{3}H-leucine incorporation), physiological status of phytoplankton (Fast Repetition Rate fluorometry), net community metabolism (Winkler method) and zooplankton grazing (dilution technique[84]).

Workplan

BIOSTATS*. *To investigate the effect of ESW and dynamical nutrient supply regimes on the life cycle, cell physiology and biomass stoichiometry of selected diatom strains (e.g. Chaetoceros and Thalassiosira spp). ESW will be simulated by adding forsteritic olivine powder in artificial and/or filtered seawater media. For the purpose of ESW, the mineral olivine ($Mg_{2(1-x)}Fe_{2x}SiO_4$) has received most attention[1,2,85,86], as it combines a fast dissolution rate with a relative widespread abundance. Olivine dissolves three orders of magnitude faster than ordinary quartz and commercial olivine mines are operating across the globe. Recent experiments show that olivine dissolution in seawater increases dissolved Si concentrations almost linearly over a 88 day incubation period to reach final seawater concentrations 10-fold higher than those observed prior to amendments[86]. The kinetics of forsterite dissolution will be investigated following temporal changes in the concentration of Si and trace elements in seawater, and from model simulations using the software PHREEQC (using the minteq.dat database).

The basic experimental design utilizes “biostats” or chemostat bioreactors in which the initial Si:N ratios in the inflow media (3, 1, 0.5 mole/mole) are supplemented with forsteritic olivine powder either in a continuous way or intermittently to simulate different nutrient supply regimes. This experimental matrix yields six combinations that simulate N limiting conditions, a “neutral” condition (Si:N of 1) and Si limiting conditions in which both constant and intermittent supplements of olivine are provided. Phosphorus is in excess relative to N. The experimental design physically consists of two distinct nutrient reservoirs at a time connected to computer-monitored digitally controlled peristaltic pumps, where the desired nutrient combination can be directed to each of biostats operating in parallel under identical light and temperature regimes[87].

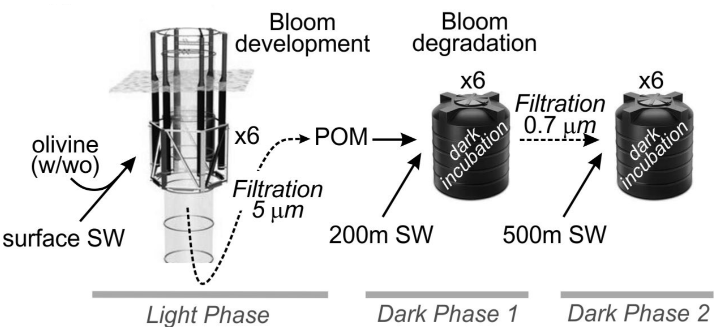
Task 1. Physiological monitoring. The cells will be counted and sized daily (using a Multisizer Coulter Counter and verified by optical microscopy and an automatized FlowCam). The physiological state of each population will be assessed using a Fast Repetition Rate Fluorometer. Single-cell stoichiometry (C:N:P:Si:others), frustule thickness and micro-morphological structures will be examined using Scanning Electron Microscopy coupled with an energy dispersive X-ray microanalysis (XRMA) currently operating at the Institute of Marine Sciences (see further description in *Task 4*)[51,67]. Vegetative cells and resting spores of diatoms will be counted separately and their specific elemental composition will be individually measured using XRMA.

Task 2. Biogeochemistry: dissolved organic matter, TEP, CSP and volatiles. The dissolved organic matter (DOM) pool is an important component of the organic C export flux either through oceanic convective mixing or by enhancing flocculation and aggregation[17,88,89]. To characterize the quality (labile, semi-labile and recalcitrant) and quantity of dissolved organic matter produced during diatom blooms, CDOM and FDOM in seawater will be determined. Four pair of excitation-emission wavelengths will be examined[90], and excitation-emission matrices will be obtained in the excitation/emission range 250-400/300-500 nm. All measurements will be performed using a PerkinElmer LS 55 Fluorescence spectrometer and the intensities calibrated subtracting the Raman scatter peak of miliQ water[91]. TEP, CSP and volatiles produced by diatom populations will be also determined following the methods previously specified.

MESOCOSMS. To investigate the extent to which accelerated olivine dissolution in seawater alters phytoplankton community ecology, stoichiometry, food web structure and biomass remineralization in distinct marine environments. ESW will be simulated by adding forsteritic olivine powder to seawater contained in ocean-based mesocosms. Again, the kinetics of forsterite dissolution will be investigated following temporal changes in the concentration of Si and trace elements in seawater, and from model simulations using the software PHREEQC.

During the first 2-years, likely in spring and summer, seawater collected at two different locations in the Catalan sea (a eutrophic coastal system) and the Ría de Vigo in the NW-Iberian Peninsula (a coastal upwelling system) will be confined in ocean-based mesocosms (a total of 4 mesocosm experiments). These two selected locations are logistically suitable owing to their proximity to research institutes in which the applicant has full access to analytical facilities and offer ideal conditions for comparing distinct marine environments. Each mesocosm unit, designed and built within the framework of previous research projects (funded by the Spanish Science foundation, IP: F.G. Figueiras, Institute of Marine Research, IIM-CSIC in Vigo), comprises of a flotation frame and a flexible bag 2-m in diameter and 4-m long. The bags are filled with seawater from each specified location, closed at the bottom by a full-diameter sediment trap and gently transported to shore, where they are attached to platforms situated at protected bays.

The experimental design consists of one Light Phase (LP) in the ocean-based mesocosm enclosures, and Dark Phases 1 and 2 (DP1&2) in opaque containers placed in temperature-controlled walking chambers (Fig. 3A). The objective of the LP is to induce diatom blooms by the addition of forsteritic olivine powder to seawater, and then to investigate changes in plankton physiology, biomass stoichiometry, food web structure and biogeochemistry. The objective of DP1&2 is to characterize the remineralization of the photosynthetic biomass produced and processed, respectively, in the LP and DP1. To do so, the particulate organic matter (POM) produced during the LP will be concentrated using a system of decantation and inverse filtration (5μm nominal pore size), and transferred to dark containers containing natural seawater from 200 m depth (DP1). After ~20 day incubation, the remaining POM will be again re-concentrated and transferred to dark containers containing seawater from 500m depth (DP2).



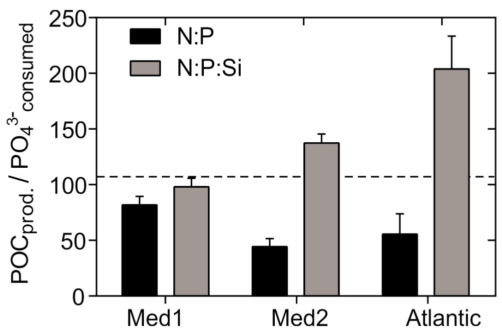


Fig. 3. A*) Experimental design depicting the three different phases (one light and two dark) involved in the MESOCOSM experiments.* ***B****) Particulate organic C (POC) production per unit of phosphate (PO_4^{3+}) consumed with and without Si additions to plankton communities of the western Mediterranean (Med1 & Med2) and the North Atlantic. Dashed line indicates Redfield.*

Task 3. Ecosystem monitoring. Seawater properties including under-water light, temperature, salinity, nutrient concentrations, pH and alkalinity will be measured routinely. Plankton abundance, community size structure and taxonomic composition will be examined using flow cytometry (for picoplankton), and optical microscopy and an automatized FlowCam (for nano-, micro- and mesoplankton). Along the LP of the experiment, the mesocosms will be sampled for size-fractionated chl-a, CDOM, FDOM, TOC, TON, POC, PON, molecular composition of DOM, TEP, CSP, Sulphur volatiles, genetic diversity (massive DNA sequencing), enzymatic activity, bacterial heterotrophic production, net community metabolism, virus mediated mortality and zooplankton grazing rates. The sampling frequency will be set during the course of the experiment. Previous experiments (unpublished) show that additions of Si to mesocosm enclosures containing natural plankton communities led to higher particulate organic C production rates per unit of phosphate consumed than same communities without Si additions (Fig. 3B). These results support the idea that additions of olivine forsterite would increase the efficiency of biomass production during the LP.

Task 4. Single-cell elemental composition (stoichiometry). The elemental composition of plankton biomass in the field is usually obtained by using bulk size-fractionation or by assuming that field quotas match those measured in laboratory cultures[64-66]. The former approach is unable to distinguish between living biomass and detrital organic matter, or among plankton species falling within the same cell size range. The later approach is problematic provided that cellular quotas exhibit an enormous plasticity and lab cultures are usually grown under nutrient replete conditions. More promising for analytical work are microscopy techniques which base detection on the characteristic radiation absorption and fluorescence properties of individual elements[67,92-94]. In Task 4, single-cell elemental composition (C:N:P:Si:others), frustule thickness and micro-structures will be determined using Scanning Electron Microscopy coupled with an energy dispersive X-ray microanalysis (XRMA)[51,67]. Special effort will be devoted to distinguish living cells from detritus, diatoms from other phytoplankton, and vegetative cells from resting spores. New technologies (requested in section C of this proposal) allow up to 17x more data to be collected at the same time with no loss of accuracy, map larger areas, have better statistics in each data point and enhance detectability of some trace elements such as Fe and Ni. These measurements will be carried out at least 2-3 times per week.

Task 5. Biogeochemistry: bloom decay, biomass processing and C export. Along the incubation periods, all dark containers will be sampled for nutrients, pH, alkalinity, CDOM, FDOM, TOC, TON, POC, PON, DOM molecular composition, TEP, CSP, volatiles, bacterial abundance, genetic diversity (massive DNA sequencing), XRMA single-cell stoichiometry (including individual cells, aggregates and detrital particles), particle abundance-size spectra (Flow Cytometry, optical microscopy, FlowCam), enzymatic activity, bacterial heterotrophic production, net community metabolism, viral mediated mortality and zooplankton grazing rates. Some data will be obtained daily, some other once/twice per week.

RS2. High-spatial resolution ocean model simulations

Motivation. Previous simulations of ESW using ocean biogeochemical models[62,63] i) assume that Si and Fe additions are homogeneously distributed over the entire ocean, ii) are coarse in spatial resolution, which prevents coastal and shelf seas from being adequately resolved, and iii) miss critical aspects of the phytoplankton ecology, stoichiometry and ocean biogeochemistry link. I argue that ESW schemes of ocean fertilization would be more effective and realistic if application efforts were targeted on specific ocean regions, those with the greatest potential for organic C export and sequestration. RS2 will explore in detail the following two specific scenarios:

Scenario 1: ESW in a coastal eutrophic system. Coastal eutrophication increases the occurrence of harmful algal blooms, lowers the efficiency of the biological pump and leads to the expansion of subsurface oxygen minimum zones. Decreased Si:N and Si:P ratios observed in many coastal systems over the past decades are likely responsible for these environmental changes[75]. ESW might potentially restore the water column silica budget in eutrophic systems thereby increasing the organic C export efficiency. Thus, if coastal eutrophication and ESW were properly coordinated, it could restore diatom productivity at the expense of plankton with lesser potential for C export and attenuate the incidence of harmful algal blooms.

Scenario 2: ESW in a coastal upwelling system. Most proposals of ESW focus on spreading fine-grained silicate over tropical land soils, where the silicate weathering process is greatly accelerated. Yet, enhanced weathering of ultrabasic silicates such as olivine minerals ($Mg_2{-}xFexSiO_4$) is feasible in marine settings. I propose to investigate the potential of applying this method in coastal upwelling systems. The strategy tackles a double goal. First, olivine dissolution consumes protons and increases alkalinity, which is expected to lower outgassing of CO_2 during upwelling. Concurrently, a higher content of dissolved Si in upwelled waters is expected to boost larger proliferations of diatoms and hence faster organic C export.

Main objectives. To scale up biogeochemical implications from experimental devices to regional scales with the following objectives: i) to explore ways of engineering the biological pump, ii) to diagnose ocean regions with greatest potential for organic C export iii) to quantify in super high resolution ocean model simulations the magnitude of organic C export and sequestration in selected ocean regions and iv) to evaluate whether ESW is a valuable option for CO_2 removal and restoration of marine systems affected by coastal eutrophication.

Modelling strategy. Ocean dynamics will be solved by the Nucleus for European Modelling of the Ocean (NEMO) (https://www.nemo-ocean.eu/)[95]. NEMO is part of the EC-Earth (http://www.ec-earth.org/) Earth System Model (ESM), the result of a community effort involving 27 European research institutions. The Earth Sciences department at Barcelona Supercomputing Centre (BSC-ES), partner on this proposal, is an active member of the EC-Earth consortium and contributes to its development in several aspects, among them ocean dynamics and biogeochemistry. EC-Earth is routinely used at BSC-ES to generate predictions and projections of global climate change and variability[96,97] . To simulate ESW scenarios at a global scale but with enough spatial resolution to reasonably resolve continental shelf dynamics we will adopt a high resolution configuration of 1/12º with 75 vertical levels.

The ocean circulation model will be coupled with the biogeochemical model PISCES-v2 (Pelagic Interaction Scheme for Carbon and Ecosystem Studies), which resolves the dynamics of lower trophic levels of marine ecosystems (phyto- and zooplankton) and the biogeochemistry of oxygen, C and major nutrients controlling phytoplankton growth (P, N, Fe, and Si)[98]. PISCES-v2 includes two phytoplankton groups (diatoms and nanophyto) and two zooplankton size classes (micro- and mesozooplankton), each with their own suite of prognostic variables: C, Fe, Chl-*a* biomasses and Si, the latter being only for diatoms. The phytoplankton primary production is limited by the availability of the main nutrients (P, N, Fe and Si) and the stoichiometric ratios of C/Chla, Si:C and Fe:C are prognostically predicted based on external concentrations of the limiting nutrients. The detritus or particulate organic matter (POM) compartment will be modelled following the Kriest and Evans model[99], in which the size spectrum of the POM is represented by a power function. In this configuration, the C content, the sinking speed and the abundance of aggregates are described by power functions of particle diameters[99]. The coupling of PISCES-v2 to ocean circulation outputs generated by NEMO-OPA enables i) to resolve coastal and shelf seas at very high spatial resolution, ii) to account for variations in key stoichiometric ratios such as the Si/C ratio and iii) to account for the sinking of POM broken down into many distinct size classes each characterized by its own sinking rate. ***This is an adequate modelling scheme to face the challenges posed in this proposal.*** If applicable, existing biogeochemical parameterizations will be implemented using new formulations based on results derived from biostats and mesocosm experiments.

This ERC proposal will use high- resolution simulations of the ocean dynamics provided by the EC-Earth ocean component (NEMO) as the physical forcing for the ecosystem dynamics provided by the PISCES-v2 model. ***The coupled NEMO/PISCES model simulations will be designed and performed at BSC in collaboration with Dr. F.J. Doblas-Reyes, head of the Earth Sciences Department and Dr. R. Bernardello who is responsible for ocean biogeochemical activities at BSC.*** Because of the high resolution and the high number of state variables in PISCES-v2 the simulations proposed are extremely expensive in terms of computational resources. We will therefore adopt an off-line strategy whereby the ocean physics are computed only once at super-high resolution, saved on hard-disk and then used as environmental forcing of the many biogeochemical simulations required to represent several scenarios. This strategy has lower computational burden than fully coupled models and so is appropriate for the high resolutions intended here. The dynamical fields required will be generated from an historical simulation performed with EC-Earth using the high resolution ocean. This simulation will be forced with observed greenhouse gases and aerosols for the period 1990-2010. Daily averaged fields will be generated to force PISCES-v2 in offline mode.

This strategy requires the availability of massive memory storage to save the dynamical fields. We will save the dynamical fields for the central 12-year segment of the historical simulation (1994-2006) to represent present-day oceanic conditions. The memory needed for this is 204 terabytes. Besides this, PISCES output from the simulations performed (2 scenarios + 2 controls, see below) is estimated to occupy a further 70 terabytes. If time allows, more scenarios will be explored so the total memory required is estimated to be 300 terabytes.

Workplan

Task 6. EC-Earth: Global historical simulation (1/12º spatial resolution) and generation of dynamical fields. EC-Earth with ocean at high resolution will be equilibrated running a 30-year simulation in which greenhouse gases and atmospheric aerosols are kept constant at levels observed in year 1990. At this stage, EC-Earth is run without PISCES to make the simulation faster. Ocean biogeochemical fields are equilibrated offline (3000 years) using a coarser resolution (1º spatial resolution) and PISCES-v2. These fields are then interpolated to the high resolution grid and a 10 year extension of the EC-Earth spin-up is performed, only this time with PISCES-v2. This extension is required to allow the biogeochemical fields to adjust to the internal variability of EC-Earth. Therefore, a total of 40 years will be performed to equilibrate the physics. Finally, starting from the end of this 40-year spin-up, a 20-year historical simulation is performed for the period 1990-2010 using EC-Earth to generate the dynamical fields needed for the offline simulations. From this last simulation, we will save daily averages of the variables needed to run PISCES-v2 offline for the central 12-year segment (1994-2006).

Task 7. NEMO-PISCES offline: Global control simulations (1/12º spatial resolution) and diagnostics. Global simulations at high 10-km grid spatial resolution will be run in off-line mode. Fluvial inputs of nitrogen (N), phosphorus (P) and silicon (Si) in various forms will be implemented in the model at coastal coupling points using the coastal segmentation and related catchments (COSCAT) global database. The model strategy considers two controls (e.g. ESW applied globally): 1) a land-based fertilization control, in which dissolved Si supply by rivers is increased two-fold (equivalent to dissolution of 1Pg olivine per year). 2) an ocean-based fertilization control, in which Si and Fe additions are distributed homogeneously worldwide following the strategy used in a previous report[63]. The ultimate objective of these global simulations is twofold: 1) to diagnose ocean regions with greatest potential for organic C export (the regions so diagnosed will be used for the two ESW scenarios described in the next task) 2) to offer a benchmark against which the two scenarios will be compared.

Task 8. NEMO-PISCES offline: Global ESW scenarios simulations (1/12º spatial resolution). High spatial resolution in coastal and shelf seas is important to account for the action of physical processes such as internal waves, tidal regimes, fronts and instabilities, and their role in nutrient supply dynamics and plankton community structure. Field and experimental evidence show that mixing conditions favour the selection of fast-growing diatom species, which benefit from their ability to exploit vast and intermittent nutrient supplies. This fundamental linkage between nutrient supply dynamics and phytoplankton community structure influences the magnitude of organic C export fluxes, and hence must be adequately represented in ocean biogeochemical model simulations intended to characterize the significance of coastal ocean Si fertilization. According to the two scenarios described above we will perform one simulation in which ESW is applied to coastal eutrophic systems and one in which ESW is applied to coastal upwelling systems. The areas will be selected from the two control simulations (Task 7).

Ultimately, the combination of experimental work (RS1) and ocean modelling (RS2), intended to extrapolate the biogeochemical implications of experimental results to broader spatial and temporal scales, will allow us to evaluate the feasibility, benefits and risks of deploying regional-scale ESW schemes.

Challenges, Contingency Plan, and Research Novelty (Risk/Gain analysis)

Challenge	Risk	Contingency plan	Gain	Impact/Novelty
The scientific foundation of SMART-ECOFIX is built upon the hypothesis that ESW will increase the efficiency of the biological pump. However, the extent to which ESW will influence microbial plankton in a way that enhances organic C export remains untested.	*Med*	ESW schemes are a plausible option to be applied for enhancing mineral carbonation and averting ocean acidification[1,2,11,85]. Thus, even in the case that organic C fluxes were only slightly altered, the resulting knowledge will be important to anticipate side-effects in marine plankton ecosystems.	*High*	The method could increase substantially the organic C export efficiency of the biological pump and contribute to the restoration of marine systems influenced by coastal eutrophication and river damming.
Ocean fertilization has shown variable, often lower than expected potential for C sequestration[72,73]. Advancing ways of engineering the biological pump and increasing its C export efficiency is the way forward towards increasing the credit of ocean fertilization.	*High*	The amount of Si supplied to marine ecosystems could be insufficient to influence diatom ecology, stoichiometry and C export. Model estimates suggest that dissolution of 1 Pg olivine would double the annual amount of Si supplied by rivers.	*High*	ESW could increase the efficiency of the biological pump either by itself or by supplementing other ocean fertilization schemes (e.g. N, Fe fertilization, artificial upwelling).
Traditional methods to determine stoichiometry in the field are unable to distinguish between living biomass and detrital organic matter[51,92,94]. SMART-ECOFIX will measure single-cell stoichiometry using state-of-the-art microanalytical techniques[51,67,92] which base detection on the unique radiation absorption and fluorescence properties of individual elements.	*Med*	Much evidence reveals that, in some diatom spp. and resting spores, C is concentrated to a greater extent than nitrogen[29,53,100]. This is of critical importance to understand biogeochemical cycles in the ocean. Even though the observed stoichiometric variability was irrelevant in terms of C sequestration, still it would allow unravelling aspects of the plankton ecology-biogeochemistry link.	*High*	Gain an understanding of the microbial plankton ecology - biogeochemistry link, which is important, but not limited, to target conditions favourable for C export. This is important to prospect ways of engineering the biological pump (e.g. to increase diatom productivity and sinking along continental margins and shallow seas).

To evaluate undesired risks of applying ESW in marine systems. ESW is expected to accelerate delivery of weathering products about 2-3 orders of magnitude relative to normal conditions and to increase the fraction of organic C that will reach deeper in the water column.	*Low*	It might lead to regional imbalances in elemental fluxes and ecosystem metabolism.	*High*	Enhanced organic C export might expand the horizontal and vertical distribution of oxygen minimum zones[101]. It might also enhance organic C preservation in the deep ocean owing to a decline in trophic pressure by metazoan zooplankton[102].
Continental margins are the most typical habitats of diatoms, yet, global ocean models are too coarse to resolve the physics of coastal and shelf seas.	*Low*	Given that continental margins are often overlooked in global ocean models, this challenge is likely to be of relatively low risk.	*High*	Realization that continental margins sustain a larger proportion of C export and deep ocean sequestration than previously thought.

Schedule by Year and Management (for all Research Streams: RS1, RS2)

I describe below the schedule for the five years of the project and the proposed management strategy (see Gantt chart).

Years 1-3: BIOSTATS and MESOCOSMS (RS1)

RS1 Task 1-2: In Year 1 (Q1,Q2,Q3,Q4) the team will set up the BIOSTATS, will select diatom strains, will perform experiments and will process samples. These tasks will be carried out by PhD student#1, a research assistant and myself at the Institute of Marine Sciences (ICM-CSIC) in Barcelona. Other members of my research department at the ICM-CSIC will participate in sampling tasks and analyses.

RS1 Tasks 3-5: During Year 2 (Q1,Q2, Q3) PhD student#2, a research assistant and myself will coordinate the setup of mesocosms in Ría de Vigo, will conduct experiments and will analyse samples according to the methodology described previously. During Year 3 (Q1,Q2, Q3) PhD student#2, a research assistant and myself will setup the mesocosms in the Catalan Sea, will complete single-cell stoichiometry, microscopy and genetic analyses (sequencing). These tasks will be carried out by PhD students#1&2, a research assistant and myself assisted by trained members of my research department at ICM-CSIC and external collaborators (***Prof. F.G. Figueiras at the Institute of Marine Research in Vigo-Spain and Dr. Mariona Segura-Noguera at University of Lincoln in UK***).

Years 3-5: Ocean modelling (RS2)

RS2: All tasks described in RS2 will be carried out by one postdoc (hosted by the Barcelona Supercomputing Centre, BSC), the computer programmer and myself assisted by ***Dr. F.J. Doblas-Reyes, head of the Earth Sciences Department and Dr. R. Bernardello who is responsible for ocean biogeochemical activities at BSC***. Task 6 includes the design and execution of a global high-resolution simulation with EC-Earth to provide dynamical fields that will be used to perform tasks 7 and 8. These include the design and execution of two control simulations (ESW land-based and ocean-based) and two area-specific scenarios (coastal eutrophic areas and coastal upwelling areas). Simulations for Tasks 7 and 8 will be executed using NEMO-PISCES offline. In Year 3 (Q1,Q2,Q3,Q4) the EC-Earth global historical simulations (1/12º spatial resolution) will be run. In Year 3 (Q3,Q4) and Year 4 (Q1,Q2) the NEMO-PISCES offline: Global control simulations (1/12º spatial resolution) will be performed. In Year 4 (Q3,Q4) and Year 5 (Q1,Q2,Q3,Q4) the NEMO-PISCES offline: Global ESW scenarios simulations (1/12º spatial resolution) will be performed.

Years1-5: Management & Dissemination (conferences, publications and outreach)

Kick-off meeting and follow up: A kick-off meeting at the beginning of the project will join all participants including external collaborators. During Years 1-3, bi-monthly meetings between PhD students and me will be organized to coordinate tasks, and remind expected milestones. A mid-term progress meeting will be organized during Year 3 upon completion of tasks proposed in RS1. This will be a forum to discuss accomplishments and plan subsequent tasks and milestones.

Project website and social network profiles: A project webpage will be created by the PI which will be both, a tool for internal communication and a window of the project activities. The window of the network activities will be under the responsibility of the PI, but all participants of the project will be involved. The PhD students will be encouraged to maintain a blog with their activities. Outreach activities will be planned through the platform ICM-Divulga (http://www.icm.csic.es/icmdivulga/es/). Further diffusion of scientific milestones will be assured through the website of ICM-CSIC.

<u>Scientific conferences, referred journals and press releases</u>: The main dissemination of the results will be through the publication of the results in relevant peer reviewed journals. There is scope for several publications in high impact multidisciplinary journals dealing with the plankton ecology, stoichiometry, biogeochemistry link and the impact of ESW in marine systems. The team will present the scientific results in international conferences in the fields of oceanography and Earth sciences (EGU, AGU, ASLO, Gordon Conferences). Special seasons with emphasis on the interplay between ocean chemistry, plankton biology and C biogeochemistry will be promoted in these meetings. We will communicate our milestones and findings to the public media through press releases prepared in collaboration with our press officers. The PI is strongly committed to communicate the scientific findings to the research community, environmental managers and the general public.

Gantt chart below summarizes the main Research Streams' tasks and milestones.

		Year1				Year2				Year3				Year4				Year5			
RS-Tasks		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
RS1	**T1**	**BIOSTATS: Physiological monitoring**																			
	T2	**BIOSTATS: DOM,TEP,CSP,Volatiles**																			
	T3					**MESOCOSMS: Ecosystem monitoring**															
	T4					**MESOCOSMS: Single-cell stoichiomet.**															
	T5					**MESOCOSMS: Biomass processing**															
RS2	**T6**									**EC-Earth: hist. sim.**											
	T7											**N-P: control sims.**									
	T8															**N-P: ESW scenarios sims.**					
Scientific production		**outreach activities (webpage, press releases, ICM-Divulga)**																			
														conferences, scientific papers							
Managemen		**research assistant, PhD students 1-2, computer programmer**																			
										postdoctoral fellow											
		kick-off meeting								**Progress meeting**											
Milestone									**1**			**2**			**3**					**4**	**5**

Key intermediate research stages: Milestones

1) Completion of BIOSTAT experiments. Results from BIOSTAT experiments will provide the basis to begin with the implementation of the biogeochemical model (e.g. formulation/parameterization of stoichiometric responses) .

2) Completion of MESOCOSM experiments. Quantification in "pilot plant" of plankton changes, organic matter processing and organic C export efficiency in response ESW. Milestones 1-2 give way to the subsequent design of strategies aimed at engineering the biological pump and enhancing its C export efficiency.

3) Completion of control global simulations and diagnostics. Diagnose regions with potential for enhancing the production and sinking of diatoms.

4) Completion of ESW scenarios simulations. This will allow us to evaluate the significance of ESW in organic C export, restoration of ecosystems and identify potential risks of applying this method on regional scales. ***5) Final report.***

<u>Technical Feasibility</u>

The applicant has strong conceptual understanding, technical expertise and computational skills related to the proposal's research themes. The applicant maintains a network of collaborations with renowned international scientist in the field of plankton ecology/evolution and biogeochemistry, and has published relevant papers related to these topics in top journals such as Science and PNAS. My expertise and skills will facilitate the implementation of the project, including:

- Cross-disciplinary training in plankton ecology, cell physiology and ocean biogeochemistry. My research department at the Institute of Marine Sciences (ICM-CSIC) in Barcelona agglutinates strong expertise in molecular tools and analytical methods for the study of marine microbial plankton ecology. All the techniques described in this proposal are currently implemented and fully operative in my lab. ***Dr. Mariona Segura-Noguera at the University of Lincoln in UK will contribute expertise in single-cell elemental analyses and data processing. Prof. F.G. Figueiras at the IIM-CSIC in Vigo-Spain has agreed to participate in the setup, sampling and sample analyses of the mesocosms***. He has enormous knowledge on the ecology and physiology of microbial plankton from coastal environments and strong expertise in experimental designs using micro- and mesocosms.
- My research group has strong skills in ocean modelling and access to high performance computational facilities at Mare Nostrum 4, the most powerful supercomputer in Spain (a peak performance of 13.7 Petaflops) managed by the

Barcelona Supercomputing Centre (BSC) in Barcelona. ***Dr. F.J. Doblas-Reyes and Dr. R. Bernardello at BSC have agreed to collaborate in this proposal in technical and scientific aspects of the modelling-computational work-package (EC-Earth, NEMO, PISCES)***. Their strong computational skills and experience in Earth system modelling will enable the successful implementation of very high spatial resolution model configurations within the timeframe of the proposal.

- Collaboration with researchers within the ICM-CSIC, the Barcelona Supercomputing Centre and other research institutions in Europe and US (within the framework of previous research projects), which has allowed me to acquire conceptual understanding and refine methodological aspects of the proposal that shall guarantee its proper execution. ***Prof. Paul Falkowski, Bennett L. Smith Chair in Business and Natural Resources at Rutgers University (USA) will participate as external advisor in developing strategies to engineer the production and sinking of diatoms along continental margins.***
- Community engagement in Europe and the US and experience in communicating scientific results, which will promise that the research results will reach, besides of the scientific community, an ample range of audiences (environmental managers, stakeholders, policy-makers and general public).

During this grant, I will be affiliated at the **Institute of Marine Sciences (ICM-CSIC)** in Barcelona, one of the leading European centres in environmental sciences. Barcelona Supercomputing Centre (BSC-ES) will be in charge of performing and analysing the simulations included in Research Stream 2. Infrastructures, research facilities and technical support at the ICM-CSIC, BSC and foreign research institutions interested in the proposal guarantee the proper execution of the project. During Years 1-2, I will devote most of my time to coordinating and supervising the implementation of the different tasks and conducting most of the experimental research described in RS1. During Years 3-5, I will supervise the computational work described in RS2, and will coordinate data analysis and interpretation, mentor the writing of the students working on the project and prepare data to be published in scientific journals and released for public use.

I will select two PhD students and one postdoc according to research excellence. PhD students will be required appropriate background to conduct the proposed research. A postdoc will be selected according to his/her programming skills, modelling expertise and potential contribution to the project. To attract the best candidates, I will post advertisements in universities, research centres, lists-servers such as Research Gate and appropriate mailing lists. Each PhD will be assigned a specific theme: *PhD#1*) Impact of ESW and nutrient supply dynamics on diatom physiology, life-cycle and stoichiometry; *PhD#2*) Simulating artificially enhanced coastal ocean fertilization experiments in mesocosm enclosures.

At the beginning of the project, as part of their training, PhD students will enrol in Earth Science courses at the U. Barcelona. Training will be carried out at the ICM-CSIC in Barcelona and at institutes/universities under the auspices of external collaborators involved in experimental and computational aspects of this proposal. The postdoc will focus primarily on modelling tasks described in RS2. Of major importance will be the recruitment of personnel with strong skills in programming (FORTRAN, C/C++) and interests in ocean modelling. I will stimulate discussion among PhD students and other participants of the project with the aim of facilitating data exchange and synergies. The postdoctoral fellow and external collaborators will help supervise, mentor and train students.

Section c. Resources (including project costs of host institution and partner institution)

-Institute of Marine Sciences (host institution)

Personnel

PI: By the time the project starts, I will have one project running (see Funding ID) and will devote 50% of my time to the ERC project during the first six months and then 80% of my time for the remaining months/years. ***PhD students****:* Starting halfway through Years 1&2, two PhD students will work on a full time (FT) basis (100%) during 4 consecutive years. ***Research Assistant (RA):*** Because large amounts of time will be spent in lab work, chemical analyses and data processing, I will hire a RA to participate in these tasks and help in project management. The RA will be hired for the full duration of the project on a FT basis (100%). ***Computer Programmer (CP):*** Starting in Year 3 a CP will work for the project providing technical assistance in programming and managing the computational services provided at MareNostrum (Barcelona Supercomputing Centre, BSC). The CP will act as link in computational tasks between researchers at BSC and ICM. The CP will be hired for the last three years of the project on a FT basis (100%).

Travel

Subsistence costs: During Year 1-2, PhD students #1&2, the RA and myself will conduct part of the MESOCOSMS experiments in Vigo (Spain). I estimate that, for two experiments, one in spring and the other in summer, a total of 4 months per capita will be required. Subsistence costs include travel, lodging, food and local transportation, estimated at €1.250/month for a total of €20.000 (€1.250*4*4).

Conference travel: In Years 4 and/or 5, each team member will present results in an international conference (except for the PI who will present in two conferences per year), a total of 6 trips across the two years (4 for PI and 2 for the PhD students) and a total cost of €9.000. Additionally, the project will cover travel expenses of external collaborators/advisors that will join the group to participate in project meetings (€500 from Spain, €1.000 from EU countries, €1.500 from US) for a total of €4.000.

Equipment

The Scanning Electronic Microscopy (SEM) Service at the ICM-CSIC in Barcelona provides an energy dispersive X-ray microanalysis system (EDS) of the samples observed in the SEM. New Silicon Drift Detector (SSD) sensors for X-ray analysis allow up to 17x more data to be collected at the same time with no loss of accuracy. These new systems enable to map larger areas, have better statistics in each data point, collect data much faster and investigate the smallest nano-structures. The requested equipment has a detector SDD technology with a window of 30 mm^2 active area and a resolution of 123 eV (Bruker Quantax 200 para SEM Hitachi, detector XFlash 6|30). The software allows the quantitative analysis, with great precision, of basic elements such as C, N, P, Si, O and more, of vital importance in the study of microorganisms (total of €79.600).

An Act2-based laboratory system fluorometer for probing oxygenic photosynthesis by phytoplankton is requested. This new technology allowing a much smaller incremental steps for incident photon irradiance is an ideal system to monitor in real time the physiological status of phytoplankton (Instrument plus software, total amount: 35.000€).

High precision peristaltic pumps (6x1.950€) and ample base magnetic stirrers (6x520€) to arrange the chemostat bioreactor (biostats) devices are requested (total of €14.820).

2 laptops (€2.500 each) are requested for the project's exclusive use (total of €5.000).

Hard-disk memory is requested for storage of model simulations (total of €40.000).

Other goods and services

Consumables (biostats & mesocosms): algal strains, chemical reactive, flasks, containers, silicone tubing, light (actinic light) spares, mesocosm plastic bags, PVC frames, assorted plastic and glassware, filter membranes, polycarbonate filters, cleaning reagents, high specification lab-ware, teflon beakers, packing materials, stationery (total of €150.000).

Analytical services at ICM-CSIC: including seawater nutrient analyses (€10 per sample), elemental analyses (€20 per sample), flow cytometry (€8 per sample) and DNA sequencing (€70 per sample). (Total of €51.840)

Dissemination: Editing and publication of scientific articles, including open access journals (total of €24.000).

Subcontracting

Mid-size vessel with capacity to sample large volumes of seawater, transport mesocosm bags and deploy them at appropriate sites (in Barcelona and Vigo) are requested for a total of 4 sampling days (two on each site) at €2.500 per day (total amount of €10.000).

Divers will be contracted to participate in tasks related to the mesocosm experiments such as sampling, deployment and manipulation of mesocosm bags, etc. Their services are requested for a total estimated of 20 days covering the four planned mesocosm experiments at €200 per day (total of €4.000).

-Barcelona Supercomputing Centre-ES (partner institution)

Personnel

Postdoctoral fellow: Starting in Year 3. His/her salary is calculated on the basis of 100% of their time during two complete years. ***Senior Researcher (Dr. Raffaelle Bernadello):*** 3 months of salary starting in Year 3 (Q1).

Travel

Conference travel: In Years 4 and/or 5, the postdoc will present results in an international conference, a total of 2 trips and a total cost of €3.000.

Other goods and services

Dissemination: Editing and publication of scientific articles, including open access journals (total of €7.500).

Cost Category			Total in Euro
Direct Costs[2]	Personnel	PI[3]	**379.365,21€**
		Senior Staff	**13.500,00€**
		Postdocs	**162.000,00 €**
		Students	**204.564,32 €**
		Other	**257.174,42 €**
	i. Total Direct Costs for Personnel (in Euro)		**1.016.603,95€**
	Travel		**36.000,00 €**
	Equipment		**134.112,00 €**
	Other goods and services	Consumables	**150.000,00 €**
		Publications (including Open Access fees), etc.	**31.500,00 €**
		Other (analytical services at host, audit)	**51.840,00 €**
	ii. Total Other Direct Costs (in Euro)		**233.340,00€**
A – Total Direct Costs (i + ii) (in Euro)			**1.249943,95€**
B – Indirect Costs (overheads) 25% of Direct Costs[4] (in Euro)			**312.485,98 €**
C1 – Subcontracting Costs (no overheads) (in Euro)			**14.800,00 €**
C2 – Other Direct Costs with no overheads[5] (in Euro)			
Total Estimated Eligible Costs (A + B + C) (in Euro)			**1.577.229,93 €**
Total Requested EU Contribution (in Euro)			**1.577.229,93 €**

Please indicate the duration of the project in months:	**60**
Please indicate the % of working time the PI dedicates to the project over the period of the grant:	**70%**
Please indicate the % of working time the PI spends in an EU Member State or Associated Country over the period of the grant:	**100%**

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Commitment of the host institution for ERC Calls 2018[1,2,3]

The **Agencia Estatal Consejo Superior de Investigaciónes Científicas M.P., (CSIC)**,which is the applicant legal entity, confirms its intention to sign a supplementary agreement with Pedro Alejandro Cermeño Ainsa in which the obligations listed below will be addressed should the proposal entitled SMART-ECOFIX : SiMulating ARTificially Enhanced Coastal Ocean Fertilization eXperiments be retained.

Performance obligations of the *applicant legal entity* that will become the beneficiary of the H2020 ERC Grant Agreement (hereafter referred to as the Agreement), should the proposal be retained and the preparation of the Agreement be successfully concluded:

The *applicant legal entity* commits itself to hosting *[and engaging]* the *principal investigator* for the duration of the grant to:

a) **ensure that the work will be performed under the scientific guidance of the *principal investigator* who is expected to devote:**
- *in the case of a Starting Grant at least 50% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country;
-*in the case of a Consolidator Grant at least 40% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country;
- *in the case of an Advanced Grant at least 30% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country.

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[1] A scanned copy of the signed statement should be uploaded electronically via the Participant Portal Submission Service in PDF format.
[2] The statement of commitment of the host institution refers to most obligations of the host institution, which are stated in the H2020 ERC Model Grant Agreement (MGA). The H2020 ERC MGA is available on the ERC website at http://erc.europa.eu&http://ec.europa.eu/research/participants/portal/desktop/en/funding/reference_docs.html.The reference to the time commitment of the Principal Investigator is stated in the ERC Work Programme 2018.
[3] This statement (on letterhead paper) shall be signed by the institution's legal representative and stating his/her name, function, email address and stamp of the institution.

b) carry out the work to be performed, as it will be identified in Annex 1 of the Agreement, taking into consideration the specific role of the *principal investigator*;

c) enter — before signature of the Agreement — into a '*supplementary agreement*' with the *principal investigator*, that specifies the obligation of the *applicant legal entity* to meet its obligations under the Agreement;

d) provide *the principal investigator* with a copy of the signed Agreement;

e) guarantee the *principal investigator's* scientific independence, in particular for the:

i) use of the budget to achieve the scientific objectives;

ii) authority to publish as senior author and invite as co-authors those who have contributed substantially to the work;

iii) preparation of scientific reports for the project (action);

iv) selection and supervision of the other *team members* (hosted *[and engaged]* by the *applicant legal entity* or other legal entities), in line with the profiles needed to conduct the research and in accordance with the *applicant legal entity's* usual management practices;

v) possibility to apply independently for funding;

vi) access to appropriate space and facilities for conducting the research;

f) provide — during the implementation of the project (action) — research support to the *principal investigator* and the team members (regarding infrastructure, equipment, access rights, products and other services necessary for conducting the research);

g) support the *principal investigator* and provide administrative assistance, in particular for the:

i) general management of the work and his/her team

ii) scientific reporting, especially ensuring that the team members send their scientific results to the *principal investigator*;

iii) financial reporting, especially providing timely and clear financial information;

iv) application of the *applicant legal entity's* usual management practices;

v) general logistics of the project (action);

vi) access to the electronic exchange system (see Article 52 of the Agreement);

h) inform the *principal investigator* immediately (in writing) of any events or circumstances likely to affect the Agreement (see Article 17 of the Agreement);

i) ensure that the *principal investigator* enjoys adequate:

i) conditions for annual, sickness and parental leave;

ii) occupational health and safety standards;

iii) insurance under the general social security scheme, such as pension rights;

j) allow the transfer of the Agreement to a new beneficiary ('portability'; see Article 56a of the Agreement).

k) take all measures to implement the principles set out in the Commission Recommendation on the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers[4] - in particular regarding working conditions, transparent recruitment processes based on merit and career development – and ensure that the *principal investigator*, researchers and third parties involved in the project (action) are aware of them.

For the host institution (applicant legal entity):

[4] Commission Recommendation 2005/251/EC of 11 March 2005 on the European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers (OJ L 75, 22.3.2005, p. 67).

Date: 23/01/2018

Name and Function

Jesús Marco de Luca, Vice-President for Scientific and Technical Research.

By the President, P.D. (Resolution from 20-04-2017, published in Spanish Official Journal BOE 23-05-2017)

Email and Signature of legal representative

programas.europeos@csic.es

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
CSIC

Juan Carlos I, Rey de España

e no seu nome *y en su nombre*

O Reitor da Universidade de Vigo

Considerando que, conforme ás disposicións
e circunstancias previdas pola lexislación vixente,

Considerando que, conforme a las disposiciones
y circunstancias prevenidas por la legislación vigente,

Don Pedro Alejandro Cermeño Aínsa

nacido o día 3 de maio de 1975 en Zaragoza,
de nacionalidade española,
e Licenciado en Ciencias Biolóxicas o 30 de xullo de 1998
pola Universidade de Salamanca, superou os estudos de doutoramento
no Departamento de Ecoloxía e Bioloxía Animal, dentro do programa
de Oceanografía e Xeoloxía de Costas do Departamento de Xeociencias Mariñas
e Ordenación do Territorio, e fixo constar a súa suficiencia nesta Universidade,
coa cualificación de Sobresaliente "cum laude",
o día 22 de marzo de 2006,
expide o presente TÍTULO de

DOUTOR POLA UNIVERSIDADE DE VIGO

con carácter oficial e validez en todo o territorio nacional, que faculta
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Dado en Vigo, a 11 de abril de 2006.

nacido el día 3 de mayo de 1975 en Zaragoza,
de nacionalidad española,
y Licenciado en Ciencias Biológicas el 30 de julio de 1998
por la Universidad de Salamanca, ha superado los estudios de doctorado
en el Departamento de Ecología y Biología Animal, dentro del programa
de Oceanografía y Geología de Costas del Departamento de Geociencias Marinas
y Ordenación del Territorio, y ha hecho constar su suficiencia en esta Universidad,
con la calificación de Sobresaliente "cum laude",
el día 22 de marzo de 2006,
expide el presente TÍTULO de

DOCTOR POR LA UNIVERSIDAD DE VIGO

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Dado en Vigo, a 11 de abril de 2006.

O interesado,
El interesado,

O Reitor,
El Rector,

A Xefa do Servizo,
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