Call for project – Climate Change Impacts on Regional Ecosystems (ICCER)

Edition 2025

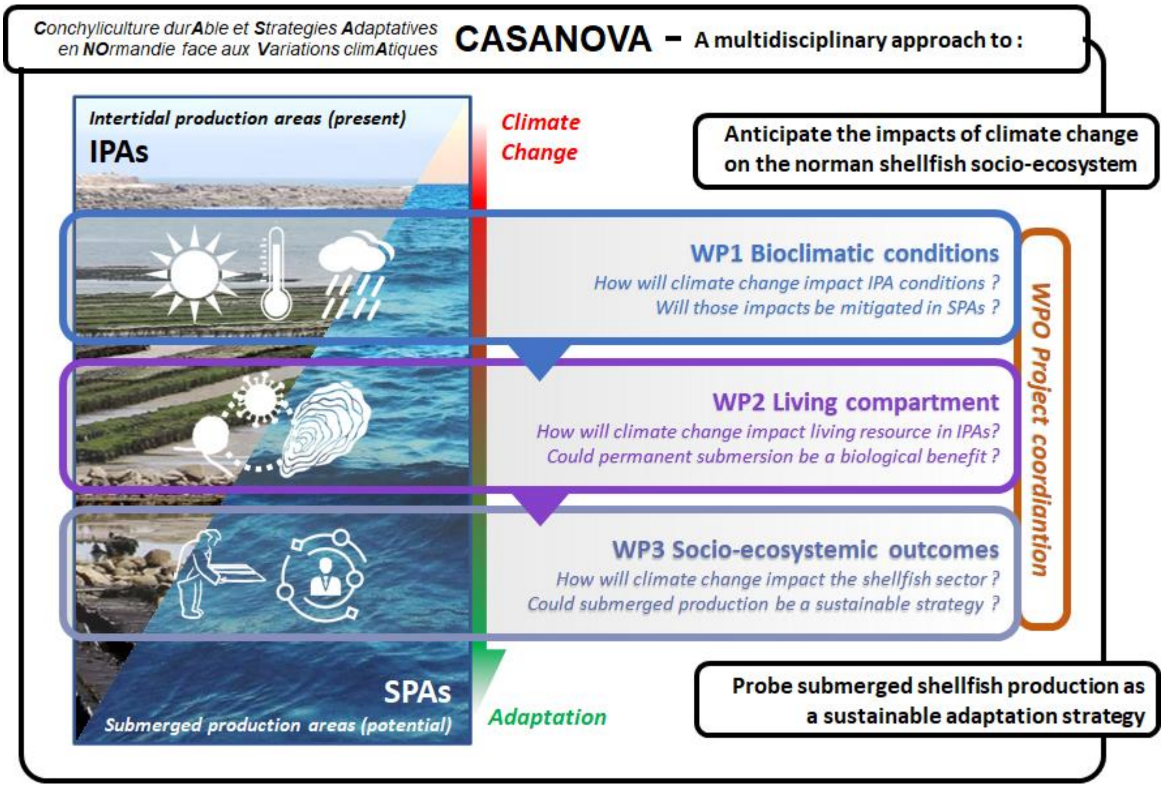
CASANOVA

Proposal summary	
Acronym	**CASANOVA**
Title	**C**onchyliculture dur**A**ble et **S**tratégies **A**daptatives en **NO**rmandie face aux **V**ariations clim**A**tiques – *Sustainable shellfish culture and adaptive strategies in Normandy towards climate change*
First name and surname of the project leader	Guillaume Rivière
Organisation of the project leader	Université de Caen-Normandie
Requested funding	243,6 k€
Project duration	36 months
Main scientific axis	☒ Natural resources conservation and restoration ☐ Adaptation to climate change risks and territorial planning ☐ Human beings and climate change: health, inequalities and psychology of risk
Research category	☒ Fundamental research ☐ Industrial research ☐ Experimental development

TABLE OF CONTENTS

Project summary 2
1. Proposal's context, positioning and objective(s) 3
   1.1. General context and relation to the objectives of the call 3
   1.2. Objectives and research hypothesis 3
   1.3. Position of the project as it relates to the state of the art 4
2. Organisation and implementation of the project 5
   2.1. Scientific program and project structure 5
   2.2. Consortium or team 9
   Summary of participants involved in the project 10
   2.3. Justification of the proposal budget 11
   Budget table summary: cost by category and by partner 11
3. Impact and benefits of the project 11
References 12

ICCER 2025	CASANOVA	36 months	243,6 k€



General diagram of the CASANOVA project.

Project summary

Climate change exerts an extreme pressure on the shellfish socio-ecosystem, a major resource worldwide and especially **in Normandy.** Indeed, it is highly prevalent in coastal areas where important shifts in **temperatures and in water column parameters** (pH, salinity, oxygen…) may have **severe impacts** on the **oyster physiology, a keystone species of the ecosystem, both directly and indirectly through biological interactions** with forage phytoplankton and/or pathogens. Therefore, **climate change threatens oyster intertidal production areas with potential dramatic impacts on the shellfish sector**. Besides, near-coastal off-shore sites beyond the intertidal zone are expected to be less subjected to environmental variations due to inland inputs and tidal cycles. The **CASANOVA** project proposes an **innovative multidisciplinary approach** to investigate the **impacts of climate change on the shellfish socio-ecosystem in Normandy** and to **question whether submerged oyster production could be a sustainable adaptive strategy to mitigate climate change consequences**. For this objective, the **CASANOVA** project consortium will **(i) record** the current and **preview the future climate-environmental** context of intertidal production areas (**IPAs**) and potential submerged production areas (**SPAs**) ; **(ii) characterize and anticipate** the **biological resilience of the oyster** living compartment by envisioning its **physiology and interactions** in the frame of the **holobiont concept** in the present and future IPA and SPA contexts ; **(iii) assess the socio-economic consequences of climate change** and potential SPA production adaptive changes on the **shellfish sector** in Normandy. Using a highly **complementary consortium** reuniting **biologists, climatologists, economists, geographers, ecologists, modellers, sociologists and professional stakeholders**, the **CASANOVA** project aims at generating **innovative fundamental knowledge** on the present conditions and **future scenarios** of the **shellfish socio-ecosystem** in Normandy under **integrated environmental, biological, and socio-economical aspects**. The results on the relevancy of submerged production will also be **usable to help public policy decision-making** processes in order to **mitigate the impacts of climate change on the oyster resource** thereby contributing to the **sustainability of the shellfish socio-ecosystem**.

1. Proposal's context, positioning and objective(s)

1.1. General context and relation to the objectives of the call

Shellfish production is an important resource worldwide and especially **in Normandy** (e.g. 6500 jobs and 25000 t/y of oysters). Shellfish are produced within **coastal (socio)ecosystems** that are highly prone to anthropic disruption and **impacted by climate change**(1), as pointed out by the ICRG. The **shellfish socio-ecosystem** relies primarily on the production of the keystone species ***Crassostrea*** (i.e. *Magallana*) ***gigas*** **(pacific oyster) within intertidal production areas (IPAs)** under estuarine influence, where alternative tidal cycles induce severe environmental shifts that fixed organisms such as oysters cannot escape. Those shifts encompass dramatic **temperature changes** when exposed to **air, and water compartment variations** (temperature, salinity, pH, nutrients and pathogens) that **depend on the climate** notably through inland **rainfall and fluvial inputs**. Due to climate change, those parameters already are, and will **increasingly be, subjected to broad variations** and extremums. As a result, the **intertidal shellfish ecosystem**, a vital marine resource in Normandy, is **in danger**. Therefore, it is necessary to understand **how climate change will impact the shellfish ecosystem** and how **sustainable adaptive strategies** could be implemented. In this context, more off-shore waters outside the intertidal zone are less subjected to environmental variations and coastal inputs. Therefore, oyster production in **submerged production areas (SPAs)** may dampen climate change consequences and provide a potential **sustainable alternative.** The **CASANOVA** project proposes a **multidisciplinary and holistic approach** to: (i) **record and preview bioclimatic states** of the present IPAs, and probe the **potential benefits of SPAs**; (ii) examine the **reaction and adaptation capabilities of the living compartment of the shellfish ecosystem** and especially its most important resource, the **oyster and its associated micro-organic communities (i.e. holobiont)**, in the present and anticipated IPA and SPA environments ; (iv) **question and anticipate the socio-ecosystemic outcomes** of both IPA and SPA scenarios. The **CASANOVA** consortium aims at **generating innovative scientific knowledge of prime fundamental interest** that are **directly transferable to local authorities to help** the implementation of **adapted public policies** towards the **oyster natural resource preservation** and **climatic resilience of the shellfish socio-ecosystem in Normandy**.

The **CASANOVA** project will study **present and future bioclimatic states** by the **modelling of impacts of future climate scenarios** taking into account **estuarine inputs** on the **evolution of the shellfish ecosystem**. We will focus on **the evolution of pressures on the** oyster **natural resource** and its impact on the **evolution of biodiversity** by characterizing **the adaptation to new conditions** of the **oyster holobiont**. Results about SPA production will give tracks on its **effectiveness as an adaptive measure**. Through the **development of data collection for the analysis of water** and air parameters, climate impacts on the terrigenous inputs, the **CASANOVA** project will study the **evolutionary dynamics of estuarine and coastal systems over time** leading to a **better understanding of the impacts of climate change on water quantity and quality in estuarine/coastal marine hydrosystems of prime aquaculture interest, taking into account the local contexts and specificities.** In addition, the **regulatory and economic aspects** of the **potential changes and associated risks** in the **shellfish socio-ecosystem** in Normandy will be investigated.

Thus, The **CASANOVA** project **perfectly fits in the Axis 1 'preservation and restoration of natural resources' of the present 'impact of climate change on regional ecosystems' call.**

Besides, the **CASANOVA** project constitutes a **prospective work on the future of the shellfish industry**. If the SPA production turns out relevant, it will **lead to proposals for land-use planning dedicated to shellfish ecosystem services.** It will also question **aquacultural practices and economic models from the angle of climate adaptation and mitigation** thereby also matches the **Axis 2 of the present call.** The **CASANOVA** project fits in the EU sustainable development objectives **ODDs "zero hunger" / Aquatic life / Measures relative to Climate change mitigation**.

1.2. Objectives and research hypothesis

Our main hypotheses are that **climate change threatens the intertidal shellfish areas in Normandy through direct and indirect effects on the oyster holobiont** and that **submerged production might mitigate climate-environmental hazards thereby improving resilience and sustainability of the shellfish (socio)ecosystem**. To test these hypotheses the **CASANOVA multi-disciplinary consortium** will develop **innovative holistic approaches** to: **(i) record and preview bioclimatic states of IPAs**, and **probe whether SPAs** might **buffer environmental extremums** due to climate change; **(ii)** examine the **reaction and adaptation** capabilities of the **living compartment of the shellfish ecosystem by exhaustive monitoring of interactions (holobiont concept)** between its prevalent resource **C. *gigas***, its forage microalgae and its pathogens in the present and anticipated modified **IPAs and SPAs** environments **in IUGR future scenarios**; **(iii) anticipate the socio-**

economic outcomes of climate change for the **future of the shellfish farming sector in Normandy** by questioning **aquaculture practices, sector sociology** as well as **investment and market issues** in both IPAs and SPAs contexts to **provide public stakeholders** with clues for a **sustainable adaptive strategy** towards **resilience of the shellfish socio-ecosystem in Normandy**.

The main objectives of the CASANOVA project are to:
1- Determine the extent of climate change impacts on the shellfish socio-ecosystem in Normandy, focusing on the keystone species *C. gigas* holobiont.
2- Examine the possibility of submerged production as a sustainable adaptive strategy for the shellfish (socio)ecosystem.

1.3. Position of the project as it relates to the state of the art

At the land/sea interface, the intertidal zone, where most shellfish are produced, is a highly variable environment, vulnerable to meteorological changes induced by global climate change combined with local human pressures. Over the past decade, profound changes have affected almost all physico-biogeochemical parameters of coastal ecosystems(2), which are prone to brutal disruption as illustrated by extreme environmental variability in the form of storms(3), marine heat waves(4) and hypoxia events(5, 6). Therefore physiologically relevant variables (temperature, salinity, dissolved oxygen, pH and pathogens) fluctuate widely over short and long time scales(7–10) and inland water inputs(11, 12). This is a challenging environment for fixed macroscopic organisms that undergo tidal cyclic submersion/air exposure, but also for small planktonic organisms that are central links of the trophic network. In Normandy, long-term observations show clear breaks, such as sharp rises in oyster mortalities since a decade(13) or primary production collapses in the Seine estuary due to reduction of phosphorus wastewater(14). In addition, coastal seawater contamination by pathogens (e.g. faecal bacteria and viruses) with detrimental effects on shellfish harvesting and market are increasing. Furthermore, chemical contaminants (pesticides, heavy metals, hydrocarbons), wastewater and plastics(15) introduced *via* terrestrial inputs by rivers accumulate in the sediment(16), and fuel long-term pollution reservoirs in direct proximity with food webs. **Although validated shellfish ecosystem models exist(17, 18), the influence of many factors including terrigenous inputs remain poorly understood despite being of primary importance in the context of climate change, notably in Normandy(19)**. Offshore oyster aquaculture has already been considered for shellfish farming expansion and restoration(14, 20). Interestingly, variations in temperature, salinity, nutrients and contaminants are highly attenuated in the open sea compared to the intertidal zone(21). Indeed, they are diluted and dampened by the water column volume and thermal inertia, and homogenized by currents. Therefore, **submerged oyster farming** beyond the intertidal zone may display **interesting potential in mitigating** climate-environmental **outcomes of global change, but** SPAs have never been **addressed in the local context of Normandy in such perspective**. **Therefore, the CASANOVA project will record and preview climate-environmental conditions in present IPAs and potential SPAs, and model their impact on the oyster ecosystem in Normandy in future IUGR scenarios.**

Although laboratory experiments have shown that extreme temperatures and low oxygen may increase mortality in marine invertebrates, **the impact of environmental conditions on survival in the field have not been fully understood**. Oysters are considered keystone taxa in the ecosystem as they regulate phytoplankton populations and blooms through filtration, nutrient cycle, and benthic diversity(14), and re-mineralization of organic deposits in the sediment(22). Past studies have largely focused on the physiological tolerances/performance of oysters and their susceptibility to environmental parameters and/or contaminants(23, 24) and to the gene-expression dependent regulation of those processes(25). Epigenetic regulation is crucial here because of its role in the inter- and transgenerational transmission of life traits with long term consequences on adaptation(26, 27). However, it is now recognized that **the phenotype is due to complex interactions between an organism and its associated microorganisms** (bacteria, archaea, protists, fungi, and viruses), defining the **holobiont(28),** instead of the host genome only. Oysters constantly interact with microbial communities in their environment, and crosstalks within the oyster holobiont shape the immune response and sensitivity to mortality syndrome(29, 30). Besides, **holobionts** are **open to and modified by interactions within the living compartment**(31), and In turn, these **interactions are changing in response to environmental variability**, as observed for microalgae, on which oysters feed, and whose primary production is altered by heat waves(32) or fatty acid content by viral infection(33). Such flexibility confers a high **adaptation capacity** to environmental stressors(34, 35), and benefits host organisms(34, 36, 37). Because of the variable concentration and representation of bacterial species with potential detrimental (pathogenic) or beneficial effects in marine environments(38), **we assume that biological interactions within their holobiont can strongly influence the physiology and performance of oysters, conditioning their response and future adaptive capacity to environmental fluctuations**. Such interactions are deemed prevalent in organism/environment interfaces (i.e., gut and gills) and likely account for some of the effects of **temperature increases or pathogen surges**[39, 40]. Epigenetic regulation by DNA methylation plays a pivotal role in those interactions[29, 41]. Besides, epitrancriptomic regulation by RNA modifications contributes stress response and environmental adaptation in microbial[42] and animal taxa[43, 44] through gene expression regulation and chromatin architecture. RNA m6A-methylation play a key role in development[45] and in intergenerational transmission of environmental life traits in the oyster (in prep.), **but the significance of epitranscriptomes within the oyster holobiome and its adaptation remains largely unknown**. Likewise, **if and how extracellular vesicles** contribute to **communication within the holobiont** is to be examined[46]. **Understanding those mechanisms is critical to envision the resilience of the oyster resource to climate change**, but **former work has widely neglected the importance of interactions and poorly addressed the complexity of the impacts of environmental changes** within the shellfish ecosystem. Therefore, the **CASANOVA** consortium will **examine the climate change impacts as a continuum of complex interactions within the oysters holobiome, focusing on epigenetic and epitranscriptomic mechanisms.** The challenge of such **holobiome characterization** will be overcome by **long-read SMaRT sequencing** technology (e.g. Nanopore[47]) that enables a holistic approach of metagenomes and epigenomes by direct sequencing of DNA (and of RNA metatranscriptomes and epitranscriptomes), a recent methodology already in use by the **MERSEA** partner of the project.

As described above, SPA rearing might display potential biological benefits which would in turn contribute to sustainability of oyster exploitation and to limitation of market restrictions, like those due to faecal bacteria contaminations from inland inputs after high rainfall events or toxic microalgae blooms that dramatically impacted the sector in the past[48]. However, oyster producers are confronted with multiple risks (health, marine pollution, global warming, etc.) and climate change questions the ability of shellfish farmers to adapt through possible changes in their practices[49, 50]. Besides, off-shore production may select high-investment capability companies with detrimental effects on the existing socio-ecosystem in Normandy. **Such economic and socio-ecosystemic services issues are critical and have to be investigated taking into account local specificities**.

Overcoming the limitations of former fragmented **reductionist approaches**, we believe the proposed **innovative multidisciplinary and holistic approach** of the **CASANOVA** project will **generate breakthrough fundamental knowledge** that will also be **directly applicable,** therefore an asset **to help political decisions towards a more sustainable shellfish socio-ecosystem in the Normandy region context.**

2. Organisation and implementation of the project

2.1. Scientific program and project structure

The **CASANOVA** project will be carried out through three functional work packages and one coordination/valorisation work package.

WP0 : SCIENTIFIC AND ADMINISTRATIVE PROJECT MANAGEMENT AND COORDINATION, COMMUNICATION, VALORISATION (*resp. G. Rivière, partners: all*)

Task O.A. Scientific coordination will be managed by **regular meetings including all the participants**. Frequent meetings will also be organised on a **per-WP basis when needed**. Meetings will be preferably live, but online sessions may be held when appropriate The *Task 0.B. Financial management* will be led by financial administration of each partner under the supervision of the coordinator. *Task 0.C. Valorisation* will be achieved by **scientific publications in international peer-reviewed scientific journals** (2 to 3 per WP are expected) and congress presentations, in scientific and **applied/professional stakeholder events** (e.g. 'Conseil Filière Coquillages'). Popularized results will also be communicated to professional stakeholders in a dedicated journal (e.g. 'Cultures Marines'). *Task 0.D. General public communication* about the **CASANOVA** project will be organized during events such as the **'Fête de la Science' or 'FENO' events**.

WP1 : CLIMATE AND ENVIRONMENTAL CONDITIONS IN SHELLFISH FARMING AREAS: SURVEY, DIAGNOSTICS AND PREDICTION (resp: O. Cantat and P Claquin, participants; IDEEs, MERSEA, Ifremer)

The objective of this work package is to describe and predict climate-environmental conditions in present IPAs and potential SPAs, as well as to model their impact on the oyster ecosystem.

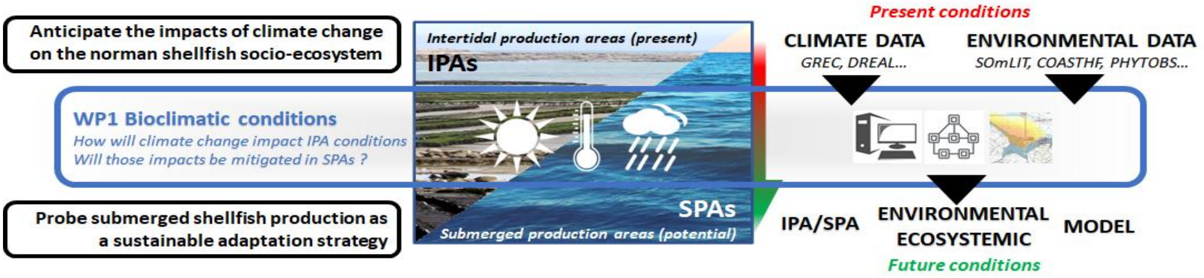


Diagram of the CASANOVA project Work Package 1.

<u>Task 1.A. Climate-environmental diagnostic of present conditions in intertidal (IPA) and submerged (SPA) shellfish production areas.</u> The Baie des Veys and the SMILE buoy locations will be used as the archetypes of IPAs and SPAs respectively, because of the amount of monitoring data available on these sites. In this task, the present climate-environmental state of the IPA and SPA will be assessed through combining existing multi-scale data provided by several multi-disciplinary and dedicated climate and biotope (Primary producers abundance and diversity, Oyster Life-History traits, Temperature, oxygen, pH, salinity…) measure networks such as REPHY [(REPHY, 2023)] and ECOSCOPA[(13)] for IPAs and the SMILE buoy[(51)], SOMLIT, PHYTOBS[(52)] for SPAs. Such data will be provided in maximum interoperability conditions (standardized frequency, interpolation and metadata) to produce a multivariate analysis of the pluri-decennial trajectory of IPAs and SPAs (cf. T1.C). The data acquired will be used to build a relevant local-scale, high resolution climate-environmental model of IPAs in Normandy.

<u>Task 1.B. Contribution of inland/river inputs to climate-environmental conditions in IPAs and SPAs:</u> Inland hydrologic system inputs from small coastal rivers are poorly understood, although they are suspected to be major contributors of the IPA environment through freshwater, organic matter and potential pathogens they convey, which in turn influence forage phytoplankton development. Besides, these soil inputs depend on rainfalls and therefore are likely impacted by climate change. A monitoring network of solid and liquid flows has existed for over 10 years in the Seulles basin located close to the Baie des Veys, but this is a rather unique example in France. The aim of this task is to (i) perform a literature survey and synthesis on these terrigenous inputs from small rivers (in France and UK) in order to determine the ranges (production per km^2/year) of such exports by small rivers to the sea (*<u>T1.B.1</u>*). Then, (ii) we will study rainfall/flow and liquid flow/solid flow relationships in order to understand transfer rhythms, seasonality and thresholds (*<u>T1.B.2</u>*). These results will be used in T1.A. to implement climate-environmental scenarios and in T1.D. for the ecosystemic modelization.

<u>Task 1.C. Prevision and comparison of future climato-environmental parameters in IPAs and SPAs.</u>
Building on the expertise acquired in T1.A and T1.B, this task aims to estimate how sediment transfers (i.e., terrigenous inputs to the coast) could evolve by 2100 under changing climate conditions. Specifically, the transfer potential in the Vire and Douves watersheds—major contributors to the Baie des Veys, the IPA 'archetype' in this project—will be modelled using the InVEST-SDR framework[(53)]. Substantial spatial data input is already available for both watersheds, and will be validated by analogy with the observed flow data from the Seulles watershed. Following the current model calibration, we will develop future projections that account for climate change, with a particular focus on the evolving rainfall erosivity factor (USLE R-Factor). This factor will be recalculated according to the DRYAS-Climat scenarios[(54)]. To capture a representative range of possible outcomes by 2100, we will implement four climate models (RCM/GCM pairs). These scenarios will help delineate the magnitude and uncertainty in sediment-transfer trajectories for coastal environments in Normandy, and compared to measures from the SMILE buoy (SPA archetype environment).

<u>Task 1.D. Ecosystem modelling of present and future IPAs and SPAs</u>.
Following and taking advantage of other tasks of this WP, an approach based on ecosystem modelling will be used to simulate spatio-temporal variations in key environmental variables (nutrient concentrations, temperature, chlorophyll-a) and oyster traits (growth and reproduction). Such models are now widely validated and used for spatial planning of marine aquaculture development[(20, 55)]. Here, we will use data from Task 1.A and Task 1.C to adjust and validate these models, and use them to: - deconvolute the respective influence of the environmental parameters generating the contrast between IPAs and SPAs (duration of exondation, temperature, nutrient concentration...) on the energy allocation to oyster growth and reproduction, in order to explain further the inter-site differences observed for the abundance and diversity of forage microalgae (T2.B), the oyster holobiont (T2.C) and the responses to experimental infections (Task 2.D) ; - model the expected ecosystemic responses for IPAs and SPAs, including oyster growth performances, under the different hydro-climatic evolution scenarios studied in

T1.C[50]. **This WP will deliver the most complete climato-environmental and ecosystemic models of the oyster ecosystem in Normandy to date.**

WP2 : RESILIENCE AND ADAPTABILITY STRATEGIES OF THE SHELLFISH RESOURCE FACING CLIMATE CHANGE (Resp: G. Rivière and J Normand, participants: MERSEA, IFREMER, LABEO)

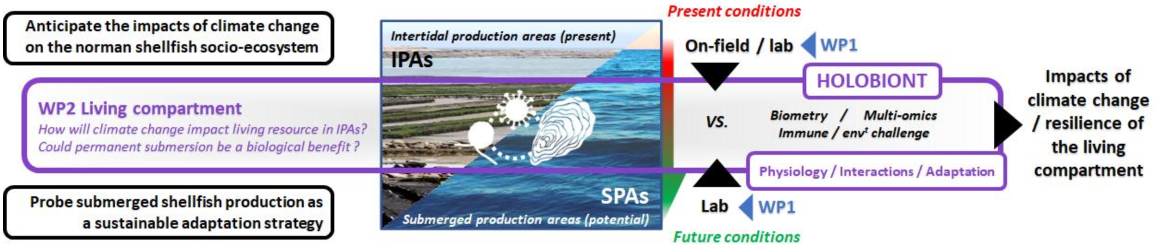


Diagram of the CASANOVA project Work Package 2.

This is **the most important experimental task** of the project, with **on-field and laboratory animal deploy, ecophysiological and immune challenges as well as combined macroscopic and innovative molecular approaches.** Parallel to the integrated muti-disciplinary approach, an important asset of the **CASANOVA** project is its **holistic systems biology ('hologenomic') approach of the living resource** compartment of the shellfish socio-ecosystem. To tackle the limitations of former fragmented visions where the system is split into individual parts, this WP will characterize the **interactions within the oyster holobiont** and anticipate the adaptive potential to future conditions (cf. WP1) of the resource in IPAs and SPAs.

Task 2.A. Biological material. Standardized oyster animals (Ifremer ASI, n=1400 18 month-old animals) will be deployed on-field on an intertidal experimental concession (ECOSCOPA and REPHY points in Baie des Veys; 49°23.2'N & 1°6.1'W)() (IPA group, n=3 replicates of 200 animals) and attached to the SMILE buoy which is anchored off-shore North of Luc s/mer (COAST-HF, SOMLIT and PHYTOBS points, 49° 20.6'N & 0° 18.8'W) (SPA group, n=3 replicates of 200 animals). The number of starting animals exceeds the number required for downstream experiments to overcome potential on-field mortality. Similar animals will be maintained in controlled laboratory conditions (MERSEA/CREC marine station) and exposed to biotopic environmental challenges that will mimic the future IPA and SPA environments determined in the WP1. On-field animals will be sampled at the time of deploy (T0), after 6 (T6) and 18 (T18) months (n=30 animals per group), and laboratory animals will be acclimated to the lab stabulation and sampled before/after environmental challenges (L0, LI and LS groups, respectively, n=3 replicates of 10 animals per group).

Task 2.B: Investigating present and future phytoplankton supply in IPA and SPA environments. A critical parameter of the shellfish ecosystem is the nutrient and/or toxic microalgae supply. Phytoplankton size classes as well as the photosynthetic yield (primary organic carbon production) will be monitored *in situ* by flow cytometry and fluorescent PAM measurements (*T2.B.1*). At the same time, the effect of microalgal viruses on forage species will be characterised *in vitro* in the context of changing environmental conditions (see WP1) and by sequencing the digestive hologenome of oysters (cf T2.C) between conditions (*T2.B.2*). This innovative combined approach will allow the quantitative and qualitative assessment of the present and estimated future phytoplankton supply and primary production in IPA and SPA environments.

Task 2.C. Effect of climate change on the physiology and holobiont of the oyster resource in IPAs. Growth and weight longitudinal surveys will be conducted by biometry for on-field animals (IPA and SPA groups) and before/after environmental challenge for laboratory animals (*T2.C.1*). **To investigate the holobiomes, DNA and RNA** will be extracted individually from the two main organisms/environment interfaces, the gills and the digestive tract[56] (n=3 replicates of 10 animal pools per group) and will be sequenced using **SMRT technology (e.g. Nanopore[47])**. This will allow **the direct characterization of the sample hologenomes, holotranscriptomes and associated epigenomes and epitranscriptomes** (*Epi2Me labs* pipelines)**,** and **chromatin structure** (*PoreC* pipeline) thereby the molecular inventory of interactions, their relative comparison between samples as well as their functional significance (*T2.C.2*). In parallel, the **microvesicles/exosomes** will be extracted and characterized by electron microscopy and flow cytometry, and their content by multi-omics (DNA/RNAseq and LC/MSMS). This approach will allow a better understanding of the **communication within the oyster holobiont** (*T2.C.3*).

Task 2.D: Effect of climate change on oyster resistance to pathogens: Because **regular massive mortality events of oyster stocks threaten the sustainability of the production**, it is necessary to understand the impact of climate change on ***C. gigas* resistance to pathogens**. First, on-field T6 adult IPA vs. SPA animals will be challenged *ex situ* for *V. aestuarianus* infection. Later in the project post-environmental challenge (parameters from

WP1) animals will be submitted to similar experimental immune challenges. For both experiments, T0 animals will be investigated for *Vibrio sp.* status and post-challenge animals will undergo survival monitoring and targeted transcriptome surveys (e.g. RT-qPCR immune and apoptosis markers[57]) will be realised.

The WP2 will deliver a holistic understanding of the impacts of climate change and of the production area environment on the shellfish resource.

WP3: ASSESS THE CONSEQUENCES OF CLIMATE CHANGE AND POTENTIAL ADAPTIVE CHANGES ON THE SHELLFISH SOCIO-ECOSYSTEM (Resp; E Le Bihan and B Drouot, participants: CREM, CERREV,MERSEA-Ivamer, CRC)

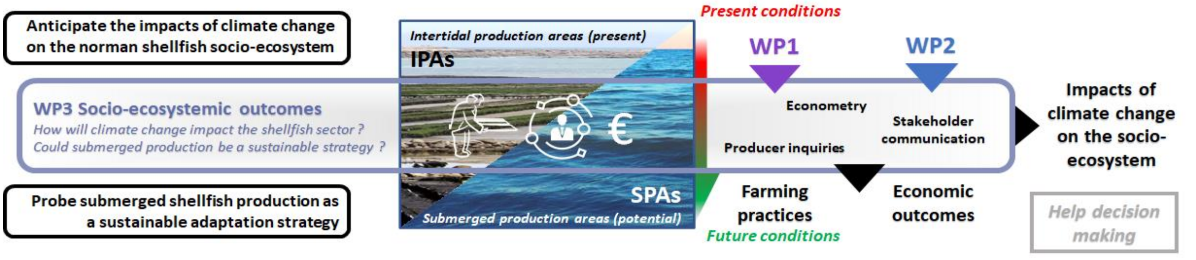


Diagram of the CASANOVA project Work Package 3.

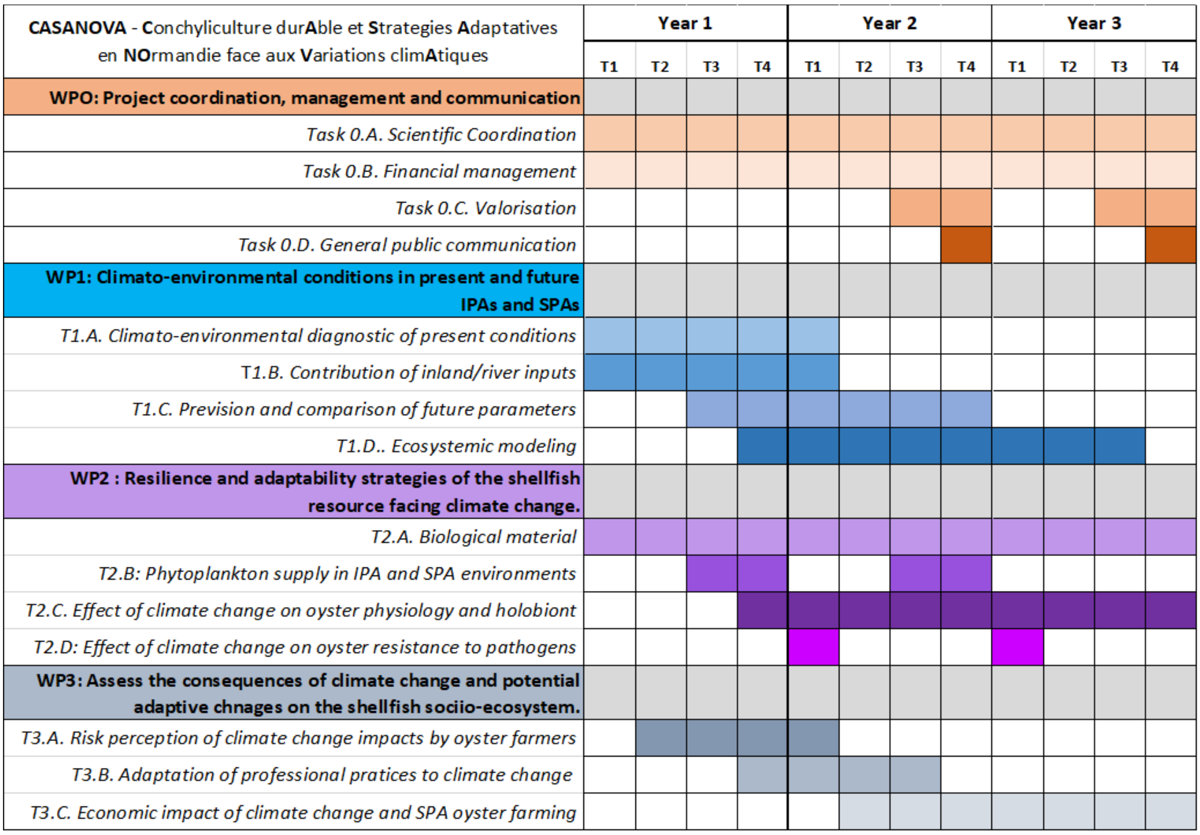
Task 3.A. Risk perception of the anticipated impacts of climate change on the future of the IPA shellfish sector by oyster farmers. The aim of this task is to classify the perception of risk according to its probability (unlikely to highly probable) and severity (low risk to high risk). Indeed, oyster producers prioritize the various risks[58], and take actions depending on the risk perception (immediate/high), but not for others (perceived in the longer term), with important socio-economic consequences. To envision this, oyster sector producers and stakeholders will be interviewed with a questionnaire designed according to the IUGR scenarios and the WP1 outputs.

In a second step, because potential SPA farming is deemed bearing profound changes in farming practices but also economic costs, a more targeted and detailed survey will be divided into two tasks depending on the considered socio-ecosystemic issue.

Task 3.B. Adaptation to climate change and practical relevance of potential oyster farming in SPAs by the sector: The objective of this task is to analyse the impact of moving oyster farming to SPAs on the organisation and practices in oyster farmers' work[50]. This shift implies new forms of work organisation that disrupt knowledge and know-how in terms of oyster farming practices (cages? cord suspension? other?). Are oyster farmers ready to change their practices? Will these changes have an impact on the way they see their profession? Which/how many companies/professionals would be willing to adapt to SPAs? To answer these questions, semi-directive interviews will be conducted with the producers in order to gain a better understanding of the upheavals involved in these practice changes. Indeed, acceptable changes will be the result of adaptation to climate change, while other changes will be the result of real reflection, taking into account all the factors facing the sector in the coming decades. The ideas developed for fishing[59] or in other locations have to be transposed to the local contexts, as does the role played by institutions (e.g. CRC) in the acceptance of changing practices[49, 50].

Task 3.C. Anticipation of the economic impact of climate change and SPA oyster farming on the diverse facets of the sector. This task will be dedicated to determine how SPA could impact the economic aspects of the diverse facets of the oyster socio-ecosystem in Normandy. Based on the results of T3.A and T3.B, several scenarios for adapting shellfish businesses to global warming, including SPA farming, will be proposed. Quantitative data will be collected from stakeholders, and the CRC databases will be used to assess the direct and indirect economic costs of changes in shellfish farming practices in the context of climate change, as already done for other risks[48]. The latter include production costs due to putative heavy investments (boats, equipment …) as well as potential benefits (e.g. reduction of contamination-induced shellfish market closures, influence on oyster growth/fitness, long-term sustainability…). Whether economic impacts of climate change could implement a new economic model for the shellfish sector (e.g. change in client/producer landscapes, transition from traditional qualitative familial companies towards massive production at reduced costs by few, important and non-local companies, insurance costs and potential public subsidy scheme modifications…) will also be questioned.

The WP3 will deliver prospective clues for the socio-economical future of oyster farming in IPAs and SPAs, usable to help public policy decision making towards a sustainable shellfish production in Normandy in the context of climate change mitigation.



2.2. Consortium or team

The CASANOVA project is a highly interdisciplinary project encompassing biologists, climatologists, geographers, sociologists, ecologists, economists, and public professional stakeholders. The different aspects of the project are not just juxtaposed but **strongly complementary** and will **highly cooperate and reciprocally benefit one another** (e.g. WP1 output will be used in WP2 and 3)**.** Consistently, The **CASANOVA** scientific team includes complementary skills and expertises. Each operational WP of the **CASANOVA** project is **co-supervised** by **two leaders from distinct partners** with the strongest implication and expertise, thereby **improving risk management** and being an **asset for the overall success of the project**.

G. Rivière is the **project coordinator** and **co-leader of WP2,** is a professor (PhD HDR) and research team leader in the UR7482 **MERSEA** research unit (Marine Ecosystems and Organisms Research, UniCaen, formerly BOREA). He is internationally recognized as an **expert and pioneer contributor in functional and environmental epigenetics in the oyster**[45, 60–62] and coordinated **national and regional programs** dedicated to oyster functional and/or environmental genomics/epigenomics. **MERSEA** gathers **marine biologists covering research from molecules to ecosystems**: P. Claquin, microalgae and primary production; B. Veron, microalgae diversity and viruses; K. Grangeré, ecosystem modelling; K. Kellner, C. Berthelin and P. Favrel, oyster cell biology and endocrinology. Also in **WP2**, the **LABEO** partner is the departmental analysis laboratory of Calvados represented by **M. Houssin**, a specialist in bivalve immunity related to water quality & pathogens. The **WP1** will be led by **O. Cantat** (UMR **IDEEs** 6266 UCN CNRS), an expert in climate science focusing on nature-society relationships in a context of global and climate changes. The **IDEEs** partner has expertise in environmental-climate diagnostics including inland and coastal hydrosystems (D. Delahaye, M. Fressard) and future projections based on IUGR scenarios. The **Ifremer** (Institut français pour la recherche et l'exploitation de la mer) **LER/N** (Laboratory Environment and Resources in Normandy) is dedicated to coastal ecosystems through monitoring networks and research projects based on the observation and restoration ecology, with expertise in the coastline of Normandy. **J. Normand** focuses on the ecophysiology of bivalves and the effect of long-term environmental variations on the evolution of shellfish farming ecosystems. He provides expert advice to public authorities on the management of shellfish-growing areas in the eastern Channel. R. Verney (Ifremer DYNECO-PELAGOS) is an ecologist specialized in estuarine factors and phytoplankton modelling. **P. Claquin** (**MERSEA**), **co-leader of WP1**, and **J. Normand, co-leader of WP2** are coordinators of **national observatory networks** (Rephy, ECOSCOPA, SMILE, PHYTOBS) which data will fuel the environmental and ecosystem studies in the project. The **WP3** is co-led by **B.**

Drouot (**CREM**) and **E. Le Bihan** (**MERSEA**) and will also benefit from trans-disciplinary expertise. **B. Drouot** specializes in marine resources and environmental economics. He is an expert in risk management and corporate social responsibility, and will work together with two economists specialised in environmental issues (J. Bonnet and J.-S. Pentecôte) at **CREM** (centre de recherches en économie et management, U. Rennes, CNRS, UniCaen), which is dedicated to financial diagnosis and risk management, evaluation models and decision-making support through econometrics, industrial know-how and applications, sector studies and analysis of investment projects. The **CERREV**, represented by **E. Deleage**, analyses individual and/or collective risks and vulnerabilities in contemporary societies from a multidisciplinary perspective (anthropology, psychology, public health, sociology) and specializes in Socio-anthropology of technoscientific and industrial risks, sustainable development, agriculture and space planning. The **CRC** (Comité Régional de la Conchyliculture), represented by his director **M. Savary,** brings together, represents and defends the general interests of all shellfish breeders of the Public Marine Domain. It proposes, participates in or carries out actions concerning the marketing and promotion of shellfish products, the management of shellfish farming activities, scientific and technical research, education and vocational training, socio-economic studies and outlook, protection of water quality and shellfish products.
The **CASANOVA** project consortium tends to **gender parity and equity** with 13 women among the 28 listed participants, and **3 being scientific coordinators of partner/work-package**. Attention to **gender parity will be paid when recruiting** non-permanent human resources throughout the project.
The **CASANOVA** consortium is committed to the **lowest carbon footprint** and will restrain the emission of **greenhouse gases to the minimum**. The Nanopore technology proposed is, to our knowledge, the **lowest energy-consuming** NGS sequencing methodology. Although missions cannot be strictly avoided (e.g. instrument maintenance, sampling, interviews, communication), the **CASANOVA** consortium **partners and experimental sites are located within a 50 km radius** thereby **minimizing the carbon footprint** of the project. All the **data** generated during the **CASANOVA** project will be **publicly accessible** through a **FAIRE science policy** according to the University of Caen-Normandy **Data Management Plan**.

Summary of participants involved in the project

Partner	Surname	First name	Current position	Role & responsibilities in the project (max. 4 lines)	Involvement in the project (person-month effort)
UCN – MERSEA	Rivière	Guillaume	Professor	Project Leader, responsible WP0, WP2	18 p./m.
	Berthelin	Clothilde	Ass. Professor HDR	Participant WP0, WP2	6 p./m.
	Claquin	Pascal	Professor	Participant WP0, WP2, responsible WP1	2 p./m.
	Dubos	Marie-Pierre	Research engineer	Participant WP0, WP2	4,5 p./m.
	Favrel	Pascal	Professor	Participant WP0, WP2	3 p./m.
	Forte	Sylvia	Admin. Assist.	Participant WP0	2 p./m.
	Grangeré	Karine	Ass.professor	Participant WP0, WP1	3 p./m.
	Kellner	Kristell	Ass. Professor HDR	Participant WP0, WP2	6 p./m.
	Véron	Benoît	Ass. Professor HDR	Participant WP0, WP2	6 p./m.
	Le Bihan	Estelle	PAST MERSEA	Participant WP0, responsible WP3	3 p./m.
	Villain-Naud	Nadège	Technician	Participant WP0, WP2	6 p./m.
	Sritharan	Sandra	Technician	Participant WP0, WP2	6 p./m.
	Roger	Christophe	Tech. Assistant	Participant WP0, WP2	3 p./m.
	Marais	Fabienne	Technician	Participant WP0, WP1	3 p./m.
	XXX	XXX	PhD student (external funding demand)	Participant WP0, WP2	36 p.:m.
	XXX	XXX	Engineer assistant	Participant WP0, WP2	6 p./m.
LABEO	Houssin	Maryline	Associate Researcher	Participant WP0, WP2	3p./m.
UCN- IDEEs	Cantat	Olivier	Assistant Professor HDR	Participant WP0, responsible WP1	3 p./m.
	Delahaye	Daniel	Professor	Participant WP0, WP1	3 p./m.
	Fressard	Mathieu	Researcher	Participant WP0, WP1	3 p./m.
	XXX	XXX	Study Engineer x2	Participant WP0, WP1	6 p./m.
IFREMER – LERN	Normand	Julien	Researcher	Participant WP0, WP1, responsible WP2	2 p./m.
	Navon	Maxime	Research engineer	Participant WP0, WP2	2,5 p./m.

	Françoise	Sylvaine	Technician	Participant WP0, WP2	1 p./m
	Louis	Wilfried	Technician	Participant WP0, WP2	0,6 p./m
	XXX	XXX	M2 student autofunded	Participant WP0, WP2	5 p./m.
IFREMER - DYNECO PELAGOS	Verney	Romaric	Researcher	Participant WP0, WP1	1 p./m
UCN - UR CREM	Drouot	Bruno	Assistant Professor	Participant WP0, responsible WP3	4 p./m.
	Bonnet	Jean	Professor	Participant WP3	0,5 p./m.
	Pentecôte	Jean-Sébastien	Professor	Participant WP3	0,5 p./m.
	XXX	XXX	Statistics/Econometrics study engineer	Participant WP0, WP3	3 p./m.
UCN – CERREV	Deleage	Estelle	Assistant Professor HDR	Participant WP0, WP3	2 p./m.
	XXX	XXX	study engineer	Participant WP0, WP3	4 p./m.
CRC	Savary	Manuel	Director	Participant WP0, WP3	1 p./m.

2.3. Justification of the proposal budget

The project is **multidisciplinary and conceptually balanced**. However, the **most important part of the budget** (156k€) will be devoted to the **WP2 which hosts most of the experimental work**. A significant budget will be used for **NNGS long read SMaRT sequencing** required for the hologenomic approaches in MERSEA (**Nanopore** GridION system, IT, reagents and consumables, 80k€). Other costs include oyster lab rearing in MERSEA/CREC marine station (10k€) as well as Immune challenges (2,5k€); biology experiments, physiological surveys and studies: biometry - microvesicles - endocrinology - molecular biology & bioinformatics (25k€) and 6 p./m. of Assistant Engineer (19,5k€), microalgae cytometry & primary production monitoring including instrument maintenance (10k€), virus/microalgae cultures (5 k€). **Ifremer** expenses in the WP1 encompass **fittings and heavy equipment for field measurements** (buoys, deck fittings, diving equipment) and **environmental parameter sensor purchase/renewal** (20 k€). For WP2, animal purchase as well as growth/mortality surveys are the main budget items. **IDEEs** expenses include **climate measure instrumentation** (3 automatic stations in the Baie des Veys lower valley 5,6 k€) and 6 p./m. of study engineers (21k€). WP3 will require mostly human resources at **CERREV** (sociology study engineer 4 p./m. 14k€ and IT 3k€) and **CREM** (econometrics/statistics engineer, 3 p./m. 10.5k€ and IT 2,5k€). Mission expenses are kept to the minimum (mandatory deploy and sampling campaigns, producer/stakeholder interviews).

Budget table summary: cost by category and by partner

	UCN-MERSEA	UCN-IDEEs	UCN-CERREV	LABEO	IFREMER	CRC	UCN-CREM	TOTAL
Staff expenses (*self-funded*) / requested	*(302881)/* 19500	*(53881)/* 21000	*(5742)/* 14000	*(18340)*	*(59932+ 5401)*	*(6569)*	*(19746)/* 10500	537492
Instruments and material costs	132500	5600	3000		20000		2500	163600
Outsourcing / subcontracting					3000			3000
Mission expenses	4000	2000	2000		2000		2000	12000
TOTAL	458881	82481	24742	18340	90333	6569	34746	716092
Requested funds	156000	28600	19000	0	25000	0	15000	**243600**

3. Impact and benefits of the project

The **CASANOVA** project will have **broad outcomes** in line with the **multi- and interdisciplinary** nature of the project. Benefits range from **fundamental knowledge of prime interest** for academic researchers from **ecosystems to molecular biology**, to tracks for **sector public authorities and stakeholders helping decisions towards a sustainable shellfish socio-ecosystem in Normandy,** and to **popularized knowledge for the general public.** The **WP1 will deliver the most complete climate-environmental description and prediction of current and potential shellfish production areas (**IPAs and SPAs), together with **the most achieved shellfish**

ecosystem model to date. In **WP2**, characterization of the **phenotypic, functional and epigenetic aspects** of the **oyster holobiome in adaptation** (D2.C.2, D2.C.3 and D2.D) would be a **scientific breakthrough**, opening **novel scientific questions** about the role of holobiomes in evolution or about the extent and functional significance of epigenetic cues in marine bivalve holobionts in an Epi-Eco-Evo-Devo context, which are prevailing and competitive issues in the field for a broad research community. **The WP3 will identify possible individual and collective transitions on a sector-wide scale regarding its present processes and organisation**, from the producers to the various stakeholder perspectives, in terms of farming practices, sociocultural impacts and economic considerations. This will provide **prospective tracks to help public policy decision makers for climate change mitigation** towards a sustainable socio-economic future for the shellfish production in Normandy.

The serious threat of climate change on the oyster socio-ecosystem urges the need for fundamental knowledge dedicated to helping the resilience of the shellfish sector and allowing adaptation and sustainability of shellfish farming in Normandy in the present and future contexts. The CASANOVA project will set up an innovative pluridisciplinary approach combining biological, geographical, climatic and socio-economic sciences to generate fundamental knowledge that can be directly used in decision support for public authorities. This is a vital issue in Normandy, in line with the urges defined by the IPBES and within the frame of the United Nations 2030 agenda[63]. Even though climate change impacts will mostly remain ineluctable, this knowledge could then be adapted and applied to other regions, both nationally and internationally, and be an asset to mitigate and limit the effects of climate change on shellfish socio-ecosystems.

References (Coordinator, Partner)

1. O. Hoegh-Guldberg *et al.*, *Science* **328**, 1523–1528 (2010). **2.** N. Metzl, *et al.*, *Earth Syst. Sci. Data* **16**, 89–120 (2024). **3.** C. López Solano, *et al.*, *Water* **14**, 321 (2022). **4.** N. J. Holbrook, *et al.*, *Nat. Commun.* **10**, 2624 (2019). **5.** B. A. Grantham, *et al.*, *Nature* **429**, 749–754 (2004). **6.** E. Hernández-Miranda *et al.*, *Mar. Environ. Res.* **79**, 16–28 (2012). **7.** R. K. Walter *et al.*, *J. Geophys. Res. Oceans* **119**, 3517–3534 (2014). **8.** F. J. Tapia *et al.*, *PLOS ONE* **9**, e110841 (2014). **9.** K. A. Adams *et al.*, *J. Geophys. Res.* **118**, 4839–4854 (2013). **10.** F. Chan, *et al.*, *Sci. Rep.* **7**, 2526 (2017). **11.** A. Derby, *et al.*, *Env. Pollut* **275**, 116545 (2021). **12.** J. Jarsjö *et al.*, *J. Hydrol.* **348**, 59–72 (2008). **13.** A. Mazaleyrat *et al.*, *Sci. Data* **9**, 392 (2022). **14.** B. Pogoda, *et al.*, *Aquat. Living Resour.* **32**, 13 (2019). **15.** J. R. Jambeck, *et al.*, *Science* **347**, 768–771 (2015). **16.** A. C. Chiaia-Hernández *et al.*, *Environ. Sci. Pollut. Res.* **29**, 85761–85765 (2022). **17.** J. S. Ren *et al.*, *Ecol. Model.* **221**, 527–539 (2010). **18.** Y. Zhao, *et al.*, *Ecol. Model.* **393**, 1–11 (2019). **19.** A. Gangnery, *et al.*, *Aquac. Environ. Interact.* **11**, 493–506 (2019). **20.** S. C. J. Palmer, *et al.*, *Front. Mar. Sci.* **6**, 802 (2020). **21.** L. D. Talley *et al.*, in *Descriptive Physical Oceanography (Sixth Edition)*, (Academic Press, 2011), p. iii. **22.** D. Gallardi, *Fish. Aquac. J.* **05** (2014). **23.** N. Howarth *et al., Sci. Rep.* **14**, 20688 (2024). **24.** R. Sussarellu, *et al.*, *Proc. Natl. Acad. Sci.* **113**, 2430–2435 (2016). **25.** S. Ibrahim, *et al.*, *Mar. Biotechnol. N. Y. N* **25**, 624–641 (2023). **26.** T. Sol Dourdin, *et al.*, *Environ. Sci. Technol.* **58**, 1865–1876 (2024). **27.** R. Rondon, *et al.*, *Environ. Epigenetics* **3**, 1–13 (2017). **28.** J.-C. Simon *et al.*, *Microbiome* **7**, 5 (2019). **29.** D. Destoumieux-Garzón, *et al.*, *Philos. Trans. R. Soc. B Biol. Sci.* **379**, 20230065. **30.** L. Dantan, *et al.*, *Sci. Rep.* **14**, 26914 (2024). **31.** M. Wahl *et al.*, *Front. Microbiol.* **3** (2012). **32.** L. Li, *et al.*, *Environ. Sci. Technol.* (2024). https://doi.org/10.1021/acs.est.4c08986. **33.** S. Malitsky, *et al.*, *New Phytol.* **210**, 88–96 (2016). **34.** R. L. Maher, *et al.*, *Front. Ecol. Evol.* **8** (2020). **35.** C. R. Voolstra *et al.*, *BioEssays News Rev. Mol. Cell. Dev. Biol.* **42**, e2000004 (2020). **36.** J. P. Da-Anoy *et al.*, *J. Mar. Biol. Assoc. U. K.* **99**, 1273–1279 (2019). **37.** L. W. Kelly, *et al.*, *Proc. Natl. Acad. Sci. U. S. A.* **111**, 10227–10232 (2014). **38.** Y. Krotman *et al.*, *Microbiome* **8**, 9 (2020). **39.** M. Fuhrmann *et al.*, *Biol. Open* **7**, bio028134 (2018). **40.** W. L. King, *et al.*, *Front. Microbiol.* **10**, 2907 (2019). **41.** J. Gawra, *et al.*, *Sci. Adv.* **9**, eadh8990. **42.** T. Vignolini *et al.*, *Curr. Opin. Microbiol.* **79**, 102477 (2024). **43.** A. Dannfald *et al.*,. *RNA Biol.* **18**, 4–18 (2021). **44.** J. Zhou, *et al.*, *Nature* **526**, 591–594 (2015). **45.** L. Le Franc *et al.*, *Genomics Proteomics Bioinformatics* **21**, 742–755 (2023). **46.** A. Casillo *et al.*, *Mar. Drugs* **22**, 363 (2024).**47.** T. Sauvage *et al.*, *BMC Genomics* **20**, 850 (2019). **48.** P. Guillotreau *et al.*, *Harmful Algae* **101**, 101968 (2021). **49.** L. van Hoof *et al.*, *Mar. Policy* **122**, 104245 (2020). **50.** L. Barillé, *et al.*, *Aquaculture* **521**, 735045 (2020). **51.** P. Claquin *et al.*, *SEANOE* (2018). https://doi.org/10.17882/53689. **52.** PHYTOBS, *SEANOE* (2023). https://doi.org/10.17882/85178. SEANOE (2023). **53.** P. Hamel *et al.*, *Sci. Total Environ.* **524–525**, 166–177 (2015). **54.** M. Fressard *et al.*, Research Report CNRS ; INRAE ; Univ. Padova (2024). **55.** P. Cugier *et al.*, *Environ. Interact.* **14**, 53–70 (2022). **56.** M. Rey-Campos *et al.*, *Int. J. Mol. Sci.* **23** (2022). **57.** J. de Lorgeril *et al*, *PLOS ONE* **6**, e23142 (2011). **58.** O. J. Bergfjord, *J. Risk Res.* **12**, 91–104 (2009). **59.** Q. Le Bras *et al.*, *Mar. Policy* **164**, 106154 (2024). **60.** G. Riviere, *et al.*, *PLOS Genet.* **13**, e1006807 (2017). **61.** A. Fellous, *et al.*, Histone Methylation Participates in Gene Expression Control during the Early Development of the Pacific Oyster Crassostrea gigas. *Genes* **10**, 695 (2019). **62.** R. Sussarellu *et al.*, *Aquat. Toxicol.* **196**, 70–78 (2018). **63.** UNSDG | 2030 Agenda and the Sustainable Development Goals. https://unsdg.un.org/2030-agenda [Accessed 5 January 2025].