SCOR Working group proposal

Mapping climate change refugia for marine conservation (MarCCR)

1. Summary

Climate change is causing rapid, major, alterations to marine ecosystems and their biodiversity, with extreme events increasingly driving mass mortalities at multiple scales. Climate-driven stressors also interact with other human pressures, posing a significant challenge to marine conservation. Marine Protected Areas (MPAs) are key tools in marine conservation intended to preserve or recover native species and communities. Knowing where to place MPAs that limit, or are adaptive to, the effects of climate change – i.e., **climate change refugia (CCR)** - remains a critical challenge. Existing approaches by-in-large ignore the fact that climate *vulnerability* combines *exposure* (deviation from historic physico-chemical variability) and *sensitivity* of organisms and communities to such deviations. CCRs emerge because many climate-driven stressors exhibit wide spatiotemporal variability. Their identification and utilization toward climate-ready MPAs thus requires knowledge of how multiple climate-driven stressors are distributed, and how species respond to their patterns. Overcoming the challenges of CCR identification and implementation in marine conservation necessitates truly international collaborative networks of scientists, working across scales and representative of diverse sustainability contexts relevant to MPA implementation; these are generally not supported through traditional funding. The planned **MarCCR** SCOR working group builds on previously limited-funded collaborations of several of its members aimed at developing the criteria and tools for defining and mapping CCR, to be used in MPA-network planning. Our extended international group will significantly improve the ability to tackle CCR challenges, and will deliver global CCR maps and detailed case-study regional maps to support international climate-adaptive marine spatial planning and conservation strategies.

2. Scientific Background and Rationale

2.1 Why identifying climate change refugia is important for marine conservation

Climate change (CC) reshapes marine ecosystems at accelerating rates [1, 2]. This emerging threat poses a fast-moving challenge to both resource exploitation [3] and marine conservation, which until now was mostly designed to deal with direct human pressures like fishing or pollution [4]. Tackling the CC challenge requires adaptive management based on quantitative environmental information, extensive biological knowledge [5], and development of strategies to incorporate environmental change into marine spatial planning (MSP) [6-9]. How species experience CC is highly variable in space and time, but this has rarely been explored for management solutions [10]. Increasingly-detailed remote-sensing data and expanding arrays of ocean sensors, as well as better biological data and modelling (improved species distribution maps and knowledge of physiological sensitivity), should enable us to tap on this variability to identify areas that can serve as **climate change refugia (CCR)** for key marine species and threatened communities. Including CCR in conservation and spatial plans [6, 11, 12] is a promising approach [13, 14], especially when refugia are assembled as well-connected networks [15] at multiple spatial scales.

Although a conservation priority, the theoretical framework for identifying current and future CCR is in its infancy. The notion of environmental refugia is based on the observation that smooth, biogeographical-scale gradients are rare, and become increasingly less evident at smaller spatial scales. Instead, environmental conditions consist of highly heterogeneous geographic mosaics at the scales relevant to most organisms [16, 17], creating areas (or periods) that can provide physiological relief from stress during extreme events [18], or by allowing species to persist amidst long-term changes [19]. Yet, while high frequency spatial [20] and temporal [21] environmental variability may drive long-term ecological responses, these scales are often overlooked by studies focusing only on long-term climatic trends [22]. Moreover, approaches to identifying CCR based solely on ***exposure*** to CC, ignore variation in the mechanisms by which affected individuals, populations, species, and communities respond to CC and other pressures, i.e. their ***sensitivity***. Combining knowledge of exposure and sensitivity yields a much-improved measure of ***vulnerability,*** which is the critical metric to detect CCR.

2.2 The challenge

In MPA research, site vulnerability to future climate is sometimes analyzed, but few real-life examples exist where such information is implemented in management [12]. Furthermore, only a few studies have assessed ecosystem-level vulnerability of MPAs to CC [23]. To deliver on international commitments towards effective ocean sustainability under CC, embedded in broader commitments for climate smart MSP [8, 24], a step change is necessary to assess ocean life vulnerability and resilience to CC. Implementing MPAs is a complex process, requiring collaboration and coordination across governments, policy implementers and stakeholders. The identification of CCR is a necessary, yet challenging, step toward long-term sustainable and climate-smart planning, ensuring that the allocation of space to MPAs is justified and effective.

CCR can be defined by seascape features as experienced by organisms, acknowledging that local environmental dynamics can be distinct from long-term regional-level change [10]. The history of a specific population within a seascape determines its vulnerability to environmental change, conditioned by adaptive plasticity, gene flow and other processes [25]. The first building block of a CCR is therefore environmental ***stability,*** defined by the area's historical environmental variability. A CCR **can** then be an area of high temporal variability (e.g., intermittent upwelling regions), where dynamics continue to reflect historical variability patterns into the future. Conversely, no change in average site conditions, does not confer stability under situations where variability increases, e.g. through exposure to new or more frequent extreme events [26]. Within-area stability can be assessed using statistical analysis to determine if the dynamics of relevant physical/biogeochemical metrics change over time, [e.g., significant shifts in seasonal weather patterns 27].

Previous attempts to identify CCR frequently considered only ***exposure***, focusing on change of the central tendency of environmental variables. This concept of CCR based on environmental "status quo" ignores whether current conditions are optimal for organisms and communities that MPAs strive to preserve. Such approaches are potentially problematic because we do not always know what aspects of environmental stability are most critical to specific organisms. To respond to environmental stress, organisms allocate energy to stress-response pathways (physiological, biochemical or behavioral), which are metabolically expensive. A site where average conditions remain constant but incidence of extreme events increases, thus represents a poor CCR. Therefore, several environmental metrics, including site heterogeneity, variability and extremes, are required to identify what may constitute current and future CCR. Equally, conditions are optimal only over some portion of a species' range. Stable but suboptimal conditions at a site, may simply indicate that organisms will remain viable, although sustaining a suboptimal physiological state. For instance, while cold edges of species distributions often represent such conditions [28], suboptimal conditions can also occur away from range edges. Considering the interaction between local- and regional-scale variability in both exposure and sensitivity is thus critical for CCR identification [29-31].

Marine spatiotemporal variability in vulnerability to climate exists at almost any spatial scale [32, 33]. For instance, variation in intertidal thermal regimes over the scale of cm can exceed that observed over thousands of km [34], and variation in thermal tolerance among individuals can exceed differences between species [35]. Such variation can lead us to question how much predictive power we gain from considering increasingly higher resolution of variability in exposure and sensitivity [33], and how can they contribute to produce a CCR or its opposite, a CC hotspot [6, 36]. While data availability limits testing this globally, it can be assessed using case-studies where the seascape and its organisms are known in detail. Practically, physiological sensitivity of individuals can be estimated directly by quantifying performance curves along environmental gradients in the laboratory [37], and the sensitivity frequency distribution of individuals within a population can then be combined with variation in exposure to estimate vulnerability of entire populations [33, 35]. At the species level, it is also possible to integrate local factors that influence species occurrences by extracting the species' thermal distribution across its geographic range (its realized niche), called the species thermal index (STI) [38]. This measure can be integrated at the community level by taking the average STI across all species present, yielding the community thermal index (CTI) [38]. CTI has now been incorporated as a global biodiversity indicator (https://www.bipindicators.net/indicators/reef-fish-thermal-index).

Our **MarCCR** SCOR group will build on these approaches to develop both the conceptual framework and the metrics to identify ***multiple-driver CCR***, and produce global CCR maps, as well as focus on regional/local-scale case-studies. These products will be used to promote ocean CC literacy among practitioners, and the uptake of CCR into real-life MSP approaches, through group members' involvement in international committees and initiatives (e.g., ICES WGMPCZM, UNFCCC COP, SDG14 process).

2.3. Why a SCOR Working Group

A SCOR Working Group is an ideal platform to develop a framework for creating global CCR maps. Initial marine CCR concepts were developed within the EU COST-ACTION project MARCONS (http://www.marcons-cost.eu/), which only funded European members and ended in April 2020. Rilov and Helmuth received support from the a joint US NSF - Israel-USA Binational Science Foundation grant during 2016-2019 to develop tools to explore small-scale refugia. We made important progress in resolving some initial challenges related to CCR identification - a strong starting point for this Working Group. But progress has stalled due to the lack of a truly international funding platform. Climate-smart marine conservation and spatial planning are driven by global aspirations, but realized through highly diverse regional and local-scale implementation. A diverse SCOR Working Group would allow capitalizing on progress made, accelerating it by leveraging global expertise, delivering tangible products to improve global marine conservation planning.

3. Terms of Reference

Objective 1 (O1) - Develop a conceptual framework for defining and identifying marine CCR at different spatiotemporal scales and for multiple drivers.

Objective 2 (O2) – Develop empirical approaches to identify marine CCR at different scales, and quantify how their different physicochemical- biological properties are linked.

Objective 3 (O3) – Produce global CCR maps at relatively coarse scales applicable for broad scale transboundary planning.

Objective 4 (O4) - Produce high-resolution maps for several regional and local case studies in different regions and marine ecosystems, that can be applicable at local to regional scales.

Objective 5 (O5) – Produce materials for conservation and planning practitioners to use CCR identification tools and maps to inform real-life planning applications.

Objective 6 (O6) – Create opportunities for training and learn-by-doing for early-career and developing country researchers.

4. Working plan

The MarCCR working group will progress the Terms of Reference by addressing the objectives 1 to 6 according to the following program of activities (by years):

Year 1. To address O1 and O2, we will build on initial efforts of some members of the group and continue to develop and refine the building blocks for identification of CCR. Specifically, we will focus on more accurately defining *stability* and its metrics, as well as measures of *sensitivity* of populations, species and communities, and how these two measures can be combined to calculate *vulnerability*. To develop the required tools, we will first build on our initial progress in identifying temperature refugia, given that temperature plays a major role in determining the distribution, fitness and survival of species, and is readily measurable both locally and at global scales using remote sensing and the increasing array of sensors, such onshore loggers and oceanic deployments (e.g. ARGOS). We will then assess refugia using other climate-change related stressors including ocean acidification [39] and deoxygenation [40], thus more accurately representing the impacts of climate change on marine ecosystems [2]. Stability in temperatures at large scales can build for example on calculations of climate velocity and/or be assessed using different statistical metrics quantifying change in means, fluctuations, extremes and state changes. The latter can also be used at small scales. Tools for assessing stability in other climate-driven stressors require the same principles, and the added challenges of techniques to synthesize this information across geographical scales (relying less on remote-sensing data), to assess ecosystem level vulnerabilities. We will examine ways to assess sensitivity using both single species data (such as performance curves and species distributions), and community metrics (including CTI and others) by expanding principles to a multiple-drivers (stressors) context towards the delivery of equivalent tools that can be applied to identify CCR. Using first case studies on a local or regional scale, we will create and test different refugia layers and their links based on metrics similar to what was developed for temperature, and then assess community level vulnerabilities based on the refinement of existing techniques [6, 23]. A MarCCR webpage or website and social media accounts (e.g. Twitter) will be used to promote WG activities with the wider community. We will also attempt to coordinate presentations by the group's members at international meetings (such as the International Temperate Reef Symposium in January 2022 in Hobart Tasmania, where we can introduce the topic and initial findings), including the proposal of special sessions, which will include student investigators.

Year 2. While different policy frameworks aim to protect large areas of the world's oceans, there is a paucity of information to support decisions on conservation priorities related to climate change. We will address this gap in year 2, by developing global (O3) maps of current multiple-driver CCR at multiple spatial scales, with a special focus on coastal regions, where most present and planned MPAs are concentrated. This will be based on existing environmental remote sensing and *in-situ* data and physiological sensitivity of key or model species, as well as species distributions for well-studied groups (e.g., fish, kelps, corals and intertidal organisms), analyzed via spatial-meta-analysis and other techniques [6]. This approach allows us to categorize regions by the emergent properties of refugia. High-resolution regional case studies (O4) will be explored in greater detail towards anticipated engagement with practitioners in years 3 and 4. We will also develop and use metrics based on circuit theory to assess connectivity among CCRs and identify climatic corridors minimizing exposure to climatically hostile areas as other key areas for conservation prioritization [41, 42]. Our case-studies will include: the eastern Mediterranean, the Portuguese coast, the Chilean coast, the Galapagos Islands, and the Hawaiian Islands, considering also other case-studies at the center of programs that can peripherally support this WG, including those used in the new EU H2020 program (FUTUREMares) co-led by members of this team (Rilov and Queiros), Vietnam's

UNESCO Man and Biosphere Reserve (UKRI GCRF Blue Communities, Queiros and Tri), and others.

Years 3-4. To address O5-6, we will develop a framework to incorporate CCR in MSP and conservation practices. We will work in collaboration with our ongoing funded research programs and networks to develop guidelines to incorporate CCR theory and modelling tools at three levels: i) MSP processes at national and supra-national scales - including transboundary CCR (crossing territorial waters, EEZ, ABNJ); ii) the identification of representative networks of MPAs within regional MSP; and iii) MPA management at local scales, focusing mainly on the case-studies. To achieve these goals, we will develop specific guidelines on how to incorporate CCR into the MSP standard phases: assess, design, implement, monitor, evaluate, and adjust [24]. We will identify the knowledge gaps and potential sources of uncertainties regarding CCR that need to be addressed, in harmony with the precautionary principle in MSP. We will also define a series of recommendations (managing potential synergies and conflicts) for the identification and designation of CCR regarding multiple uses. The identification of a representative network of MPAs (level ii) will be addressed by identifying strategies to prioritize CCR within an MSP context. The proposed guidelines will focus on how the metrics developed and implemented in O1-4 will deliver climate-resilient criteria for the selection of climate-ready MPAs, that further consider Convention on Biological Diversity (CBD) criteria of "effectively and equitably managed, ecologically representative and well-connected" protected areas (Art. 11). We will organize a workshop with resource managers and planners to co-develop such guidelines and recommendations (using web-based tools, where needed) in tandem to the WG meetings and possibly other more local activities involving our early career members and, when needed, specifically targeting developing nations where our members reside (e.g., in Chile, Ecuador, Vietnam). Potential participants in the workshop include resource managers and heads of conservation networks, building on our professional circles to include for example, ICES Working Group on Marine Planning and Coastal Zone Management (Queiros), H2020 FutureMARES (Rilov, Queiros), MEDPAN and MSPMED (Gissi), and other initiatives and committees within which our members participate.

5. Deliverables

(1) **Published articles**. Workgroup papers will highlight and synthesize the knowledge gained, as well as summarize the approaches developed and introduce the main scientific products. We envision at least three high-impact peer-reviewed papers focusing on: a) theory and guiding principles of multi-driver marine CCR; b) global maps of current CCR highlighting several local case studies; c) incorporating CCR in ocean management at different spatial scales. We will strive to publish at least one of those papers as open access, depending on funding.

(2) **CCR maps**. These will include gridded raster layers with globally distributed CCR and associated metrics, as well as detailed maps of our case-study regions. These maps will be published in long-term open access data repositories such as *Pangaea* and made available at the project

webpage/website. To maximize the utility and encourage the usage and further development of the products from this project, we will make our code available to any interested party through a GitHub repository and eventually compile it into an R package.

(3) **Policy briefing**. This briefing will include recommendations for conserving biodiversity given rapid climate change relevant to marine assessments (CBD, IPBES and IPCC), the United Nations Sustainable Development Goals and Aichi Targets, as well as the recent goals set by the Decade of the Ocean UN initiative https://en.unesco.org/ocean-decade, specifically: the need for “adaptation strategies and science-informed policy responses to global change“.

(4) **Layman's report**. This report will be co-developed with resource and MPA managers and ocean planners on guidelines and recommendations to incorporate CCR in ocean management. It will be posted on our MarCCR webpage/website and disseminated via social media.

6. Capacity Building

Many senior workgroup members have extensive experience in capacity building (CB) activities. The purpose of this CB workplan is to create literacy development, mentoring and training opportunities related to CCR identification and incorporation in MSP and conservation, specifically targeting: i) Early Career Researchers (ECR); ii) Researchers in Developing Countries (RDC); and iii) practitioners involved in planning and management decisions related to MPA design around the world.

i) **Early career researchers (ECR)**. Throughout the group’s activities, the workgroup will strive to provide an inclusive environment that presents opportunities for training and mentoring of ECR. This includes membership of the workgroup (six ECR members), as well as opportunities for involvement in workgroup activities by ECR within the professional networks, external to the group. ECR will be expected to contribute to, engage in, and benefit from, all research activities of the workgroup. ERC will be given authorship of group-related publications and reports commensurate with these activities, and are expected to participate and present in high level activities, such as that at the Ocean Conference side-event submission (see iii). Secondly, we aim that one of our meetings will be held in parallel to the Ocean Sciences Meeting 2022 (FEB 27-MAR 4, 2022 - Honolulu, HI, USA) conference of the Association for the Sciences of Limnology and Oceanography (ASLO), where we will submit a proposal for a session focused on this workgroup products. This will allow ECR from around the world, which represent the bulk of attendees at the conference, to be exposed to the workgroup research, and external contributions will be encouraged on the subject of CCR.

Participation in workgroup activities by ECR will be encouraged through workgroup members’ research networks, UKRI GCRF programs, Blue Communities and SOLSTICE (which focus on capacity development of sustainable marine management in developing states in the Western Indian Ocean and SE Asia), and the MBON Pole to Pole initiative, a Community of Practice across the Americas (https://marinebon.org/p2p/index.html). The workgroup will put in place several activities specifically targeted to PhD and graduate students on the topics and methodology developed.

To enlarge the potential targets of the training activities, the MarCCR working group will explore the possibility of preparing an *e-learning* training workshop in the form of a Massive Open Online Course (MOOC), a free online course available for anyone to enroll. The MOOC learning objectives are targeted to introduce the theoretical and modelling problems of establishing CCR, as well as the implications for ocean management. The MOOC will follow a problem-based approach, building on specific case studies developed in the first two years of the project. The contents and the problem-based learning of the MOOC will be tested in a training workshop, which will be held in a third-year meeting. The MOOC will be issued at the end of the third year or early in the fourth year, and uploaded in the websites of one of the Institutes of the workgroup members, and open to anyone who has a specific interest in the topic.

ii) Researchers in Developing Countries (RDC). The workgroup will build on its professional network and ongoing activities to promote the representation and participation of RDC in all core group activities and engagement events in Years 1-4. This participation creates opportunities for learning-by-doing, as well as ensuring that developing state perspectives are given due consideration during analyses of data, tool development and workgroup recommendation development. As well as contributing to CB, this focus ensures that the outputs of this workgroup have real potential for global applications, in all sustainability contexts.

Participation of RDC includes membership in the workgroup (four RDC members), opportunities to contribute to, engage in, and benefit from, all research activities of the workgroup; and an encouragement to present in high level engagement activities, such as that at the Ocean Conference side-event submission (please see iii).

Participation of at least some of the RDC in workgroup activities will be supported and funded via existing ongoing networks and projects that workgroup members are active in, including:

1) UKRI GCRF programme Blue Communities (which focuses on capacity development of sustainable marine planning in developing states in SE Asia)

2) UKRI GCRF programme SOLSTICE (which focuses on capacity development of sustainable marine management in developing states in the Western Indian Ocean)

iii) Practitioners. During the activities of this workgroup, we will draw on our professional networks to promote CCR literacy and increase awareness of MSP, Integrated Coastal Zone Management and MPA practitioners around the world. Specifically, we will build on the activities of existing expert groups (e.g. ICES WGMPCZM), research programs (H2020 FutureMARES, UKRI GCRF Blue Communities), and policy advisory committees (e.g., MSPMED) where workgroup members and associate members are active in, and that already involve practitioners. We aim to hold at least one targeted demonstration workshop in Year 3, organized in tandem with the activities of those groups, where the aims and outputs of the workgroup are presented and explored within the context of real-life MPA or MSP programs. We will also consider applying for a workshop as an event at the United Nations Ocean Conference, targeting the participation of decisionmakers and ocean managers interested in the sustainable management of ocean resources worldwide. This workshop will build on workgroup members' experience within the UNFCCC processes and community. During such a workshop, the results of the workgroup will be presented to conveners, which typically include representatives of policy, industry, business, research, and civil society interested in sustainability and ocean management. Guidelines and recommendations for the incorporation of CCR in ocean management will be disseminated as a short layman's report at the event, as well as being the focus of a Q&A session around the theme of operationalizing a CCR approach in decision making processes related to ocean management. The report will also be disseminated through marine managers networks previously described, and others such as the Marine Ecosystems and Management (MEAM) network serving over 10,000 members of the global resource management community.

Working Group composition

Full Members

The sign * indicates early career member

Name	Gender	Place of work	Expertise relevant to proposal
1 Gil Rilov (Chair)	M	Israel Oceanographic and Limnological Research, Haifa, **Israel**	Marine community ecology, conservation biology, climate change impacts
2 Ana Queirós (Co-chair) *	F	Plymouth Marine Laboratory, Plymouth, **UK**	Climate modelling solutions for sustainable management of marine ecosystems under climate change. Science-policy.
3 Amanda Bates	F	Memorial University of Newfoundland, **Canada**	Physiological ecology, macroecology, conservation biology
4 Elena Gissi	F	University Iuav of Venice, **Italy**	MSP, ecosystem-based approach, conservation planning
5 Brian Helmuth	M	Northeastern University, Boston, MA, **USA**	Ecological forecasting, Physiological ecology, Science communication
6 Fernando Lima *	M	CIBIO, University of Porto, Porto, **Portugal**	Environmental monitoring, Biodiversity, Thermal stress,

			Macroecology, Climate change impacts
7 Yunwei Dong	M	Ocean University of China, Qingdao, **China**	Physiological ecology, marine spatial planning
8 Michael Burrows	M	Scottish Association for Marine Science, Oban, Scotland, **UK**	Predicting Responses of marine species and communities to climate change
9 Catriona Hurd	F	University of Tasmania, **Australia**	Macroalgal physiology, ocean acidification
10 Catarina Frazão Santos *	F	University of Lisbon, MARE–Marine and Environmental Sciences Centre, **Portugal**	MSP, ocean policy, climate change adaptation, sustainable ocean management

Associate Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
1 Mary O'connor	F	University of British Columbia, **Canada**	Adaptive capacity of biodiversity and ecosystem function in changing environments
2 Larry Crowder	M	Stanford Woods Institute for the Environment, Stanford University, **USA**	Marine ecology and conservation, sea turtle ecology, fisheries
3 Nicolas Moity *	M	Charles Darwin Foundation, Galapagos, **Ecuador**	Marine ecology, GIS, MSP, fisheries, anthropic impacts, conservation research, mangroves

4 Bernardo R. Broitman	M	Departamento de Ciencias, Facultad Artes Liberales, Universidad Adolfo Ibáñez, **Chile**	Marine ecology, coastal oceanography, ecophysiology, ocean remote sensing
5 Anthony Richardson	M	University of Queensland, **Australia**	Zooplankton, deep ocean, fishing, conservation prioritization
6 Jorge García Molinos *	M	University of Hokkaido, Sapporo, **Japan**	Coastal ocean connectivity, climate responses and conservation
7 David Schoeman	M	University of the Sunshine Coast, **Australia**	Ensemble climate forecasting for response modelling
8 Nguyen Hoang Tri	M	UNESCO Man and Biosphere Program; **Vietnam**	Integrated coastal zone management; marine conservation; equitable marine management
9 Laura Antao *	F	Research Centre for Ecological Change, University of Helsinki, **Finland**	Macroecology, climate change, global patterns in biodiversity change, biodiversity synthesis
10 Greg Asner	M	Center for Global Discovery and Conservation Science, Arizona State University, **USA**	Coastal and marine mapping; Marine geospatial analysis and A.I.; Coral reef ecology

Working Group contributions (full members)

Rilov's research focuses on marine community ecology and how marine biodiversity and ecosystem functions are affected by human (fishing) and global (climate change and bioinvasions) stressors, from the species to the ecosystem. He also applies this knowledge to developing ways for adaptive conservation planning strategies to deal with climate change impacts.

Queirós develops ocean climate modelling and modelling analyses methods for dynamic ocean management and sustainability of marine policies under CC. She co-leads the ICES WGMPCZM

ToR on CC and MSP, and works at science-policy interface. She recently led a CC assessment for the Irish government MSP framework; was engaged in various sustainable development initiatives (UKRI GCRF).

Bates' research quantifies biodiversity in time and space with relevant environmental data and the physiological tolerances of species. Her group transforms physiological data into predictive tools incorporating both exposure and species' sensitivities to global change drivers. In doing so, Bates generates novel theory and approaches for managing and conserving marine resources.

Gissi's research incorporates ecosystem-based approach in ocean management, and in MSP processes, by understanding the uncertainties in assessing cumulative effects assessments from multiple stressors. She also addresses transboundary conservation challenges in marine spatial prioritization for systematic conservation planning. Her work also supports EU Member States in MSP implementation in the Mediterranean.

Helmuth's research centers on predicting the likely impacts of CC on coastal ecosystems using coupled biophysical and ecophysiological approaches, including the development of novel sensors. His lab also develops decision support tool design and testing, as well as novel methods for public engagement such as visualizations and citizen science.

Lima works on intertidal biogeography, studying the processes and mechanisms driving species distributions. He studies the mechanistic links between climate, thermal stress, physiology and macro-ecological processes. His research brings together climatology, biogeography, electronics, experimental ecology, behavior, physiology and modelling.

Dong's research focuses on developing an integrated understanding of the impacts of CC and human activity on biogeographic patterns of intertidal species. Mechanistic studies provide critical insights into the physiological and biochemical adaptations of intertidal invertebrates to environmental stresses, providing cause-effect frameworks for the mechanisms driving species range shifts.

Burrows's research addresses species and community responses to CC using long-term and spatially-extensive datasets to detect the effects of changing patterns of abundance and distributions in response to warming and other climatic change, comparing observed changes to expectations based on spatiotemporal metrics of CC (e.g. rates of shifting isotherms) and anticipated species responses to temperature.

Hurd examines the environmental regulation of seaweed primary production by light, nutrients, temperature, CO_2/pH and water motion. She takes a mechanistic physiological and biochemical approach to understand how seaweeds, and the communities that they support, will respond to CC - ocean acidification, temperature and marine heatwaves, and local stressors, focusing on the role that seaweeds play in creating refugia for coastal calcifiers from ocean acidification.

Frazão Santos's research focuses on the links among MSP, sustainable ocean governance, and CC effects in the ocean. She develops interdisciplinary research, investigating how human dimensions and political aspects influence sustainable use and ocean conservation. She is currently leading a R&D project on how MSP can be affected by and adapt to CC, and she supports UNESCO and the European Commission in MSP-related events.

Relationship to other international programs and SCOR Working groups

MarCCR will work in parallel with a new EU Horizon2020 project, FUTUREMares, co-led by members of this team (Rilov and Queiros), that is focused on climate change impacts and nature-based solutions in the marine environment that will start in September 2020. The results of **MarCCR** could naturally translate into implementations and recommendations for application within FUTUREMares. FUTUREMares might also be able to provide some support for personnel to help with data analysis for MarCCR, and students and postdocs from the EU project could benefit from capacity building through **MarCCR** activities. Queiros co-leads the ICES WGMPCZM (Working Group for Marine Planning and Coastal Zone Management) terms of reference on climate change and MSP, and the results from both groups present natural synergies that benefit the development of climate-adaptive MSP practices in Europe and elsewhere. Queiros is a Co-I in two UKRI Global Challenges Research Fund programmes (GCRF) focused on the development of capability in climate-adaptive approaches for ocean sustainability that support resilience of vulnerable communities in the developing world, with activities focused in the Western Indian Ocean and SE Asia, with **MarCCR** associate member Tri being part of the latter. Synergies will be explored with those projects, towards the delivery of: training activities led by this SCOR group with students, researchers and practitioners involved in those projects; synergies with the ICZM work delivered by PEMSEA in SE Asian partner countries involved in GCRF, including the Vietnam UNESCO Man andBiosphere Reserve (Tri); and the representation of developing country perspectives within this SCOR workgroup through engagement activities and contribution towards the publications of this workgroup. Gissi has been awarded a Marie Sklodowska Curie Global Fellowship for the project MEDIX "Marine Environmental DynamIcs and seX-based analysis for climate change adaptation in MSP" in collaboration with Stanford University. The 3-year project will start by March 2021. Frazão Santos is the coordinator (PI) of project OceanPlan (www.oceanplan-project.com), a 3-year R&D project on how marine spatial planning can both be affected by and adapt to global climate change (2018-2021). The project is funded by the Portuguese National Science Foundation (FCT) and carried by an international team of scientists (including L. Crowder, T. Agardy, C. Ehler, H.O. Portner). OceanPlan outputs will provide support to **MarCCR**, namely regarding conceptual links between MSP-climate change (Frazão Santos et al. 2020), vulnerability assessments (preliminary work awarded at ICES ASC 2018), and MSP adaptation approaches. Catriona Hurd is an associate member of SCOR WG149 "Changing Ocean Biological Systems" (https://scor149-ocean.com) whose focus was to develop an online "Best Practice Guide" for designing and implementing laboratory multiple-stressor experiments (https://scor149-ocean.com/decision-support-tool). The team also runs training workshops to enable students and scientists with the skills to undertake multiple stressor experiments. We received a support letter for this **MarCCR** proposal from Prof. Philip Boyd, chair of WG149, stating that "the proposal is very timely, and I support it very strongly. It would be exciting for SCOR

WG149 (COBS) to interact with MarCCR, in particular around the identification of suitable refugia to offset complex multi-faceted ocean change."

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Appendix

For each Full Member, 5 key publications related to the proposal.

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