Proposal for a SCOR Working Group to form the International Network for the Study of How Organisms Respond to Environmental change

Acronym: INSHORE

Abstract

Climate change and ocean acidification are the greatest global threats facing the world's ecosystems, significantly altering the structure and functioning of coastal systems around the globe[1,2]. The financial cost of not undertaking adaptive management in coastal areas is estimated at $1 trillion by 2100[3]. In this era of unprecedented anthropogenic pressures, limitations in basic and applied knowledge on the distribution of organisms, and the paucity of multiple stressor research programmes impedes our ability to predict change and responsibly manage coastal systems.

INSHORE will use an interdisciplinary approach to understand and predictively model responses of ecosystem engineer species, including commercially farmed and Non-Indigenous Species to climate change and ocean acidification (OA). The Working Group will focus on ten species of mussels; *Mytilus edulis* and *Mytilus galloprovincialis* (Europe), *Brachydontes pharaonis* (invasive to Mediterranean Europe), *Mytilus californianus* and *Mytilus trossulus* (USA), *Septifer virgatus* (China & Hong Kong), *Perna viridis* (China & Hong Kong), *Mytilopsis sallei* (invasive to Hong Kong), *Perna perna* (South Africa) and *Mytilus chilensis* (Chile).

The Working Group objective is to develop an integrative framework and modelling tool that can be applied internationally to coastal marine ecosystems. This will be achieved by 1) creating a global database of relevant ecological, biological and environmental datasets 2) developing a biophysical model framework capable of operating over a range of spatial and temporal scales, 3) publishing a methodological best practice guide 4) hosting targeted workshops and a themed session at an international conference to engage the coastal research community in an integrated scientific approach.

Scientific Background and Rationale

Global climate change is now the milieu within which all biological, ecological and socio-ecological interactions must be positioned. Understanding and predicting impacts of climate change and OA on the physiology, abundance and distribution of species have been highlighted as a 'grand challenge' for physiologists worldwide[4], with a recognized need amongst the international research community to understand the organism's role in organism–environment linkages and how organisms respond to change.

The importance of a quantitative understanding of biological and physiological impacts of global climate change and OA, and resultant changes to distributions and abundances of species within the marine environment is clear, with an emphasis on predicting "winners" and "losers" among commercially, ecologically and culturally important species. Understanding how these stressors will alter resilience and sustainability of ecosystems is a priority for marine scientists working across molecular to ecosystem scales.

Species and ecosystems respond to stressors via multivariate changes in abiotic conditions and biotic interactions across a range of spatial and temporal scales, yet this is under-represented within current research programmes. Analyses of ecological responses to climate change are frequently communicated in generalized terms such as 'poleward range shifts', with drivers represented as trends in long-term averages across large spatial scales[5,6], however, decadal-scale increases in mean climate are not the proximate drivers of organismal survival. Instead, vulnerability is through mortality or sub-lethal performance; species' distributions respond more directly to shorter-term variation in environmental conditions including extreme 'climatic' events and anomalies[7]. Consequently, predictions may have little relevance for individual species, nor be appropriate for ecosystem status assessments at local to regional scales. In stark contrast, due to inherent difficulties in studying impacts within natural systems, research into ocean acidification has focused on detailed physiological- and organismal-scale experiments conducted in controlled mesocosms or natural experimental areas, although there is a recognized need for larger scale approaches.

Small-scale physiological studies provide yardsticks to gauge the sensitivity of organisms to changes in their environment, but their applicability to observable patterns in nature is difficult to assess due to the often single-species approach taken, and discipline-specific narrow focus adopted. Importantly, the stressors of greatest concern resulting from changing climatic conditions, temperature and ocean acidification frequently interact with one another and with other non-climatic stressors, subsequently altering sublethal responses for a species[9]. To avoid potential misinterpretations we propose that expectations of how climate and OA are likely to affect ecologically important species should be based on ecologically-functional trait-based metrics over appropriate spatio-temporal scales[10-12]. Such predictions should emphasize how multiple stressors interact to drive local-scale processes, and acknowledge the importance of biological responses and interactions in determining patterns of vulnerability over multiple spatio-temporal scales.

INSHORE will employ a multidisciplinary approach, integrating analyses of functional mechanisms and ecological processes with climatic and ocean chemistry data to provide realistic insights into the effects of global change on marine biological systems. We will scale up from organismal to biogeographic processes, identifying biological mechanisms underpinning the responses of ecosystem engineer species to climate change and OA, and link organism physiological performance to changes in population abundances and productivity. INSHORE will develop a dynamic energy budget model (DEB) and associated mechanistic species distribution model (SDM), and produce a methodological best practice guide for data collection and analysis to enhance our understanding of the most important and appropriate aspects of the responses of ecologically and commercially important coastal marine species to global change. INSHORE will focus on species of mussel to assist with future management objectives, and progress the ability to predict invasions of pest species in coastal areas across the globe.

Scientists cannot account for every possible combination of environmental conditions when forecasting ecological responses to global change. Our central tenet is to determine what comprises an appropriate test of model skill and stationarity, meaning that models constructed from contemporary observations can effectively predict responses under future, often novel, environments. To be effective, forecasts need to capture bio/eco-logically relevant stressor metrics[10-19], over appropriate spatio-temporal scales (10-100 km) applicable to the scientific research agenda and national and international policy drivers.

INSHORE will review existing climate and OA models alongside published experimental research and methodologies for climate change and ocean acidification experiments and studies for rocky intertidal systems. From this review and expert knowledge within the group a best practice guide to designing and carrying out experimental and observational studies to deliver fit-for-purpose data for use in multiple stressor modeling will be prepared and submitted for publication in *PLOS Biology*.

We will integrate detailed information on the mechanistic biology of species from experimental studies with molecular, physiological and ecological data, biogeographical time-series and environmental datasets using DEB and SDM models, sensu[15]. The DEB will use these data to simultaneously estimate impacts of temperature and pH on physiological performance, and the SDM will generate predictions of the impacts on the future biogeographic distributions of the target species. SDM outputs will be created at a regional scale (100s km) within areas of the Atlantic and Pacific oceans for which physiological, ecological, biogeographical and environmental data exist.

Rocky intertidal systems provide a highly tractable, data-rich system in which to develop and test such models. An important component of coastal habitats globally, they underpin both benthic and pelagic food webs, represent an important carbon pathway and support many species of both commercial and conservation value. The rocky intertidal also represents some of the most extreme and dynamic habitats in the marine realm. Organisms inhabiting this highly variable system are subject to high selection pressure arising from diurnal, seasonal and interannual fluctuations in environmental drivers and biological interactions and are at high risk from multiple human-induced pressures, exhibiting some of the fastest responses to global change in any natural system[12,18,19].

INSHORE comprise a multidisciplinary team of researchers with international track records on impacts of climate change and OA on marine species. Expertise spans time-series data collection and analysis (Mieszkowska, Krueger-Hadfield, Russell, Lima), biogeography, macroecology and population ecology (Mieszkowska, Helmuth, Harley, Williams, McQuaid, Broitman, Fawzi, Chan, Christopholetti), physiological experimentation (Russell, Sarà, Williams, Dong, McQuaid, Kroeker, Rilov) and modelling (Sarà, Helmuth, Williams, Mieszkowska), dynamic energy budget modeling (Sará, Helmuth, Williams), climate and OA modelling impacts modeling (Broitman, Helmuth, Lima, Fawzi, Harley). Some members have previously collaborated and published together as evidenced by the cited research in this proposal.

A SCOR Working Group grant will provide a unique mechanism by which world-leading researchers with complementary cross-cutting, multi-disciplinary expertise can develop a novel, standardized multidisciplinary approach to research on multiple stressor impacts. This scope does not fall within the remit of national research council funding, given the variety of biological, spatial and temporal scales at which such questions need to be addressed. The wide geographical spread of expertise and datasets, and the global distribution of rocky intertidal systems far exceeds geographical boundaries defining existing regional or bi-national funding schemes (e.g. NSF, EU Horizons 2020).

The proposed topic of advancing climate change and OA impacts research via an integrated, international approach is timely given the major findings of the 2014 IPCC Report on Impacts, Adaptation and Vulnerability[22] that CO_2 emissions are driving unprecedented changes in global marine climate and ocean pH, and may be 'irreversible in terms of possible futures'. This knowledge gap with respect to marine ecosystems will be addressed within the sixth IPCC Assessment Report, involving contributions from the Working Group team, and is also identified

within the EU Marine Strategy Framework Directive. Given these needs, this Working Group could be instrumental in leading a global, standardized approach to detecting, quantifying and predicting the impacts of climate change and OA on marine systems.

Terms of Reference

INSHORE will pursue the following terms of reference:

1. Disseminate the Working Group activities and outputs via development of a website with associated blog and Twitter account; hosting targeted sessions on multiple-stressor impacts research at major international meetings to increase awareness and engage scientists from multiple countries with the need for a standardized, multi-disciplinary approach to address this complex problem.
2. Create a web-based platform of relevant biogeographical, ecological, biological and environmental datasets held by, and accessible to the group.
3. Review existing climate models and ecological, biological and physiological experimental research into climate change and ocean acidification to develop a best practice for integrated multiple stressor research protocols. These best-practice approaches will consolidate the international research effort into marine climate change and provide standard protocols by which scientists new to this research field can produce comparable, robust data across research groups and nations.
4. Produce a best practice methodology and a case study output for the region of each Working Group member using the multiple stressor model.
5. Develop and test a next generation multiple stressor impacts model using existing time-series, experimental and environmental datasets collated in ToR 2.

Working plan

(1) Form an international Working Group with expertise in physical, ecological, and physiological sciences, to develop a Dynamic Energy Budget model and associated mechanistic Species Distribution Model for ten species of commercial or invasive priority for coastal systems globally. The DEB model will calculate organismal performance across thermal and OA environments, and the results will be input into the mechanistic SDM, which will model current distributions and forecast future impacts of climate change and OA.

(2) Tailor these models to the target species. The group will utilize their extensive collection of scientific and monitoring datasets, and those collected by the wider global research community including data repositories (e.g. ICES, PICES, OBIS, EMODnet, Redmap) and time-series such as the UK MarClim (Mieszkowska) and Pacific PISCO dataset (Broitman) and the NOAA Mussel Watch data to create a dataset of biogeographic distributions, traits, lifecycle and population dynamics for the target species. Data will be entered into a purpose-built database and used to derive best practice methodologies and to develop the models for all ten target species.

(3) Based on the outcomes from (2) the climate impacts modeling experts in the Working Group and Associate Members will lead a review of existing global change impacts models with input on novel methodologies and parameters necessary to develop next-generation predictive models provided by the Working Group and Associate experts.

(5) A Dynamic Energy Budget Model will be run for each of the ten target species, incorporating species-specific physiological performances and tolerances, and data on distributional range

shifts and abundances. DEB outputs will be integrated with the IPCC AR-5 scenario climate models input into mechanistic Species Distribution Models. These will provide quantitative assessments of the future biogeographic distributions, and identify areas within the species ranges where the species will become highly vulnerable to climate change and OA.

(6) The SDM model outputs will be designed at spatio-temporal scales relevant to policy and management drivers including OSPAR Regions, EU Regional Seas and Marine Protected Areas (e.g. Australian Representative Network of MPAs, UK Marine Conservation Zones, EU MPA Network) and disseminated via the INSHORE website and direct communication from Working Group members to policymakers via existing science-policy groups such as the UK Marine Climate Change Impacts Partnership, Australian National Climate Change Research Facility).

Understanding the impacts of climate change and OA on core ecological processes is an essential first step to mitigating their influence on ecosystem functioning, productivity and carbon sequestration, safeguarding species and communities, and adapting to changes in biodiversity and ecosystem service provision[11,24]. INSHORE will work closely with SNCBs providing fit-for-purpose data informing national marine policies. Outputs will be disseminated through peer-reviewed publications and press releases via Research Councils of the partner nations and partner institutes. Knowledge exchange workshops, IPCC, and MCCIP report cards will communicate the findings to policy makers and NGOs, with public engagement via national citizen science projects on which Working Group members are PIs or collaborators (e.g., the UK Capturing Our Coast Project).

The INSHORE imeline is detailed in Table 1. The first Working Group meeting will be held in January 2018 at the Marine Biological Association, Plymouth, UK. Co-Chair Mieszkowska will host the four-day workshop, with venue costs covered as an 'in-kind' contribution. The existing DEB model for *Mytilus galloprovincialis* will be showcased and the Working Group will test and validate the model using the metadatabase collated by the Working Group prior to this meeting (ToR 5, Deliverable 5).

The second Working Group meeting will be a three-day workshop and themed session held at the 'Twelfth International Temperate Reefs Symposium', January 2019 in Hong Kong and organized by Co-Chair Williams, from the conference host institute the University of Hong Kong, who will cover venue costs as an 'in kind' contribution. The workshop and themed session will be open to students from University of Hong Kong, SWIRE Institute of Marine Science and other conference participants. This meeting will involve presentations of working group members' research activities and launch of a website (Term of Reference 1, Deliverables 1,2), the construction and population of a meta-database of relevant biogeographical, ecological, biological and environmental datasets (ToR 2, Deliverable 3), a review of existing climate models (ToR 3, Deliverable 4) and a best practice guide for climate change and OA impacts research drafted (ToR 4, Deliverable 4). Presentations on the state of climate impacts modeling and availability of datasets for climate and OA at ocean basin, national and regional scales will be given by Broitman, Helmuth, Lima, Kroeker, Harley, Fawzi, Lundquist and Mieszkowska who are world-leaders in this field. Ecological responses to multiple stressors will be presented by Williams, Krueger-Hadfield, Harley, McQuaid, Helmuth, Chan and Christofolettii. Williams, McQuaid, Dong, Sarà, Rilov and Mieszkowska will present work on molecular and physiological multiple stressors. Working Group discussions will include datasets to be incorporated into the new models and a time-line for remote participation and delivery of data to the modelers. An early career workshop will be held by the group alongside the Working Group workshop to allow international students and early career researchers to learn about the development of these new models, and potential applications to their own ecosystems and research.

Between workshops two and three the review manuscript of the status of the research field into climate change and OA impacts on ecosystem engineer species will be written by the Working Group using cloud file sharing and virtual group working methods successfully employed by some members for previous publications.

A third workshop will be held in January 2020 at the Centro de Estudios Avanzados en Zonas Áridas, Chile, hosted by Working Group member Broitman. The DEB and SDM models will be run for all ten target species, with an extensive QA process carried out for each model by the relevant experts within the Working Group. Model runs will be carried out at regional scales relevant to invasive species management strategies and harvesting of commercial species. Manuscripts will be written on DEB and SDM models for submission to open access journals by the end of 2020 (Deliverable 6).

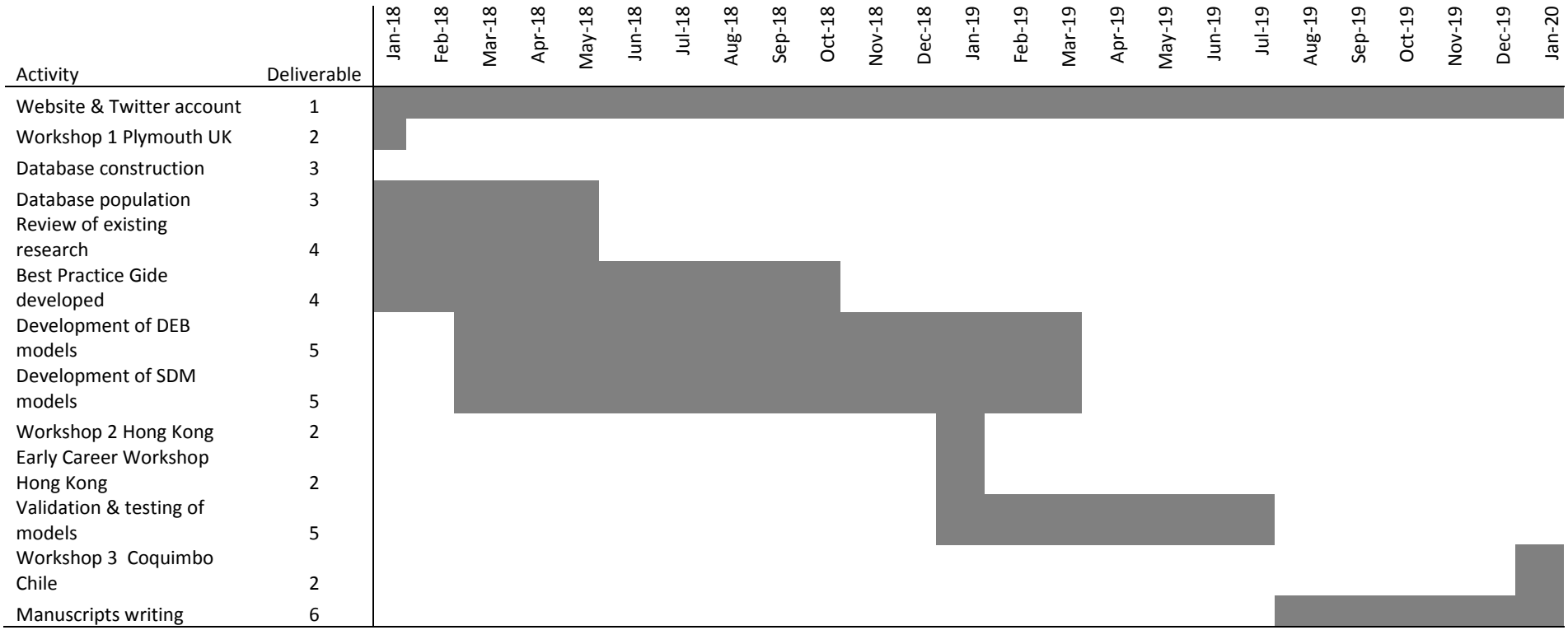
Deliverables

The Working Group will provide a mechanistic approach to understanding how coastal marine species of ecological and commercial value and/or invasive concern will respond to climate change and ocean acidification. This will develop new, biologically realistic predictions based on existing time-series and physiological data from the ICES community and high resolution (10-100 kilometers) environmental data.

Specific outputs:

1) Launch a website and Twitter account providing information on project activities, model outputs and links to related ICES activities.
2) Present Working Group expertise in climate change and OA research and promote ongoing activities of the Working Group at international scientific meetings.
3) Create a database of biological and environmental datasets for use in developing and the best practice guide (4) and testing the DEB and SDM models (5).
4) Publish a review of existing climate models alongside a best practice guide of the multidisciplinary, integrated methodological approach to next generation multiple stressor profiling modeling in the open-access journal *PLOS One*.
5) Develop novel DEB models and mechanistic SDMs and make the codes available to the international marine research community.
6) Publish model codes and outputs in international journals including open-access journals (e.g., *Ecological Modelling*, *Global Change Biology*, *PLOS Biology*) highlighting the roles of climate and ocean acidification in shaping and changing ecosystem engineer and commercially important species.
7) Provide project outputs to the IPCC 6th Assessment Report and governmental policy bodies for implementation in international policy drivers including OSPAR and MSFD via existing science-policy knowledge exchange roles of the team.

Table 1. Timeline of proposed INSHORE Working Group activities



Capacity Building

Understanding responses to climate change and ocean acidification requires the study of organisms at multiple levels of biological organization, from organismal physiology, population dynamics to species distributions. This integrated approach requires a multi-disciplinary research programme integrating global experts in physiological, ecological, experimental, monitoring and modelling disciplines.

The INSHORE Working Group membership encompasses researchers from developing nations (Chile, South Africa, China, Iraq) and associate members from Brasil, Israel and Taiwan. INSHORE comprises ten Working Group members and five Associate members spanning early to mid-career international researchers (Mieszkowska, Krueger-Hadfield, Broitman, Harley, Russell, Sarà, Dong, Kroeker, Lima), and international experts in global change biology running research institutes and university departments (Helmuth, Williams, McQuaid, Fawzi).

The membership of leading scientists in global change impacts spans all major continents to ensure an international scope for the exchange of knowledge, data and expertise. The range of expertise from molecular genetics through physiology, biology, ecology to climate modeling will ensure exchange of knowledge and skills between participants and nations. SCOR Working Group funding would allow the individual members to foster long-term collaborative working relationships, and increase this collaborative research base to the wider Working Group and Associate Group members. The SCOR funding would facilitate exchange of skills and expertise across developed and developing nations that would not be possible under other existing funding opportunities (e.g., research council or regional networking grants), and establish long-term collaborative links across the globe.

The group will present their contributions to an integrated multiple-stressor research perspective at the Eleventh International Temperate Reefs Symposium in Hong Kong, and host workshops to develop the integrated methodology and associated multiple stressor profiling model in Hong Kong, Chile, the UK and China. The Hong Kong conference will be attended by PICES and ICES member nation researchers, ensuring an international scientific audience, as well as the international science-policy community via the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). This global science-policy meeting is a high-profile venue for the dissemination of the Working Group's activities and best practice integrated research programme. Students attending this conference will be invited to interact with the global Working Group during an early career workshop that the Working Group will hold at this event.

Working Group members will give presentations on this project at their host universities and associated research laboratories. These dissemination activities will promote the INSHORE project to the benthic research communities and early-career scientists and students associated with the Working Group members and workshop host institutes in South and North America, Europe, Africa, Asia and Australasia.

An INSHORE project website will be set up with an associated blog and Twitter account to provide continuous dissemination of project activities and outputs, including the DEB and SDM model methodologies and codes and the best practice guide that will be promoted as an integrated standard approach within the global change research community. The website will be linked to the SCOR website and all Working Group and Associate Member laboratory websites. This will provide a lasting, open access record of achievements and activities, and facilitate exchange and sharing of experimental approaches developed across member countries.

Working Group composition

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Nova Mieszkowska	Female	Research Fellow, Marine Biological Association of the UK	CoChair. PI, MarClim; most spatio-temporally extensive intertidal species time-series globally. Macroecological responses to multiple stressors. Mesocosm and field experimental physiology; responses to climate, OA, nutrients. PI national research grants on climate change and OA impacts on marine biodiversity.
2 Gray Williams	Male	Director, The SWIRE Institute of Marine Science, University of Hong Kong	CoChair. 20+year experience in tropical intertidal ecology: field and laboratory approaches to physiological responses and impacts on local and regional community dynamics. Large-scale latitudinal projects in Japan, China, Vietnam, Thailand, Malaysia, Singapore.
3 Brian Helmuth	Male	Director, Sustainability Science and Policy Initiative. Professor, College of Science, Northeastern University, USA	Ecological forecasting, physiological mechanistic responses to climate, thermal engineering technology, mathematical modeling. Species Distribution Modelling. Biomechanical modeling.
4 Bernardo Broitman	Male	Director, Centro de Estudios Avanzados en Zonas Aridas, Santiago, Chile Associate Professor, Facultad de Ciencias del Mar, Universidad Catolica del Norte, Chile.	Community ecology, responses of coastal organisms to climate. Environmental modelling, coastal oceanography. PI most extensive coastal observation network on the Southeast Pacific. Deputy Director, MUSELS multiple stressor research centre.
5 Stacy Krueger-Hadfield	Female	Assistant Professor, University of Alabama at Birmingham, USA	Intertidal population dynamics, Seascape genetics, microgeographic structure, connectivity of populations across biogeographic scales, invasive species.
6 Christopher McQuaid	Male	Chair of Zoology and SARCHI Research Chair in Marine Biology, Rhodes University, South Africa	Substantial track record in ecology of benthic ecosystems, species interactions, invasive species, climate change. Importance of multiple stressors through multiple spatial scale experiments.
7 Gianluca Sará	Male	Associate Professor, Department of Earth and Marine Science, University of Palermo, Italy	Experimental estimation of functional traits under multiple stressors to feed Dynamic Energy Budget models assessing life-history traits of bentho-demersal organisms.
8 Chris Harley	Male	Associate Professor, Department of Zoology, University of British Columbia, Canada	Impacts of climate and OA on coastal ecology. Physiological responses of intertidal invertebrates and macroalgae.
9 Yunwei Dong	Male	Professor, State Key Laboratory of Environmental Science, Xiamen University, China	Physiological and molecular (transcriptomics, proteomics) responses of intertidal invertebrates to multiple stressors.
10 Nadia Al-Mudaffar Fawzi	Female	Head of Department, Biological and at Marine Science Centre, University of Basra, Iraq	Impacts of anthropogenic stressors on coastal ecosystems. Eutrophication & water quality research programme.

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Fernando Lima	Male	Centro de Investigação em Biodiversidade e Recursos Genéticos, Portugal	Biogeography of intertidal organisms, climatic reconstruction and analysis, modelling.
2 Kristy Kroeker	Female	UC Santa Cruz, USA	OA impacts on marine invertebrates. Forecasting and managing the emergent effects of environmental change in dynamic, complex ecosystems.
3 Ronaldo Christofolettii	Male	Instituto do Mar, Universidade Federal de São Paulo, Brasil	Trophic interactions within intertidal ecosystems.
4 Benny Chan	Male	Principal Scientist & Associate Professor, Coastal Research Laboratory, Academia Sinica, Taiwan	Intertidal, supply-side and larval ecology, biogeography of tropical intertidal invertebrates.
5 Gil Rilov	Male	Senior Scientist, National Institute of Oceanography, Israel	Community biodiversity, biogeography, benthic-pelagic coupling. Multiple stressor mesocosm and long-term field programme.
6 Bayden Russell	Male	Associate Professor, University of Hong Kong	Experimental assessment of physiological changes and resultant ecosystem functioning due to CO_2, temperature through primary productivity and trophic interactions.
7 Carolyn Lundquist	Female	National Institute of Water and Atmospheric Research, New Zealand	Benthic ecology. Invertebrate larval dispersal. Restoration of shellfish habitats.

Working Group Contributions

Mieszkowska. International track record spanning biogeographical to molecular impacts of global change on intertidal species and ecosystems. PI and primary data collector of world-leading UK MarClim Project and New Zealand, Australian and Icelandic sister projects with associated extensive experimental mesocosm and field datasets for physiological impacts of multiple stressors.

Williams. Established the first trans-Chinese field time-series of biophysical and environmental sensor network within rocky intertidal habitats, leads internationally renowned SWIRE Institute research programme into multiple stressor impacts on intertidal systems.

Helmuth. World leader in thermal engineering, energetics and bioclimate research using intertidal ecosystems as a testbed for NASA- and NSF-funded climate modeling projects. Leads biophysical experimental latitudinal research projects along Atlantic coastline of USA.

Broitman. Internationally acclaimed bioclimate modeler, PI of most extensive Pacific intertidal time-series dataset, PI of Chilean research programme into multiple stressor impacts on marine systems.

Krueger-Hadfield. International research profile on population connectivity and marine ecosystem resilience, seascape genetics, biogeographic distributions of native and invasive species.

McQuaid. South African National Research Foundation 'A rated' researcher with a global profile in environmental impacts on intertidal systems, McQuaid has held posts including Director of the Southern Ocean Group (SOG) at Rhodes University for 20 years, South African Research Chair (SARChI) in Marine Ecosystem Research at Rhodes University. Holds extensive datasets for South African intertidal.

Sará. Developed dynamic energy budget models that have been adopted as the international standard for coastal marine invertebrate species. IPCC AR5 national reviewer and research co-ordinator for Italian-Asian binational research networks.

Harley. Leading expert in field experimental research into impacts of climate change and ocean acidification on species physiology and ecology, community structure and functioning.

Dong. Driving cutting-edge physiological and molecular techniques for application to mechanistic research into responses of marine intertidal species to environmental stress. Leading the Chinese research drive into climate change impacts.

Fawzi. Leading authority in Iraq for water quality and impacts on coastal ecosystems. Heads research efforts into eutrophication and pollution research in the Persian Gulf system.

Relationship to other international programmes and SCOR Working Groups

INSHORE will link to existing international working groups and research networks via the proposed Working Group and Associate members. This will ensure wider knowledge exchange, continued dialogue and ensure complementarity without overlap between the various networks. These include:

- GRIEN Global Rocky Intertidal Ecology Network that involves field monitoring of intertidal biodiversity and environmental parameters, led by Dr Gil Rilov and involving Working Group members Mieszkowska, Williams, Helmuth, Sará, Harley and McQuaid.
- Ocean Acidification Network led by Dr Kristy Kroeker and involving Working Group members Russell and Harley.
- Millennium Nucleus Center for the study of multiple-drivers on marine socio-ecological systems - MUSELS, investigating the effects of environmental and socioeconomic drivers on the shellfish farming industry both in northern and southern Chile, PI Working Group member Broitman.

INSHORE will establish links to the SCOR WG149 Changing Ocean Biological Systems (COBS) to continue the theme of multiple stressor impacts on the global oceans within the SCOR Network and the wider international research community.

Key References

1. Pew Research Centre (2015). http://www.pewglobal.org/2015/07/14/climate-change-seen-as-top-global-threat/

2. World Economic Forum (2016). Global Risks Report 2016 11th Edition. Geneva. Pp103

3. Kollipara (2014) Science Magazine http://www.sciencemag.org/news/2014/12/climate-change-could-cost-us-coasts-1-trillion-2100

4. Mykles, D.L. et al. (2010). Grand challenges in comparative physiology: integration across disciplines and across levels of biological organization. *Integrative and Comparative Biology*, **50(1),** pp.6-16.

5. Burrows, M.T. et al. (2014). Geographical limits to species-range shifts are suggested by climate velocity. *Nature*, ***507*****(7493),** 492-495.

6. Wethey, D.S. et al. (2011). Response of intertidal populations to climate: Effects of extreme events versus long term change. *J. Exp. Mar. Biol. Ecol.* **400**, 132-144.

7. Mieszkowska N. et al. 2014. Multidecadal signals within co-occuring intertidal barnacles *Semibalanus balanoides* and *Chthamalus* spp. linked to the Atlantic Multidecadal Oscillation. *J. Mar. Systems* **133**, 70-76.

8. Russell, B.D. et al. (2009). Synergistic effects of climate change and local stressors: CO_2 and nutrient-driven change in subtidal rocky habitats. *Global Change Biol.* **15**, 2153.

9. Hoegh-Guldberg, O. et. al. *(*2007). Coral reefs under rapid climate change and ocean acidification. *Science*, ***318*****(5857),** 1737-1742.

10. Jentsch, A. et al. (2007). A new generation of climate-change experiments: events, not trends. *Frontiers in Ecology and the Environment* **5**, 365.

11. Helmuth, B. et al. (2010). Organismal climatology: analyzing environmental variability at scales relevant to physiological stress. *J. Exp. Biol.* ***213*****(6),** 995-1003.

12. Mieszkowska, N. et al. (2006). Changes in the range of some common rocky shore species in Britain - a response to climate change? *Hydrobiologia* **555**, 241-251.

13. Craig, R. K. ,(2010). Stationarity is dead – long live transformation: five principles for climate change adaptation law. *Harvard Environmental Law Review* **34**, 9.

14. Dong, Y. W., & Williams, G. A. (2011). Variations in cardiac performance and heat shock protein expression to thermal stress in two differently zoned limpets on a tropical rocky shore. *Marine Biology* ***158*****(6)**, 1223-1231.

15. Sarà, G. et al. (2013). Parameterisation of bivalve functional traits for mechanistic eco-physiological dynamic energy budget (DEB) models. *Mar Ecol Prog Ser 480*, 99-117.

16. Russell, B.D. et al. (2013). Ocean acidification and rising temperatures may increase biofilm primary productivity but decrease grazer consumption: evidence from a mesocosm experiment. *Phil. Trans. B* **368**, 1627.

17. Mieszkowska, N. et al. 2013. Dynamic species distribution models from categorical survey data. *Journal of Animal Ecology* **82(6)** 1215-1226.

18. Harley, C.D.G. et al. (2012). Effects of climate change on global seaweed communities. *Journal of Phycology* **48**, 1064-1078.

19. Broitman, B.R. et al. (2008). Climate and recruitment of rocky shore intertidal invertebrates in the eastern North Atlantic**.** *Ecology* **89(11 Suppl)**, S81–90.

20. Blanchette, C. et al. (2008). Biogeographical patterns of rocky intertidal communities along the Pacific coast of North America**.** *J. Biogeography* **35(9)**, 1593–1607.

21. Helmuth, B. et al. (2006). Living on the edge of two changing worlds: forecasting the impacts of climate change on rocky intertidal ecosystems. *Ann. Review Ecology Systematics Evolution* 37: 373-404.

22. IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report.

Appendix 1
Five key publications per Working Group Member (author and co-authors who are also WG members highlighted in bold):

Mieszkowska

1. **Mieszkowska, N.** & Sugden, H. (2016). Climate-Driven Range Shifts Within Benthic Habitats Across a Marine Biogeographic Transition Zone. Advances in Ecological Research 55: 325-369.
2. **Mieszkowska N.**, Burrows M., Pannacciulli, F. & Hawkins, S.J. (2014). Multidecadal signals within co-occuring intertidal barnacles *Semibalanus balanoides* and *Chthamalus* spp. linked to the Atlantic Multidecadal Oscillation. 10.1016/j.jmarsys.201211008.
3. **Mieszkowska, N**., Sugden, H. Firth, L. & Hawkins, S.J. (2014). The role of sustained observations in tracking impacts of environmental change on marine biodiversity and ecosystems. Philosophical Transactions of the Royal Society A, in press.
4. **Mieszkowska, N**., Milligan, G., Burrows, M.T., Freckleton, R. & Spencer, M. (2013). Dynamic species distribution models from categorical survey data. Journal of Animal Ecology 82(6) 1215-1226.
5. **Mieszkowska, N**., Kendall, M.A., Hawkins, S.J., Leaper, R., & A.J. Southward (2006). Changes in the range of some common rocky shore species in Britain - a response to climate change? Hydrobiologia 555: 241-251.

Williams

1. Ng, T.P., Cheng, M.C., Ho, K.K., Lui, G.C., Leung, K.M. & **Williams, G.A.** (2017). Hong Kong's rich marine biodiversity: the unseen wealth of South China's megalopolis. Biodiversity and Conservation *26*(1), pp.23-36.
2. Giomi, F., Mandaglio, C., Ganmanee, M., Han, G.D., Dong, Y.W., **Williams, G.A.** and Sarà, G. (2016). The importance of thermal history: costs and benefits of heat exposure in a tropical, rocky shore oyster. Journal of Experimental Biology *219*(5), pp.686-694.
3. Cartwright, S.R. & Williams, G.A. (2014). How hot for how long? The potential role of heat intensity and duration in moderating the beneficial effects of an ecosystem engineer on rocky shores. Marine Biology 161(9), pp.2097-2105.
4. Marshall, D. J., **Dong, Y. W., McQuaid, C.D.,** & **Williams, G.A. (**2011). Thermal adaptation in the intertidal snail Echinolittorina malaccana contradicts current theory by revealing the crucial roles of resting metabolism. *The Journal of experimental biology*, *214*(21), 3649-3657.
5. **Dong, Y.W.,** & **Williams, G.A.** (2011). Variations in cardiac performance and heat shock protein expression to thermal stress in two differently zoned limpets on a tropical rocky shore. *Marine Biology*, *158*(6), 1223-1231.

Helmuth

1. Kroeker K.J., Sanford, E., Rose, J.M., Blanchette, C.A., Chan, F., Chavez, F.P., Gaylord, B., **Helmuth**, **B.,** Hill, T.M., Hofmann, G.E., McManus, M.A., Menge, B.A., Nielsen, K.J., Raimondi, P.T., Russell, A.D. & Washburn, L. (2016). Interacting environmental mosaics drive geographic variation in mussel performance and predation vulnerability. *Ecology letters* DOI: 10.1111/ele.12613.
2. Matzelle, A., Sará, G., Montalto, V., Zippay, M. Trussell, G.C. & **Helmuth**, **B.** (2015). A biogenergeticks framework for integrating the effects of multiple stressors: opening a 'black box' in climate change research. American Malacological Bulletin 33(1):150-160.
3. Mislan, K. A. S., **Helmuth, B.,** & Wethey, D. S. (2014). Geographical variation in climatic sensitivity of intertidal mussel zonation. *Global Ecology and Biogeography*.
4. **Helmuth, B., Broitman, B.R.,** Yamane, L., Gilman, S.E., Mach, K., Mislan, K.A.S., & Denny, M. W. (2010). Organismal climatology: analyzing environmental variability at scales relevant to physiological stress. *The Journal of experimental biology*, *213*(6), 995-1003.
5. **Helmuth, B., Mieszkowska, N.,** Moore, P., & Hawkins, S.J. (2006). Living on the edge of two changing worlds: forecasting the responses of rocky intertidal ecosystems to climate change. Ann. Rev. Ecol. Evol. Syst. 37: 373-404.

Broitman

1. **Broitman**, **B.R.** Halpern, B.S., Gelcich, M.A., Lardies, S., Vargas, C.A., Vásquez-Lavín, F. Widdicombe, S. & Birchenough, S.N.R (2017) Dynamic interactions among boundaries and the expansion of sustainable aquaculture. Frontiers in Marine Science 4(15) doi: 10.3389/fmars.2017.00015
2. Aravena,G., **Broitman, B.R**. & Stenseth, N.C. (2014) Twelve years of change in coastal upwelling along the Central-Northern coast of Chile: Spatially heterogeneous responses to climatic variability**.** PLoS ONE 9(2): e90276. doi:10.1371/journal.pone.0090276
3. Valdivia, N., A.E. Gonzalez, A.E., Manzur, T. & **Broitman, B.R.** (2013) Mesoscale variation of mechanisms contributing to stability in rocky shore communities**.** PLoS ONE 8(1) e54159.
4. **Broitman, B.R.,** Szathmary, P.L., Mislan, K., Blanchette, C., & **Helmuth, B.** (2009). Predator-prey interactions under climate change: the importance of habitat vs body temperature.Oikos, 118(2), 219–224. doi:10.1111/j.1600-0706.2008.17075.x
5. **Broitman, B.R., Mieszkowska, N., Helmuth, B.,** & Blanchette, C. (2008). Climate and recruitment of rocky shore intertidal invertebrates in the eastern North Atlantic**.** Ecology, 89(11 Suppl), S81–90.

Krueger-Hadfield

1. **Krueger-Hadfield, S.A.,** Carmona, G.H., Terada, R., López-Vivas, J.M. & Riosmena-Rodríguez, R., (2016). New Record of the non-Native Seaweed Gracilaria parvispora in Baja California-A Note on Vergara-Rodarte et al.(2016). Cryptogamie, Algologie.
2. **Krueger Hadfield, S.A.** & Hoban, S.M., 2016. The importance of effective sampling for exploring the population dynamics of haploid–diploid seaweeds. Journal ofPphycology, 52(1), pp.1-9.
3. **Krueger-Hadfield, S.A.,** Roze, D., Correa, J.A., Destombe, C. & Valero, M., 2015. O father where art thou? Paternity analyses in a natural population of the haploid–diploid seaweed Chondrus crispus. Heredity, 114(2), pp.185-194.
4. **Krueger Hadfield, S.A.,** Kübler, J.E. & Dudgeon, S.R., 2013. Reproductive effort of *Mastocarpus papillatus* (Rhodophyta) along the California coast1. Journal of Phycology, *49*(2), pp.271-281.
5. Dudgeon, S., Benes, K.M., **Krueger Hadfield, S.A.,** Kübler, J., Mroz, P. and Slaughter, C.T., 2009. On the use of experimental diets for physiological studies of hydrozoans. Journal of the Marine Biological Association of the United Kingdom, *89*(01), pp.83-88.

McQuaid

1. Lathlean, J.A., Seuront, L., **McQuaid, C.D.,** Ng, P.T.P., Zardi, G., Nicastro, K. (2016). Cheating the locals: invasive mussels steal and benefit from the cooling effect of indigenous mussels. PLoS One 11 (3):e0152556.doi:10.1371/journal.pone.oi52556
2. Tagliarolo, M. & **McQuaid, C.D. (**2016). Field measurements indicate unexpected, serious underestimation of mussel heart rates and thermal tolerance by laboratory studies. PloS one, 11(2), p.e0146341.
3. Baldanzi, S., **McQuaid, C.D.,** Cannicci, S. & Porri, F. (2013). Environmental domains and range-limiting mechanisms: testing the Abundant Centre Hypothesis using Southern African sandhoppers. PLoS ONE 8(1): e54598. doi:10.1371/journal.pone.0054598
4. Teske, P.R., Zardi , G.I., **McQuaid, C.D.**, Nicastro, K,R. (2013). Two sides of the same coin: extinctions and originations across the Atlantic/Indian Ocean boundary as consequences of the same climate oscillation. Front Biogeogr 5: 48-59
5. Teske, P.R., Papadopoulos, I., Barker, N.P., Beheregaray, L.B. & **McQuaid, C.D.** (2013). Dispersal barriers and stochastic reproductive success do not explain small-scale genetic structure in a broadcast spawning marine mussel. Mar Ecol Prog Ser 482: 133-140.

Sarà

1. Giacoletti, A., Maricchiolo, G., Mirto, S., Genovese, L., Umani, M. & Sarà, G. (2017). Functional and energetic consequences of climate change on a predatory whelk. Estuarine, Coastal and Shelf Science, *189*, pp.66-73.
2. Montalto, V., **Helmuth, B.,** Ruti, P.M., Dell'Aquila, A., Rinaldi, A. & **Sarà, G.** (2016). A mechanistic approach reveals non linear effects of climate warming on mussels throughout the Mediterranean sea. Climatic Change, 139(2), pp.293-306.
3. Montalto, V., Rinaldi, A. & **Sarà, G.** (2015). Life history traits to predict biogeographic species distributions in bivalves. The Science of Nature, 102(9-10), p.61.
4. **Sarà, G.,** Rinaldi, A., & Montalto, V. (2014). Thinking beyond organism energy use: a trait□ based bioenergetic mechanistic approach for predictions of life history traits in marine organisms. *Marine Ecology*.
5. Matzelle, A., Montalto, V., **Sarà, G.,** Zippay, M., & **Helmuth, B.** (2014). Dynamic Energy Budget model parameter estimation for the bivalve *Mytilus californianus*: Application of the covariation method. *Journal of Sea Research*.

Harley

1. Gilbert, B., Tunney, T.D., McCann, K.S., DeLong, J.P., Vasseur, D.A., Savage, V., Shurin, J.B., Dell, A.I., Barton, B.T., **Harley, C.D.G**., Kharouba, H.M., Kratina, P., Blanchard, J.L., Clements, C., Winder, M., Greig, H.S., & O'Connor, M.I. (2017). A bioenergetics framework for the temperature dependence of trophic interaction strength. Ecology Letters 17(8), pp.902-914.
2. **Harley, C.D.,** Anderson, K.M., Lebreton, C.A.M., MacKay, A., Ayala-Díaz, M., Chong, S.L., Pond, L.M., Maddison, J.H.A., Hung, B.H., Iversen, S.L. and Wong, D.C., 2013. The introduction of Littorina littorea to British Columbia, Canada: potential impacts and the importance of biotic resistance by native predators. Marine Biology, 160(7), pp.1529-1541.
3. **Harley, C. D.,** Anderson, K. M., Demes, K. W., Jorve, J. P., Kordas, R. L., Coyle, T. A., & Graham, M. H. (2012). Effects of climate change on global seaweed communities. *Journal of Phycology*, *48*(5), 1064-1078.
4. **Harley, C.D.G.** (2011). Climate change, keystone predation, and biodiversity loss. Science 334:1124-1127.
5. Kordas, R.L., **Harley, C.D.G.,** & O'Connor, M.I. (2011). Community ecology in a warming world: the influence of temperature on interspecific interactions. Journal of Experimental Marine Biology and Ecology 400:218-226.

Dong

1. Chen, N., Luo, X., Gu, Y., Han, G., **Dong, Y.,** You, W. & Ke, C., (2016). Assessment of the thermal tolerance of abalone based on cardiac performance in Haliotis discus hannai, H. gigantea and their interspecific hybrid. Aquaculture, *465*, pp.258-264.
2. Giomi, F., Mandaglio, C., Ganmanee, M., Han, G.D., Dong, **Y.W., Williams, G.A**. & **Sarà, G.,** 2016. The importance of thermal history: costs and benefits of heat exposure in a tropical, rocky shore oyster. Journal of Experimental Biology, 219(5), pp.686-694.
3. Zhang, S., Han, G. D., & **Dong, Y. W.** (2014). Temporal patterns of cardiac performance and genes encoding heat shock proteins and metabolic sensors of an intertidal limpet *Cellana toreuma* during sublethal heat stress. Journal of Thermal Biology.
4. Han, G. D., Zhang, S., Marshall, D. J., Ke, C. H., & **Dong, Y. W.** (2013). Metabolic energy sensors (AMPK and SIRT1), protein carbonylation and cardiac failure as biomarkers of thermal stress in an intertidal limpet: linking energetic allocation with environmental temperature during aerial emersion. Journal of Experimental Biology, 216(17), 3273-3282.
5. Marshall, D. J., **Dong, Y. W., McQuaid, C. D**., & **Williams, G. A.** (2011). Thermal adaptation in the intertidal snail *Echinolittorina malaccana* contradicts current theory by revealing the crucial roles of resting metabolism. The Journal of experimental biology, 214(21), 3649-3657.

Fawzi

1. Abdul, A., **Al-Mudhafer Fawzi**, N.A., Alhello, A.A., Al-Saad, H.T. Al-Maarofi, S.S.. (2012). Restoration versus Re-flooding: Mesopotamia Marshlands. *Journal of Hydrology Current Research* 3: 1-6.
2. **Al-M Fawzi,N.,** Issam N. Fawzi & Hamid Al-Saad, (2010).Examining the condition of Iraq's water ways and their impact on the water quality of the North-Western Arabian Gulf. World Conference on Middle Eastern Studies in Barcelona, Spain (WOCMES 2010).

3. Al-Saad, H., **Al-M.Fawzi,** Al-Hello, A. (2008). Is the restoration program working for the Southern Iraqi Marshes? Water quality of Southern Marshes of Iraq, for the year 2008. Environmental Protection Council, Ministry of Health, Iraq.

4. Marsden, I., Wong, C. & **Fawzi, N. Al-M**. (2001). Assessment of an estuarine amphipod (*Paracorophium excavatum*) as a bioindicator of a contaminated sediment. The Australian Journal of Ecotoxicology.
5. Ba-Issa, A.A., Fawzi, I.N. & **Fawzi, N. Al-M**. (1995). Groundwater Pollution in Sanaá Basin. Environmental Protection Council, Ministry of Health, Iraq.