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

## Abstract

Climate change and ocean acidification currently lead the international research agenda for marine ecosystems. Increased awareness of the effects of additional pressures arising from human activities has also led to the emergent research priority of 'multiple stressors', a theme recognized within international policy requirements for assessments of impacts on marine biodiversity. Despite increased understanding that global scale drivers will interact in complex ways with regional to local scale stressors to affect marine ecosystems, most research programmes currently study stressors in isolation. The effects of climate change are likely to be more complex than suggested by the simple trends and averages presently recognised. Similarly, most ocean acidification research has focused on single species mesocosms or small-scale observational studies across unrealistically short timeframes. A more realistic understanding of long term ecological responses to environmental change and multiple stressors requires a multidisciplinary organisms-to-ecosystems approach.

The overarching objective of the INSHORE Working Group is to develop a standard, integrative framework and modelling tool that can be applied internationally for research into multiple stressor impacts on coastal marine ecosystems. This will be achieved by 1) creating a global database of relevant ecological, biological and environmental datasets 2) developing a multiple stressor dynamic biostressor envelope 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 benthic research community in an integrated scientific approach.

## Scientific Background and Rationale

### Scientific Background

Global climate change is now the milieu within which all biological, ecological and socio-ecological interactions must be positioned. The importance of a quantitative understanding of biological and physiological impacts of global change, and resultant changes to distributions and abundances of species within the marine environment is clear[1,2], with an emphasis on predicting "winners" and "losers" among commercially, ecologically and culturally important species[3,4]. Understanding how multiple stressors will alter resilience and sustainability of ecosystems is thus a priority for marine scientists working across molecular to ecosystem scales.

Species and ecosystems respond to multiple 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]. It is increasingly clear, however, that decadal-scale increases in mean climate are not the proximate drivers of organismal survival. Instead, vulnerability through mortality or sub-lethal performance and consequently species distributions respond more directly to shorter-term variation in environmental conditions including extreme 'climatic' events and anomalies[7,8]. Consequently, predictions may have little relevance for individual species, nor be appropriate for ecosystem status assessments at local to regional scales. Eutrophication studies suffer from similar problems of scale, being predominantly focused on localized coastal areas and results scaled up to produce 'regional' generalized trends[9]. Such extrapolation can produce misleading or incorrect biological impacts forecasts due to a poor understanding of the biotic response mechanisms to changes in water chemistry in different locations. 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 small, 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 such as eutrophication, which subsequently alter sublethal responses within the same species[10,11]. To avoid potential misinterpretations we propose that expectations of how climate, OA and eutrophication are likely to affect ecologically important species should be based on ecologically-functional trait based metrics over appropriate spatial and temporal scales[12-14]. Such predictions should emphasize how multiple stressors interact to drive local-scale processes, and acknowledge the often overriding importance of biological responses and interactions in determining patterns of vulnerability over multiple spatio-temporal scales.

**Rationale**

The proposed INSHORE (International Network for the Study of How Organisms Respond to Environmental change) Working Group will employ a multi-disciplinary 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. Using an organism-to-ecosystem perspective we will develop a multiple stressor version of a dynamic bioclimate envelope model (DBEM) and methodological best practice guide for data collection and analysis to enhance our understanding of the most important and appropriate aspects of the responses of coastal marine species and ecosystems to global change.

We recognize that scientists cannot account for every possible combination of environmental conditions when forecasting ecological responses to global change. Rather, 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[15]. To be effective, forecasts need to capture bio/eco-logically relevant stressor metrics[1,2,8,14,16,17], over appropriate spatio-temporal scales (10-100kms) applicable to the scientific research agenda and national and international policy drivers (e.g. EU Marine Strategy Framework Directive, Water Framework Directive).

The Working and Associate Group members will review existing climate and ocean acidification models alongside published experimental research and methodologies for climate, ocean acidification and eutrophication 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 One.

We will integrate detailed information on the mechanistic biology of species from experimental studies with molecular, physiological and ecological data[14,16,17,18], biogeographical time-series[8,19-21] and environmental datasets[22,23] within a macro-scale DEBM, sensu[24,25]. The DEBM will use these data to simultaneously estimate impacts of temperature, pH and nutrient levels on physiological performance, population dynamics, and dispersal to generate predictions of the impacts of multiple stressors on the biogeographic distributions of intertidal species. Model outputs will be created at a regional scale (100s km) within areas of the Atlantic and Pacific for which physiological, ecological, biogeographical and environmental data exist (e.g.[19,26]).

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[27] and are at high risk from multiple human-induced pressures, exhibiting some of the fastest responses to global change in any natural system[8,19].

The INSHORE Working and Associate Groups comprise researchers with international track records and ongoing research projects determining the impacts of climate change, OA and other human stressors on intertidal ecosystems. Expertise spans marine biodiversity time-series data collection and analysis (Mieszkowska, Russell, Lima), biogeography, macroecology and population ecology (Mieszkowska, Helmuth, Harley, Williams, McQuaid, Broitman, Fawzi, Chan, Christopholetti), physiological and behavioral experimentation (Russell, Sarà, Williams, Dong, McQuaid, Kroeker, Rilov) and modelling (Sarà, Helmuth, Williams, Mieszkowska), molecular transcriptomics (Dong, Williams), dynamic energy budget modeling (Sará, Helmuth, Williams), ecological climate impacts modeling (Broitman, Helmuth, Lima, Fawzi, Harley), climate and OA modelling (Broitman, Lima). Several 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 multiple stressor impacts research via an integrated, international approach is timely given the major findings of the 2014 IPCC Report on Impacts, Adaptation and Vulnerability[28] that $CO_2$ emissions are driving unprecedented changes in global marine climate and ocean pH, multiple stressors ‘impinge on resilience from many directions’ and may be ‘irreversible in terms of possible futures’. This knowledge gap with respect to marine ecosystems is also identified within the EU Marine Strategy Framework Directive[29]. Given these needs, this Working Group could be instrumental in leading a global, standardized approach to detecting, quantifying and predicting the impacts of multiple stressors 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 database 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, ocean acidification and eutrophication 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**

To achieve its goal INSHORE will:

(1) Integrate an international Working Group with expertise in physical, ecological, physiological and molecular sciences which will have the goal of developing a novel multiple stressor profiling model. This model will assess recent change and forecast future impacts of short-term weather and decadal-scale climate on biodiversity, functioning and resilience of rocky intertidal ecosystems.

(2) To initiate this model, the group will utilize their unique wealth of scientific and monitoring datasets as well as those collected by the wider global marine climate research community including existing data repositories (e.g. ICES, PICES, OBIS, EMODnet, Redmap) and time-series such as the UK MarClim dataset (led by CoChair Mieszkowska) and Pacific USA dataset (Broitman) to create a dataset of biogeographic distributions, species traits (e.g. thermotolerance), lifecycle dynamics and population abundances for rocky intertidal ecological-engineer species. These data will be entered into a purpose-built database and used to derive best practice methodologies and to develop and test the DBEM.

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

(5) Assessment of species-specific physiological performances and tolerances, changes to trophic interactions, and macroecological data on distributional range shifts and abundances will be integrated with the climate models in a context of IPCC AR-5 scenarios (2014) to develop a Dynamic Biostressor Envelope Model that will provide quantitative assessments of the future vulnerability of organisms and ecosystems to climate change.

(6) Finally, the 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. the Australian Representative Network of MPAs, UK Marine Conservation Zone and Special Areas of Conservation Networks, 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 Healthy and Biologically Diverse Seas Evidence Group, Marine Climate Change Impacts Partnership, Australian National Climate Change Research Facility).

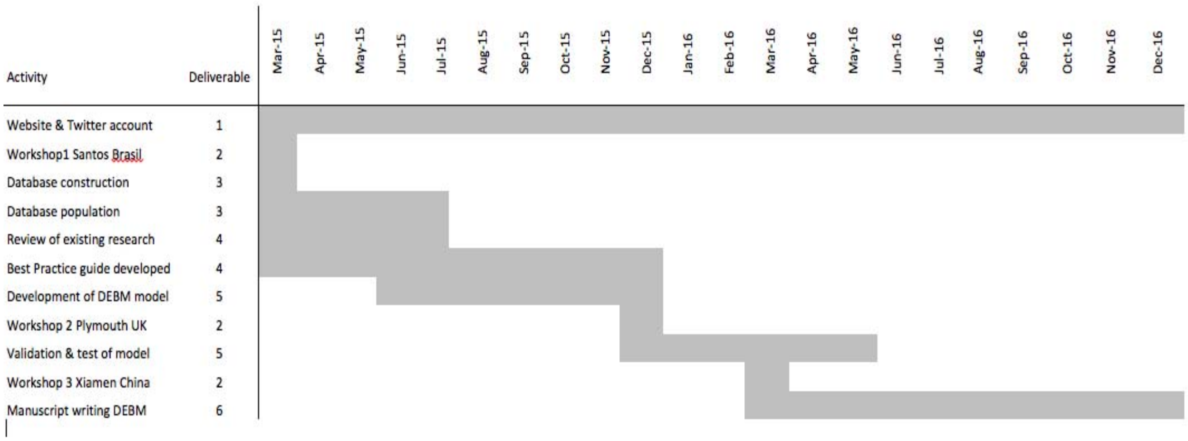
**Timeline**

The first INSHORE working group meeting will be a three day workshop and themed session held at the 'Third International Symposium on Effects of Climate Change on the World's Oceans', 23-27 March 2015 in Santos, Brazil. This meeting is coordinated by ICES and sister affiliations the North Pacific Marine Science Organization (PICES) and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). The driver is a recognized symbiosis between the oceans and society, underpinned by the role of science, and a need for the assessment of the consequences of climate change on the world's waters, ecosystems and living resources. The associated SCOR workshop will be organized by Co-Chair Mieszkowska and INSHORE Associate Member Christofoletti, from the conference host institute Universidade Federal de São Paulo, who will cover venue costs as an 'in kind' contribution. The workshop and themed session will be open to participation by students from Instituto do Mar and other registered participants of the conference.  Working Group members will present relevant research at the symposium and participate in the workshop.

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 held by, or accessible to the group (ToR 2, Deliverable 3), a review of existing climate models will be carried out (ToR 3, Deliverable 4) and a best practice guide for multiple stressor impacts research in coastal marine systems drafted (ToR 4, Deliverable 4). Presentations on the state of climate impacts modeling and availability of datasets for climate, OA and eutrophication at ocean basin, national and regional scales will be given by Broitman, Helmuth, Lima, Kroeker, Harley, Fawzi and Mieszkowska who are world-leaders in this field. Ecological responses to multiple stressors will be presented by Williams, Harley, McQuaid, Helmuth, Chan and Christofolettii. Williams, McQuaid, Dong, Sarà, Rilov and Mieszkowska will present work on molecular and physiological single and multiple stressor research. Discussions between the group members will include datasets to be incorporated into the new multiple stressor model and an agreed time-line for remote participation and delivery of data to the modelers.

A second workshop will be held at the end of 2015 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 developing DEBM model will be showcased at this workshop and the working group will test and validate the model using the metadatabase collated at the first workshop in Brasil (ToR 5, Deliverable 5). Between workshops two and three the review manuscript of the status of the marine multiple stressor research field will be written by the Working Group using cloud file sharing and virtual group working methods successfully employed by members for previous publications.

A final workshop will be held in early 2016 at Xiamen University, China, hosted by Working Group member Dong. Here the working group will test the final version of the model with datasets held by the Working Group and perform model runs targeted at regional scales relevant to management of adaptation strategies, harvest of commercially important species, and zonation and planning of Marine Protected Area networks. The working group will write a manuscript on the DEBM model using this case study for submission by the end of 2016 (Deliverable 6).




## Deliverables

The WG will provide a mechanistic approach to understanding how coastal marine species and ecosystems will respond to climate change, ocean acidification and eutrophication to challenge the paradigm of predictions based on existing time-series and physiological data from the ICES community and new, high resolution (10-100 kilometers) environmental data.

Specific outputs are to:

1) Launch a website and Twitter account providing information on the project activities, model outputs and links to related ICES activities.
2) Present Working Group expertise in multiple stressor research and promote the 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 multiple stressor model (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 international journal PLOS One.
5) Develop a novel DEBM multiple stressor profiling model and make the code available to the international marine research community.
6) Publish model codes and outputs in international journals (e.g. Ecological Modelling, Global Change Biology) highlighting the roles of climate, ocean acidification and eutrophication in shaping and changing intertidal ecosystems.

## Capacity Building

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, 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 facilitate continued 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).

The group will present their contributions to an integrated multiple stressor research perspective at the Third International Symposium on Effects of Climate Change on the World's Oceans in Brasil, and host workshops to develop the integrated methodology and associated multiple stressor profiling model in Brasil, China and the UK. The Brasil conference will be attended by PICES and ICES member nations 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 from host and local institutes will be invited to interact with the global Working Group at these events, and Working Group members will give presentations on this project at 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 DEBM model methodology and code 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.<br><br>Professor, College of Science, Northeastern University, USA | Ecological forecasting, physiological mechanistic responses to climate, thermal engineering technology, mathematical modeling. |
| 4 Bernardo Broitman | Male | Director, Centro de Estudios Avanzados en Zonas Aridas, Santiago, Chile<br><br>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 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. |
| 6 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. |
| 7Yunwei Dong | Male | Professor, State Key Laboratory of Environmental Science, Xiamen University, China | Physiological and molecular (transcriptomics, proteomics) responses of intertidal invertebrates to multiple stressors. |
| 8 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. |
| 9 Bayden Russell | Male | Southern Seas Laboratory, University of Adelaide, Australia | Experimental assessment of physiological changes and resultant ecosystem functioning due to eutrophication, $CO_2$, temperature through primary productivity and trophic interactions. |
| 10 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. |

**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 | | OA impacts on marine invertebrates. |
| 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. |

**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 experimetnal 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.

**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.

**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.

**Russell.** Expert in experimental testing of multiple stressor impacts on macroalgae and trophic interactions via development of state-of-the-art mesocosm systems. High impact publication record for climate change and ocean acidification impacts on macroalgae, with associated field and experimental datasets for Australia.

**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.

**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.

No current SCOR Working Groups are investigating global change multiple stressor impacts, but INSHORE will continue to monitor the activities of all Working Groups including WG137 that is collating large datasets on plankton distributions via an international database similar to the one planned for benthic species through INSHORE.

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27. Helmuth, B., Mieszkowska, N., Moore, P. & Hawkins, S.J., (2006). Living on the edge of two changing worlds: forecasting the impacts of climate change on rocky intertidal ecosystems. Annual Review of Ecology Systematics and Evolution 37: 373-404.

28. IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report http://www.ipcc.ch/report/ar5/wg2/

29. EU Marine Strategy Framework Directive http://www.msfd.eu/

**Appendix**

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

**Mieszkowska**

1. **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.
2. **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.
3. **Mieszkowska, N**., Milligan, G., Burrows, M.T., Freckleton, R. and Spencer, M. 2013. Dynamic species distribution models from categorical survey data. Journal of Animal Ecology 82(6) 1215-1226.
4. **Mieszkowska, N.** & Lundquist, C., 2011. Biogeographical patterns in limpet abundance and assemblage composition in New Zealand. Journal of Experimental Marine Biology & Ecology 400(1), 155-166.
5. **Mieszkowska, N**., M.A. Kendall, S.J. Hawkins, R. Leaper, P. Williamson, N.J. Hardman-Mountford & 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. 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.
2. Chan, B. K., Morritt, D., De Pirro, M., Leung, K. M., & **Williams, G.A.** (2006). Summer mortality: effects on the distribution and abundance of the acorn barnacle Tetraclita japonica on tropical shores. *Marine Ecology Progress Series*, *328*, 195.
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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.

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3. **Helmuth, B., Mieszkowska, N.,** Moore, P. and S.J. Hawkins. 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.
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**Russell**

1. Falkenberg, L.J., **Russell, B.D**. & Connell, S.D. (2013). Contrasting resource limitations between competing marine primary producers: implications for associated communities under enriched CO2 and nutrient regimes. *Oecologia*, 172: 575-583.
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