Meeting report

Predicting ecosystem shifts requires new approaches that integrate the effects of climate change across entire systems

Bayden D. Russell1,*, Christopher D. G. Harley3, Thomas Wernberg2,4, Nova Mieszkowska5, Stephen Widdicombe6, Jason M. Hall-Spencer7 and Sean D. Connell1

1 Southern Seas Ecology Laboratories, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia 5005, Australia
2 Australian Institute of Marine Science, 39 Fairyway, Craleys 6099 WA, Australia
3 Biodiversity Research Centre, University of British Columbia, 6270 University Blvd, Vancouver, British Columbia, Canada V6T 1Z4
4 UWA Oceans Institute and School of Plant Biology, University of Western Australia, Crawley 6009, Western Australia, Australia
5 Marine Biological Association of the UK, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK
6 Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL13DH, UK
7 Marine Institute, Marine Biology and Ecology Research Centre, University of Plymouth, Plymouth PL4 8AA, UK
*Author for correspondence (bayden.russell@adelaide.edu.au)

Most studies that forecast the ecological consequences of climate change target a single species and a single life stage. Depending on climatic impacts on other life stages and on interacting species, however, the results from simple experiments may not translate into accurate predictions of future ecological change. Research needs to move beyond simple experimental studies and environmental envelope projections for single species towards identifying where ecosystem change is likely to occur and the drivers for this change. For this to happen, we advocate research directions that (i) identify the critical species within the target ecosystem, and the life stage(s) most susceptible to changing conditions and (ii) the key interactions between these species and components of their broader ecosystem. A combined approach using macroecology, experimentally derived data and modelling that incorporates energy budgets in life cycle models may identify critical abiotic conditions that disproportionately alter important ecological processes under forecasted climates.

Keywords: climate change; ocean acidification; global warming; species interactions; ecosystem shift; productivity and consumption

1. INTRODUCTION

The role of global environmental change in altering marine ecosystems has received increasing attention over the past decade. Global sea surface temperatures have been warming at approximately 0.13 °C per decade since the current period of climate warming began in the mid-1980s [1]. Further, marine waters have absorbed approximately 30 per cent of CO2 emissions and many marine species are already being forced to cope with increasing ocean acidification in combination with rising temperatures and other anthropogenic stressors (e.g. eutrophication and over fishing) [1,2]. While there is now a substantive body of literature demonstrating some of the potential negative and positive effects of these combined stressors, the vast majority of studies currently focus on a single species and life stage and very few examine effects on species which play dominant structuring roles in ecosystems (e.g. herbivores [3]; habitat-forming species [4,5]). Knowledge of the physiological responses of individual species to environmental change and their limits to performance is an informative first step in understanding the possible effects of climate change [6]. Extrapolating these physiological effects on single life-history stages of individual species to generalize about changes in populations or ecosystems is, however, fraught with potentially large forecasting errors because it fails to take into account two important aspects: (i) the effect of altered environmental conditions across entire life cycles of the organism and (ii) the interactions of these species with other components of their ecosystem (e.g. trophic interactions). Yet experimental manipulations of complete life histories and whole ecosystems are often impractical, so an approach which combines experiments and modelling may be necessary.

To reconcile these issues, a workshop was convened at the University of Plymouth, UK, 28 June–1 July 2011, to identify gaps in the current research into the role of climate change in causing ecosystem shifts, how these shifts may be countered by adaptation of plants and animals, and to set future directions for linking seemingly disparate fields of research (e.g. physiology and macroecology). The workshop included a selection of international specialists spanning plant and animal physiology, experimental and broad-scale ecology, and ecosystem modelling.

2. INTEGRATING INFORMATION ACROSS LIFE STAGES

(a) Empirical experiments

Understandably, most experimental studies to date have focused on the most easily manipulated life stage of species, usually mature adults, to quantify physiological changes and early life stages (e.g. larvae and spores) for growth and development. However, adult stages often respond differently from earlier life stages and either, or both, may be responsible for regulating population growth and equilibrium population size. For example, it may be of limited predictive value to detect minor effects of increasing temperature on the adult stage of a species if it has higher thermal tolerances and/or lower body temperatures than the juvenile stage (e.g. [7]). Conversely, altered mortality of the early life stages may be trivial if recruitment rates are more than sufficient to saturate adult habitat (e.g. [8]).

In addition to this current narrow focus, the perceived necessity of having significant biological differences among treatments in order to publish has meant that experimental conditions are often manipulated to
unrealistic levels (e.g. CO₂ of greater than 1500 ppm, acute temperature gradients greater than 20°C) to
detect an effect on the more robust adult life stages. While such extremes are informative about the tolerance
limits of the species in question, their use neglects to
detect smaller biological effects that may have multi-generational effects in populations. Further, these extreme
manipulations may not reflect real changes to conditions
over the next century. For example, mature marine mol-
luscs may survive temperature increases within what is
predicted in the next 100 years [9,10], yet if increased
temperatures within this range cause altered reproductive
capacity that is not identified in short-term experiments,
then potentially important population and ecosystem
effects may not be predicted. One way to potentially over-
come this issue would be to identify the energy budget of
animals and how they allocate resources to different bio-
llogical processes. This should then identify if individuals
are changing their allocation of energy to ensure maxi-
mum survival in altered environmental conditions at the
expense of, or benefit to, other processes important to
population dynamics, such as gonad development [11].

(b) Multi-life stage models
Identifying the stage in the life cycle which is most sus-
ceptible to changing environmental conditions can be
challenging, yet necessary to discover where population
effects may occur and any appropriate management or
conservation actions to counter them. Detection of an
effect of predicted future conditions (e.g. increased
CO₂ and temperatures) with empirical experiments
does not necessarily demonstrate that a particular life
stage is the most susceptible to these conditions or that
impacts on this life stage will alter population size
unless experiments are conducted across all of the life
stages and these life stages are integrated into a complete
development. Demographic population models incorpor-
ating all life cycle stages, which force different scenarios
of environmental conditions, can be useful tools to
identify which life stages are most susceptible and how
this susceptibility may respond to different combina-
tions of stressors. For example, time-series data for
co-occurring species of warmwater, coldwater and
non-native barnacles in the UK have been used to
build population models which show alternate responses of
the species to changing conditions; the coldwater
Semibalanus balanoides is directly affected by tempera-
ture, with pre-recruitment larvae being the most
susceptible stage, whereas the warmwater Chthamalus
montagu and Chthamalus stellatus are predominantly
controlled by competition for settlement space. Impor-
tantly, the invasive Austrominius (Elminius) modestus is
least likely to be affected by temperature or acidification,
owing to its wide thermal and pH tolerance ranges
[12,13], suggesting that a community shift is likely
under future conditions. We suggest that this compara-
tive approach between interacting species is one of the
next key steps in identifying potential ecosystem shifts
driven by changing environmental conditions.

4. OUTCOMES AND CONCLUSIONS
There is clearly a need for research into the potential
effects of climate change to move beyond studies of
single species and towards identifying where ecosystem
change is likely to occur and the drivers for this change.
The derivation of conceptual models that can be tested
across multiple coastal systems globally will also help to
address the current problem faced by studies of regime
shifts; namely that although detection of past shifts is
improving with the benefit of time-series spanning
multiple trophic levels, it is still not possible to predict
when and where future events may occur [23]. For this
to happen, we advocate two directions of research: (i)
identifying the critical species within the ecosystem in
question, and the life stage(s) which is most susceptible
to changing conditions and (ii) the interactions of these
species with other components of their ecosystem (e.g.
increased or decreased consumption, whether individual
or population-based). A combined approach using
macroecology, manipulative experiments and modelling,
incorporating energy budgets in life cycle models,
may identify points where critical biological processes
are strongly altered at predicted future conditions.

3. CASE STUDY
Variation in abundance of ecosystem dominants (e.g.
kelp forests and coral reefs) reflects a balance between
Importantly, bringing this group of researchers together from seemingly disparate fields revealed consensus on the need for the field to progress beyond single-species studies. We advocate that with a combined approach it may be possible to predict likely ecosystem changes before reaching what is currently thought of as critical thresholds that are notoriously difficult to predict.

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