2012 Yeosu Workshop on "Climate Change and Range Shifts in the Oceans: Detection, Prediction and Adaptation"

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A 1-day workshop on "*Climate change and range shifts in the ocean: Detection, prediction and adaptation*" was convened on May 20, 2012, immediately after the 2nd International Symposium on "*Effects of the Climate Change on the World's Oceans*" held from May 15–19 in Yeosu, Korea. Over 40 scientists, resource managers and policy advisors gathered to explore issues associated with ecosystem level impacts arising from the increasing frequency of species shifting their range.

Climate change driven changes in the phenology, distribution and abundance of marine species are being reported around the globe[1-3]. Range shifts in marine taxa have been described for waters around all continents, including Antarctica, and the Pacific Islands[4]. Distributional changes are the most commonly reported, sometimes involving shifts of 100's of km. Changes in exploited species may subsequently affect the utilization of marine resources with ramifications that range from fishers' profitability and livelihoods to food security, poverty and social cohesion[5-7]. Despite this importance, there are currently limitations to the detection and prediction of range shifts. Overcoming these limitations is critical for policy adaptation to manage shifting marine resources in order to enhance food security[8] and minimize negative socio-economic consequences. Additionally, range shifts will not occur uniformly around the world as climate change is not impacting all areas equally. Regions where ocean warming is occurring most rapidly (marine hotspots) represent an opportunity to quickly advance our understanding of current and likely future changes.

The un-replicated nature of species' range shifts renders attribution of causality notoriously difficult[9]. However, some 75% of marine range shifts reported in the peer-reviewed literature have been polewards in direction – symptomatic of broad-scale environmental changes such as those predicted under global climate change scenarios[4]. In light of even the most conservative future climate change projections[10], coupled with the available evidence that climate change is likely responsible for shifts in many species' biogeographic ranges, more research is needed to understand the full extent of realized and potential future range shifts in marine taxa, and in particular, the role that climate change plays in these shifts[10]. Because range shifts affect the distribution and abundance of harvested marine resources, as well as the dynamics of the ecosystems that underpin the productivity of marine resources, examining the diverse consequences of climate change-induced marine range shifts is critical. Although range shifts have been documented in the marine environment, far fewer studies consider the mechanisms of range-shifting dynamics[11,12], and even fewer the socioeconomic consequences or optimal management responses[13]. Likewise, the appropriateness of existing or potential management responses has not been comprehensively explored[14]. As the climate continues to change, range shifts driven by this globally ubiquitous process will likely broaden in both number and geographic extent. Considering the ecological, socioeconomic, and management implications of these changes before they occur is essential to mitigating the negative effects of the global redistribution of species and for developing effective adaptive response strategies and to seize opportunities.

The ultimate aim of the workshop was to draft a manuscript assessing ecosystem-level impacts of the increasing frequency of single-species range shifts, and evaluating our capacity for prediction and adaptation to these likely impacts. In doing so, we will develop a conceptual framework that links the responses of science, management, policy and governance to shifting marine resources at relevant spatial and temporal time scales. This is a necessary task to lay the groundwork to develop contextually relevant response strategies to ensure sustainable resource use, management and food security under a changing climate. The workshop had three objectives (Fig. 1), achieved through break-out sessions involving small group work:

1. Identify the key biological and ecosystem responses to increasing range shifts;
2. Determine the possible impacts (negative or positive) that will result from various responses;
3. Highlight potential adaptations in the human-system that may minimise impacts or maximise opportunities arising from range shifts.

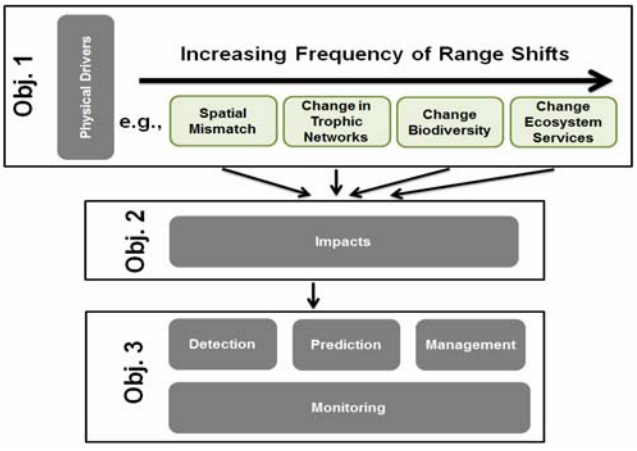

Fig. 1 Aims of the range shift workshop.

To set the scene for the day, three talks were prepared by the convening team building on the themes of detection, prediction and adaptation.

Detection: Thomas Wernberg began with a presentation outlining methods to quantify climate-driven range extensions and contractions at different time scales, and highlighting several important issues associated with the detection of such responses. While species distribution changes are the most commonly detected, and subsequently reported, response to climate change, within assemblages, only ~30 to 80% of species present have been observed to shift in a polewards direction with increasing environmental temperature (Fig. 2). Moreover, of the species that have shifted, the rate of range extension towards the poles (leading range boundary), or contraction away from the equator (trailing range boundary), varies in both space and time. However, it is currently unknown how much of the variability in range response between species and at different scales is a product of our capacity to detect range shifts in the first place. Are the generic biological monitoring programs that are presently underway sensitive enough to detect climate-forced distributional changes? By identifying knowledge gaps in the methods used to detect range shifts over space and time, we can rethink monitoring strategies in a range shift context to optimize prediction capabilities and therefore, be pro-active about resource management required as range shifts occur.

Prediction: Alistair Hobday then presented a talk about the role and potential of monitoring and modelling in predicting species range shifts in the ocean. Detailed investigation of ocean warming hotspots, or regions of rapid warming, can advance our understanding of climate-driven distributional change in marine species, and indicate to what capacity we may be able to predict biological responses. This presentation highlighted the various modelling approaches to predict species' vulnerability to ocean warming at both trailing and leading range boundaries. Several discussion points were raised, such as whether it is possible to gather the data required to identify species traits or parameterize species-specific models for entire assemblages in order to compare the shifting potential of different species within the timeframes required to implement adaptation strategies. How 'typical' prediction approaches can be supported by real-time monitoring to provide critical baselines and early identification of shifting species to enable timely human responses to range shifts, was also discussed.

Adaptation: Warwick Sauer introduced the topic of adaptation, highlighting the possible responses that could be undertaken in the human system in terms of marine resource management, policy and governance. Distributional changes in exploited species may affect the utilization of marine resources, with ramifications that range from fishers' profitability and livelihoods to food security, poverty and social cohesion. Thus, contextually relevant response strategies to ensure sustainable resource use, management and food security should be robust to uncertainty in both detection and prediction of species shifts. The group subsequently explored the question of whether emerging trends in biological data sets are sufficiently reliable to enable management and policy actions to be taken even in the absence of higher confidence limits.

The final discussion session focused on several key issues that were raised throughout the day in the smaller break-out groups, and included questions such as:

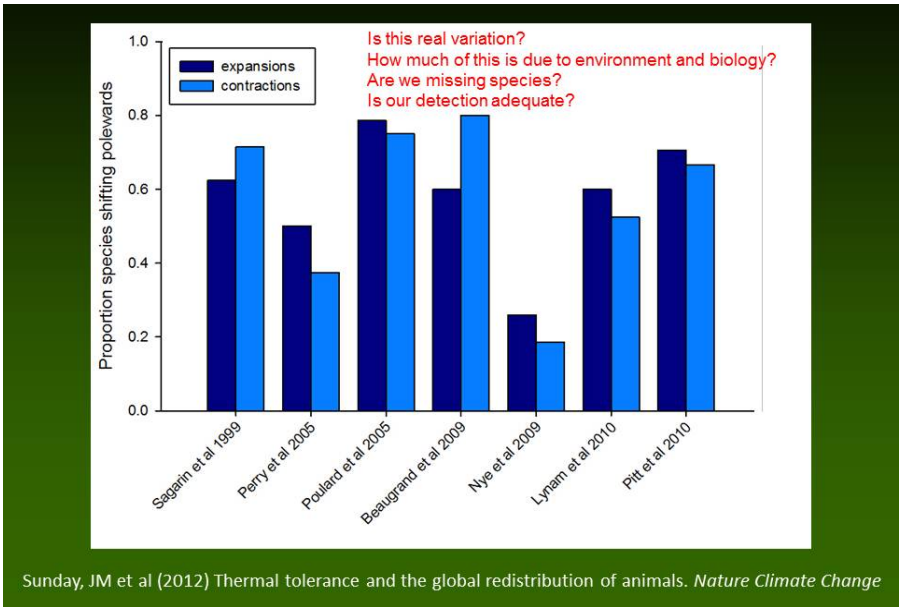

Fig. 2 The proportion of species identified as shifting polewards, from a variety of studies around the world, is highly variable. Some of this is most probably genuine variation in the assemblage level responses due to temporal and spatial patterns in environmental factors and differences among species in their biology. However, some of this variation may also be associated with particular sampling approaches and our capacity to detect range shifts in particular species[15].

Fig. 3 Four evidence-based approaches to the detection of single-species range shifts in marine systems.

1. What will be the major implications of increased frequency of range shifts for ecosystem goods and services?
2. Will there be differences among trophic levels or marine systems in their resilience to range shifts? Can we expect different trophic levels or marine systems to display different levels of responsiveness to climate warming?
3. Are regions experiencing high rates of range shifts likely to be more unpredictable?
4. Can we predict what increasing 'tropicalisation' of temperate systems will look like? And what is a better general term than 'tropicalisation' that applies to all ecosystems, *e.g.*, polar regions becoming more temperate?
5. What human activities will magnify range shifts?

The workshop participants represented an inter-disciplinary team from around the globe and were successful in their endeavor to identify knowledge gaps in the detection and prediction of range shifts at different temporal and spatial scales. Adaptation responses to the predicted changes should be robust to uncertainty in both detection and prediction, and shared experience is critical to minimize independent adaptation failures.

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