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Report of the Workshop on Global Assessment of the Implications of Climate Change on the Spatial Distribution of Fish and Fisheries (WKSICCME-Spatial)

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Executive summary

The ICES-PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME) workshop on changes in spatial distribution (WKSICCME-Spatial) took place on 22–24 May 2013 in St Petersburg, Russia. The workshop was attended by 67 scientists from 13 nations as well as representatives from ICES, PICES and the FAO. The workshop was chaired by Anne Hollowed (USA, PICES), Suam Kim (Korea, PICES) and Myron Peck (Germany, ICES). The workshop was convened to foster the development and testing of analytical methods for detecting changes in distribution, assessing the skill of different modelling approaches, and quantifying uncertainty in projected changes. Other important topics were how best to design a global database of marine observations and the strategies used to assess vulnerability (of resources and those that depend upon them) to shifts in distribution.

The workshop had six theme sessions: 1) Analytical methods for detecting changes in spatial distribution, 2) Skill assessment and model intercomparison, 3) Quantifying uncertainty, 4) Design specification for database of observations of distribution of living marine resources, 5) Vulnerability assessment, and 6) Communicating outcomes to inform decisions regarding management of living marine resources under changing climate. Each session had 1 or 2 keynote speakers and 3 breakout group leaders, the latter guided participants through a set of predefined discussion questions. Group leaders summarized discussions in plenary. The following provides a very brief overview of key discussion points and findings in each session:

Session 1: Changes in distribution have been assessed using a variety of approaches tailored to fit the scale of the question. Comparing different approaches within the same system is needed. Responses at the center, leading and trailing edges of a species' distribution may vary and fisheries oceanographic (process) studies are needed to verify mechanisms. Tagging and fish behaviour studies need to be revived.

Session 2: Skill assessments of modelled responses at the base of the marine foodweb have been aided by the availability of satellite data, while those at upper trophic levels remain more challenging due to gaps in observations. It is important to identify life-history bottlenecks to guide auxiliary surveys for model verification. The attribution of climate change impacts will be advanced by developing and applying techniques to disentangle the effects of multiple drivers.

Session 3: Short-term projections (now casts) provide an opportunity to test assumptions but users must be informed about the uncertainty of projections. For biological models, both within (sensitivity analysis) and between (ensemble) model comparisons are needed. There is a need to identify regions where multiple modelling approaches have been developed and compare them after finding a "common currency".

Session 4: There is a need for an aggregated database of fishery-independent and fishery-dependent data collected at a higher-resolution in time and space than existing databases. This database will be challenging to compile and is best supported by national or international institutions. Given the nature of these datasets (e.g. non-standard, gear, region, design specificity), it is important data collection experts remain engaged.

Session 5: ICES and PICES are uniquely placed to provide vulnerability assessments of climate change impacts on living marine resources. There are pros and cons to performing both quantitative and qualitative assessments. When possible, applying

vulnerability, statistical and dynamic simulation modelling to the same problem is recommended.

Session 6: Managers need clearly communicated, concise and reasonably accurate advice. Management strategy evaluations illustrating the implications of policies and actions on the future state of nature will be useful. A variety of fruitful communication pathways exist (from report cards, status reports, and peer-reviewed publications) and evaluations that summarize suites of products for decision-makers can be effective.

Manuscripts stemming from each session of this workshop will form a special volume or theme section of a peer-reviewed journal. Those manuscripts will include recommendations of methods to apply to assess regional and latitudinal differences in the vulnerability of species or species groups to climate change induced shifts in ocean conditions. An additional recommendation is to create a synthesis of climate-driven changes in distribution (by creating new, merged datasets and applying novel methods in specific case studies). The future activities discussed at the WKSICCME-Spatial will better inform future decisions regarding the governance and management of marine resources in light of climate change and variability.

1 Opening of the meeting

The three-day workshop was opened with a presentation by Anne Hollowed (USA, PICES) that extended a warm welcome on behalf of ICES, PICES and the other co-conveners to the 67 participants (see Annex 1). Each participant briefly introduced themselves and their expertise. The goals and terms-of-reference of the workshop were reviewed (see Annex 2) and the agenda (see Annex 3) was discussed. A relatively novel format was used in each of the six scientific theme sessions. Each session contained 1 to 2 keynote presentations immediately followed by separation into three groups. Each group was provided a list of questions and the discussion was moderated by a breakout group leader. The three breakout group leaders summarized discussions within plenary. The terms of reference were adopted and the first scientific session was introduced.

2 Session Summaries

2.1 Session 1: Analytical methods for detecting changes in spatial distribution

Leaders: Franz Mueter (USA, PICES), Brian MacKenzie (Denmark, ICES), and William Cheung (Canada, PICES).

2.1.1 What types of statistical methods and summary measures (e.g. spatial gams, simple means, bio-climatic windows, centroids, other) have been employed to quantify changes in distribution? What are the strengths and weaknesses of these methods?

A number of simple summary statistics can be calculated based on existing in situ data (FM presentation: centroids, ellipses, range limits), all of which have benefits and drawbacks. The former include simplicity of calculation and ease of interpretation, the latter include that they ignore spatial complexity and they lack mechanisms. Bio-envelope models (BEMs) and variants have often been employed to project possible changes. Current BEMs can typically be defined and mapped and these maps are good for communicating results. However, existing bio-envelop model outputs do not include species interactions (e.g. Cheung *et al*. 2009, 2010, 2012, etc.) and, thus, place no limit on future abundance in a given area. Also, BEMs assume that species moves if 'envelope' moves, which may not be true in many cases (e.g. when temperature is not the overarching driver).

Neither simple summary statistics, or BEMs can distinguish range shifts from differential changes in local production (requires process studies).There is a great deal of literature, some in marine systems (Petitgas *et al*. 2012) discussing how range shifts do not necessarily mean “migration” but rather differential changes in local productivity. Understanding the mechanisms is thus important. For example, density-dependence may interact with environmental factors to establish patterns of species-specific responses. In most cases, it is unknown how density will affect the displacement of species from an area or the expansion of species into new areas. Furthermore, baring information on all species, it is likely prudent to distinguish different species types such as those tightly linked to (structural) habitat (e.g. reef species), habitat-independent species (e.g. mackerel) or habitat-dependent but capable of using many habitats (e.g. anchovy, pollock).

All methods depend on adequate surveys and surveys do not always cover the full distribution area so that important changes occurring at the edges of distributions are likely to be missed. Fisheries data can complement survey data ('presence' only data) and it is important to note caveats of using different data sources (e.g. catch data may include both biological processes and changes in fishery practices and non-target species may not be recorded. Catch data consist of 'presence only' data: methods in terrestrial literature are available to deal with presence data Terrestrial researchers often use presence/ absence data – approaches for to defining distributional range can be adopted.

2.1.2 What dynamic simulation methods have been applied to forecast changes in distribution? What are the strengths and weaknesses of these methods?

At the moment, bio-climate envelope modelling is the prominent tool to forecast changes because of it capabilities. The lack of species interactions in the basic algorithms is an issue, which has recently been addressed through carrying capacity limits (Fernandes *et al*. 2013) and the fact that these models are deterministic are challenges to be surmounted. Possible solutions include classifying species within a particular region based upon their degree of association with particular, local habitats (e.g. habitat-free, habitat-flexible or habitat-linked). Also, considerable literature exists on terrestrial models of species abundance distribution and community distribution which may not be fully exploited by the scientists examining aquatic / marine systems.

Inverse linear models employed successfully by the climate modelling community may also work well for models of fish. Both statistical and dynamic approaches to forecasting require survey data that may have problems: short time-series, selectivity issues, changes in gear, probability of detection may change! Also, both approaches assume stationarity in observed relationships, which may be violated. However, apparent non-stationarity may merely due to lack of understanding of the mechanisms – hence mechanisms need to be understood.

2.1.3 What mechanisms can explain observed shifts in distribution? How can these mechanisms be implemented in predictive models?

A number of mechanisms may be responsible for shifts in the distribution of marine fish and other living marine resources. These include behaviourally mediated movements in response to environmental changes to maintain individuals within preferred ranges of environmental conditions (temperature, salinity, etc.). Fish have “memory” and many species make seasonal migrations to summer feeding and overwintering grounds, spawning grounds, etc. These seasonal migrations have been incorporated within full life cycle models developed for key species in both the Pacific (see Ito abstract) and Atlantic (see work by Huse, IMR, Norway). Changes in local productivity due to changing in environmental conditions (e.g. increased productivity at northern edge, decreased productivity in South) can also occur (Petitgas *et al*. 2012). Changes in productivity are difficult to distinguish from movement with existing surveys but coupled lower and upper trophic level models can provide spatially explicit estimates of productivity, particularly for species that are zooplantivorous (small pelagic fish).

Stochasticity needs to be incorporated within dynamic models such as old / young fish making the right / wrong migration decisions (blue whiting - Payne *et al*. 2012). It is also important to realize that a response of a species to a particular cue does not mean that the response is reversed when the cue is reversed. Thus, non-reversible changes and/or hysteresis may be important elements to incorporate within model frameworks. A second mechanism that is poorly considered within predictive models is adaptation (phenotypic or evolutionary).

There is a need to strike the correct balance between generality and specificity within models to make them reliable but not overly complicated? Some practitioners believe that generic models are only valid in some instances (at some temporal / spatial scales) while in other instances, full life-history modelling of species is the best approach to identify the processes acting at different stages and the important environmental cue / factors (Peck *et al.*, 2013). Are there bottlenecks that determine non-linear response (e.g. disruption of migration)? Also, mechanisms and types of responses will differ among (for example) coastal, shelf, and oceanic species and among other habitats and life-history types: their response to climate change will differ as the scales of operation change as well.

2.1.4 Can observed shifts be attributed to climate variability and / or climate change? Is it possible to disentangle the effect of fishing from the effects of climate variability and change?

Observed shifts in the distribution of living marine resources can be attributed to changes in climate variability but, to date, there is no unequivocal attribution to climate change. This is partly due to a lack of standardized surveys that have been conducted for a long enough period of time and the difficulties of disentangling effects of different drivers, but primarily because climate models indicate that the climate change signal is not expected to dominate over the climate variability signal until ca. 2040. Fishing as a driver has typically been incorporated in form of a total catch series, but there is a need to include the spatial footprint of fishing to understand effects, explore adaptation patters and reveal efficient practices. For example, if fishing truncates the age structure of populations, and a truncated age structure increases the sensitivity or responsiveness of a species to environmental change, would it be important to maintain a specific age-structure?

2.1.5 What additional data, process studies, and theoretical developments would help to resolve the mechanisms and their functional form?

Theoretical work is ahead of experimental work in terms of process understanding. There is a need to test theoretical predictions with empirical data. Examples are needed where we link the output of projection tools with historical observations. Furthermore, we need to develop methods to evaluate models with relatively sparse data. One possibility is to develop models for a given species in one region and examine whether they predict distribution of the same species in other regions ('portability') Finally, intercomparisons of models need to be made. Even models based on the same principles (e.g. bioclimate envelopes) have very different responses (Jones *et al*. 2012), which makes the assessment of impacts largely driven by model structures.

These modelling tools are, in many respects, only as reliable as the observations and process knowledge used to build them. There is a basic need to identify (and maintain) long time-series of survey data with good spatial coverage. With this in mind, better data are needed on to understand seasonal changes in distributions to interpret distributional patterns in once- or twice-a-year surveys. Furthermore, it is critical to examine changes in spatial distribution occurring at the limits of the distribution of a species to better understand the underlying processes. Finally, economic data are needed for modelling the distribution of fisheries.

2.1.6 If you had the funds and international agreements what type of experiment would your group develop to assess projection skill, resolve mechanisms, and enhance our ability to evaluate attribution to climate variability and change?

The following is a list of recommendations based upon breakout group discussions in session 1:

- Learn from the climate modelling community: standard scenarios, model intercomparisons, ensemble runs.
- Need data to assess projection skills, and better use of existing regional data.
- Explore the scale of projections: Different models are better predictors of processes at different spatial and temporal scales? Conclusions must recognize modelling strengths and limitations in relation to scale.

2.2 Session 2: Skill Assessment and model intercomparison

Leaders: Miranda Jones (UK, ICES), Mark Payne (Denmark, ICES), Enrique Curchitser (USA, PICES)

A number of key ideas were born from discussions of skill assessment and model intercomparisons. First, a model can only be addressed in the context of the question being asked (e.g. is the model "fit for purpose". Second, validation needs to be matched to the same spatial and temporal scale as the question being asked. Various techniques of assessing the skill of models and examples of model intercomparisons were provided by workshop participants.

2.2.1 Have skill assessments been performed in your region? Describe the methodology.

Workshop participants provided a short list of examples of skill assessments.

Stocks	Modelling Approach	Skill Assessment Method	Reference
Pollock (Gulf of Alaska)	Hindcast: ROMS+NPZ+IBM	Pattern matching	Hinckley *et al*. 2001
	Hindcast: Dynamic diffusion + behavior	Pattern matching	Kimand Kendall 1989.
Krill (California Current)	Hindcast: ROMs + NPZ	Pattern matching (spatial, temporal and link to top predators	Jeff Dorman (UC Berkeley) *et al*.
NPZ (California Current)	Downscaled GCM + NPZ	Timing and size of blooms	In Prep
HAB Alexandria (Northwest Atlantic)	Hindcast / Forecast	Iterative forecast	McGuillicudy (2010)
North Sea Plaice	Dynamic Energy Budget	Pattern matching	Teal *et al*. (2012)
30 Fish Spp. (North Sea)	Bio-climate Envelope	Area Under the Curve	Jones *et al*. (2012)
Japanese Sardine (Oyashio-Kuroshiro)	Downscaled GCM + NPZ + Fish	Mechanisms	Ito (see abstract Annex 5)

Stocks	Modelling Approach	Skill Assessment Method	Reference
Forage Fishes (Global)	Downscaled GCM + NPZ + size spectrum	Matching observed and predicted slopes	Blanchard *et al*. 2012 Polovinia and Woodward-Jeffcoats 2013 Watson *et al*. 2012
Plankton Blooms (East Japan Sea	Climatological hindcast: ROMS +NPZ	Pattern Matching: satellite data to assess Timing and bloom distribution	In Prep

Examples for the North Sea and Barents Sea compared GLMs, GAMs, regression trees. In the North Sea case, large variations in projections of three different bioclimate envelope models were found for fish species in the North Sea (Jones *et al*. 2012), although all models performed well according to the test statistics (Area Under the Curve value). Similar results have been produced using different methods in the Barents Sea.

There are different options for assessing model skill. For example, one can consider skill mechanics of model outputs (how well are specific processes captured within the distribution models). A second, useful approach is to keep data out of the model fitting procedure and sample them later for validation. Finally, the mean square error was recommended as a skill indicator as well as residual analysis of model outputs.

In summary, there has been considerable work on lower trophic levels but advances are needed for comparisons of higher trophic levels.

2.2.2 Climate impacts differ by life stage and the impacts are compounded over time. Which life stages should be used to assess predictive skill with respect to shifts in spatial distributions of the resource and fisheries?

This depends upon the mechanism of action behind shifts in distribution. Where processes affecting recruitment are involved, it is essential to sample life stages early life stages. Although some long-term ichthyoplankton surveys exist (CalCOFI, western European shelf mackerel survey, North Sea herring survey, etc.), surveys on young-of-the-year (YOY) juveniles are largely lacking. Assessing the growth and survival of juveniles may be particularly important to gauging recruitment strength and resolving changes in local productivity from shifts in the distribution of a stock. An example was provided for the distribution of YOY walleye Pollock in the Bering Sea that coupled fish condition (growth bioenergetics) and recruitment.

In particular, whole life cycle models are needed to examine climate-driven bottlenecks in life cycle closure.

2.2.3 Identify regions where more than one projection modelling approach has been conducted. How different were the projections and why?

A short list of approaches included:

- Sardine – California Current
- NEMURO Fish – Northwest Pacific
- FEAST – Bering Sea
- Herring – North Sea
- 30 fish species – NE Atlantic Shelf + North Sea
- Cod/Sprat/Herring – Baltic Sea

- Capelin – Barents Sea
- Size based community assessments – 29 LMEs (Blanchard *et al*. 2012)

2.2.4 If you had the funds and international agreements what type of experiment would your group develop to assess projection skill, resolve mechanisms, and enhance our ability to evaluate attribution to climate variability and change?

The breakout groups agreed that the type(s) of experiment(s) depended upon where climate change imposes the most severe bottleneck in the life history of target organisms (e.g. overwintering success, match–mismatch for first-feeding, disruption of spawning activity, etc.). This might be determined by the construction of Paulik diagrams (correlation breakdown plots for multiple life stages). For comparisons among regions, the selection of key time periods will be more complicated in tropical or subtropical waters where multiple spawning events occur throughout the year, however, in general – spring and fall sampling of ichthyoplankton/juveniles would be useful. Larvae stages are likely modelled with greater skill than later life stages where behavior influences distribution and because of the interplay between growth and reproduction. For example, adult temperature preference during feeding is often much broader than that during spawning (Pörtner and Peck, 2010). Emphasis should be placed on advancing models of later life stages to gain a mechanistic understanding of such phenomina. Another, broader point of comparison would be to understand niche conservatism in terms of climate-driven changes in foodweb dynamics.

2.2.5 What initiatives should ICES and PICES advance to facilitate progress on skill assessment and model intercomparison?

To the extent practicable, workshop participants suggested that biological modelers follow practices currently employed for climate modelling for evaluating hindcasts with contemporary observation. Key elements include assessing model skill in terms of spatial and temporal patterns (e.g. by calculating EOFs). However, there are fundamental differences in the choices made in spatial and temporal resolution of models (particularly in IBMs) and one must consider the course scale of resolution of biological observations and whether observation offer a reasonable representation of populations. Moreover, it is critical to consider that biological response to climate change may result from a complex set of processes and models that have both process and structural uncertainty may offer numerous possible solutions – thus the true functional relationships are more difficult to identify.

An important point within biological modelling is that a common currency is needed to make regional comparisons and within region inter-model comparisons. Adopting climate modelling approaches for biology will require assessment at more than one time and of spatial density and overall abundance. Also, the development of mechanistic models is considered critical, particularly if one wishes to extrapolate beyond observed, historical ranges in key drivers. Hence, statistical models that incorporate mechanistic understanding can be useful tools for projecting climate change impacts on the distribution of fish. Modelling the responses of zooplankton to climate appears to be a bottleneck in the development of coupled lower and upper trophic level models as well as the development of full life cycle models of key species.

Ensemble modelling of biological responses was encouraged. Unlike physics models that may differ more subtly in parameterizations or structures, a variety of different biological models are currently employed and models may have little in common. Finding a set of underlying approaches and biological principles in models which can project changes in distribution of living marine resources (conservation of mass in

Ecosim, common physiological mechanisms within dynamic bioclimate envelope models) would facilitate comparison. On the other hand, comparison models of different structure may be important for a "weight of evidence" approach. Therefore, ensemble modelling could apply 1) multiple biological modelling approaches, 2) within model ensembles (sensitivity analysis), and 3) multiple modelling approaches (ensemble of ensembles of different ecosystem models). The latter is particularly important because it allows one to gauge whether the uncertainty of the group projection is lower than that stemming from the projection of any single model. The danger is amplifying the common bias of a GCM. In terms of different types of modelling, it was important to remember the outputs of statistical projection models are not comparable to dynamic models. Ensemble modelling could focus on robust outcomes to reduce uncertainty. However, a fear was expressed that comparing the outputs from different types of biological models could distract from the aim of understanding processes and that decisions regarding weighting (whether and how to do it) will need to be made.

Specific initiatives recommended by workshop participants included:

- Select several regions where a common suite of modelling approaches have been applied and compare results across regions. VECTORS project in EU attempting to implement this for the North Sea.
- Select a "species" that is present within ICES and PICES regions and compare model outcomes. Examples might include: herring, sardine, gadids, flatfish, mackerel, rockfish/redfish
- Joint workshop – 2014 (FUTURE OSM) or 2015 (3rd Climate change effects on the world's oceans)
- IPCC decadal scale approach – develop model for observations in the 1970s to predict the 80s and for the 1980s to predict the 1990s, etc.
- Develop a best practices manual for model validation and inter-model comparison.

2.3 Session 3: Quantifying uncertainty

Session Leaders: David Reid (Ireland, ICES), Emanuele Di Lorenzo (USA, PICES), Manuel Barange (UK, ICES)

Breakout group discussions within Session 3 were far ranging and did not necessarily attempt to answer each of the specific questions posed by the workshop conveners. It was acknowledged that the sources of uncertainty and our ability to estimate them is greater for physical models than for biological models. Within GCMs, model uncertainty and emission scenario uncertainty are carried forward but not within model uncertainty. At the present time, cumulative uncertainties are too large to make "predictions" warranted but projections using scenarios will remain the mainstay of estimates of climate impacts on changes in species distributions. For projecting impacts, the best use of GCM output depends upon the biological model being employed. A variety of model applications and sources of uncertainty were discussed (from structural to parameter uncertainty). Workshop participants recommended mechanism to increase the dialogue between GCM/ESM and biological modelling communities.

2.3.1 What are the key sources of uncertainty in GCMs or ESMs?

It was important to define uncertainty within the context of global climate models (GCMs), Earth System Models (ESM) and other types of models. Uncertainty can arise from a number of different sources including "conceptual uncertainty (e.g. SRES), structural (model) miss-specification (e.g. parameters, structure and scales), there can be "process error" (e.g. the lack of adaptation within biological models), and "sampling uncertainty". An important source of uncertainty is the greenhouse gas emissions (hence the use of scenarios of pathways).

It is important to note that GCMs are designed to get the statistics of events such as the frequency of ENSO but cannot predict the timing of specific events. Also, these models do not include responses of upper trophic levels but focus on physics and carbon cycles). The downscaled GCMs have been more successful with matching historical data and less successful with projections. Statistical downscaling (which uses historical data) and dynamic downscaling (outputs of GCM forcing a regional climate model) are inherently different. One may not need to downscale if biological process occurs at very large-scales (i.e. tuna migrations) but will likely be needed to examine regional climate impacts.

2.3.2 Can your group agree on a single best practice for use of GCM or ESM outputs in projecting distributional shifts of marine species? If not, why not?

There was no general agreement on a single best practice for use of GCM or ESM outputs to examine distributional shifts. Model outputs will depend on the biological model selected which depends upon the question being asked and the availability of data availability.

2.3.3 What are the key sources of uncertainty in dynamic population models? How are these errors addressed in studies of shifts in spatial distribution?

Workshop participants agreed that the key sources of uncertainty depended upon the type of model being evaluated. The following table outlines a few commonly used approaches to examine climate-driven changes in fish.

Type of Model	Notes
Size spectrum	Data requirements (moderate), do not capture shifts in the spatial distribution of species / Parameter uncertainty can be explored
Life history (Individual-based or population dynamic)	Costly – data rich / - Population dynamic models (MSE) are stochastic and incorporate wide range of parameter uncertainty / - IBMs allow some stochasticity in movement / - Typically regional
Habitat-based models (bio-climatic windows, statistical (e.g. GAMs) and DEBs	Generally deterministic / - Useful for global synthesis / - Bio-climatic models can be run/developed in data poor regions / - Dynamic energy budget models are physiological-based but data intensive

Beyond these examples of single model types, coupled model approaches are rapidly advancing. These, more complex frameworks carry multiple sources of biological uncertainty (e.g. shifts in fishery removals, shifts in distribution). A few examples include:

1) FEAST – fully coupled end-to-end model with fishing (Aydin; R&D)

2) Full life cycle IBMs with fishing (Ito and Rose; operational)

3) Atlantis type models – exploring feedback (Operation in many regions, R&D in others)

4) Fishers choice type models (Haynie; Operational)

5) ERSEM coupled with Ecosim/ Ecospace (Beecham; Northeast European shelf) or coupled with dynamic size spectrum (Blanchard *et al* 2012)
6) MARS3D-OSMOSE-ISIS Fish (Traverse; R&D; Bay of Biscay / Channel / Southern North Sea)

In terms of modelling the population dynamics of species, a large list of uncertainties was constructed which included vital rates (rates of mortality, feeding, growth and reproduction) and fish behaviour. Specific aspects of the impacts of fishing on target species may also be poorly understood including selectivity, catchability and human / fishers' behavior. There are also great uncertainties in stock–recruitment relationships and population productivity. What most important / influential source of uncertainty will depend upon the context of the question (e.g. whether one is examining stock recruitment, predicting changes in fish distribution, or both).

As discussed in Session 3, the underlying data needs to be scrutinized to minimize the error known to exist within observations. The most simple approach may be to rely on methods that can utilize presence-absence data. For spatially explicit models, the development of simple approaches that provide coarse descriptions of important life cycle events (moving from higher latitude feeding to lower latitude overwintering grounds) may be sufficient. In short, it is important to describe what is known well then discuss uncertainty. It is important to incorporate expert judgment to identify and best cope with biases and uncertainties.

2.3.4 How should key uncertainties be incorporated into projections?

"Carefully". There are different ways to estimate uncertainty in model projections including running a model ensemble (sensitivity analysis) using a range of assumptions. Second, including stochasticity within models (e.g. IBMs with stochastic parameterizations) to explore probabilities of responses. One can also use the mean and two extremes of a situation (scenarios). However, in general, uncertainties should be incorporated when they have explanatory power and increase the predictive power of the model.

2.3.5 How was measurement error, process error, and model misspecification error addressed in studies of shifts in spatial distribution? Should future studies incorporate other sources error?

There are key, structural errors within specific types of models. One key point is that very few models include adaptation. Some examples include the incorporation of physiological adaptation (Cheung in R+D phase), phenotypic adaptation (examples in OA), evolutionary adaptation and ecosystem adaptation (species replacement studies). There is significant literature on evolutionary adaptation of planktonic (e.g. Lohbeck *et al*. 2012. Nature Geoscience 5) and invertebrate (e.g. Sunday *et al*. 2011. PLOS One 6) species to ocean acidification, and temperature should provide similar constraints and adaptation opportunities.

2.3.6 What can ICES and PICES do to improve collaboration between marine ecosystem modelers and earth system modelers?

Breakout group discussions listed a few potential mechanisms that could increase collaboration between marine ecosystem modelers and earth system modelers. These included:

1) Case Studies - develop case studies of regional climate and ecosystem downscaling with focus on both climate variability and climate change projections. This could be done in a small group setting where participants

cover a broad range of expertise (e.g. IPCC climate modeler and detection/uncertainty expert, regional physical modeller, regional ecosystem modeller, fishery economist, Bayesian statistician, etc.). The case study would attempt to evaluate both terrestrial and aquatic (marine) impacts of climate change. The goal would be to provide a draft for a roadmap towards performing future climate projections of biological impacts with uncertainties.

2) Summer School - A summer school on regional climate and ecosystem modelling can be organized (e.g. at NCAR Boulder, PICES WG27, WG28, WG29) that incorporates climate and human dimensions in fish and fisheries management (e.g. ICES) The range in expertise would be similar to that mentioned above for the case studies. The goal would be to generate online lecture material with references and examples to allow the community to access information and training useful to expand the interdisciplinary modelling.

3) More generally, it was encouraged that workshops were convened where participants focus on end-to-end climate impacts (from physics to fish to fisheries and feedback loops). The group should include experts in incorporating human behavior within modelling frameworks.

2.4 Session 4: Design specification for database of observations of distribution of living marine resources (including filling data gaps).

Leaders: William J. Sydeman (USA, PICES), Toru Suzuki (Japan, PICES), and Jon Hare (USA, ICES)

Analyses of changes in spatial distribution have been conducted at two scales. First, global studies use globally gridded data (e.g. Cheung *et al*. 2013). Second, regional studies use station-specific data originating from single surveys (e.g. Perry *et al*. 2005, Mueter and Litzow 2008, Nye *et al*. 2009). The session discussed the datasets and the techniques to combine high-resolution regional studies to examine larger-scale changes in distribution.

2.4.1 What are the relevant datasets available for use in documenting climate induced shifts in spatial distribution of fish, shellfish and their fisheries? Is this information available online either through a public or password protected site? What are the best data delivery systems?

There are a wide variety of datasets available for documenting shifts in fishery species distributions. These can be categorized broadly: fishery-independent surveys (including different gears and life stages), fishery-dependent data (including different gears and approaches), tagging data, fish biology surveys (e.g. age, diet, parasites, genetics), process-oriented research data (e.g. GLOBEC, EU-BASIN, CLIOTOP), biological oceanographic data (including ship-based, satellite observations, moorings, etc.), archeological or palaeontology datasets (sediments, middens), and assorted point observations (museums, scientific literature species lists).

Fishery-independent surveys are one of the most useful sources of data for studying distributional changes and a list of identified surveys is provided in Table 1. This is a partial list and based on meeting participants and two studies that have combined trawl survey data (Pinsky *et al*. In prep, Fogarty *et al*. 2010). Numerous regional specific or survey specific studies have demonstrated shifts in distribution related to climate (Perry *et al*. 2005, Mueter and Litzow 2008, Nye *et al*. 2010). Most of these surveys focus on adult stages, but there are numerous egg and larval surveys around the globe that could be analysed. These early life-history surveys can provide important information, since the catchability of egg and larval stages is very different from the catchability of adult stages. Numerous surveys also exist for oceanographic information including hydrography, phytoplankton and zooplankton. Many of these surveys have been ongoing for decades (summarized in several working groups and status reports[1]). Although not providing data regarding fish distributions per say, these surveys can provide oceanographic context for observed changes. Most of fishery-independent surveys are operated by national and state governments, but research and non-profit organizations also conduct fishery-independent surveys (e.g. Reef Environmental Education Foundation[2] and Sir Alister Hardy Foundation for Ocean Science[3]).

Table 1. Fishery-independent surveys identified during the workshop.

Dataset / Data Center	Region	Notes
ICES Data Center	Northeast Atlantic	Multi-nation accumulation of trawl survey data
US (NOAA NMFS)	Available for Northeast US, Gulf of Mexico, West Coast of the US, Gulf of Alaska, Eastern Bering Sea, and Aleutian Islands	Not centrally available, available for each regional NMFS Center; some areas have larval, juvenile, and adult data
Canada (DFO)	Available for West Coast of Canada, Scotian Shelf, Northern Gulf of St Lawrence, Southern Gulf of St Lawrence, Newfoundland, Grand Banks, St Pierre Bank	Partially available online also available on request
US-Canada Joint Hake Survey	West Coast North America	
Pacific Salmon Commission	West Coast North America	Stream-by-stream
Russian (TINRO) trawl survey data	Several regions	Some access is limited for domestic use only, partially aggregated
OSHORO-MARU, Hokkaido University Surveys	Multiple regions	Includes adult, larval, and zooplankton data. Reports mostly in Japanese
NFDRD (Korea)	Multiple regions	Trawl survey data
South Africa	West and South Coast	Available from South Africa's Department of Agriculture, forestry and fisheries
New Zealand	Chatham Rise	Available from New Zealand National Institute of Water and Atmospheric Research
GOA Small Mesh Survey	Gulf of Alaska	Alaskan Department of Fish and Game

[1] http://www.scor-int.org/Working_Groups/wg125.htm, http://www.scor-int.org/Working_Groups/wg137.htm, http://wgze.net/zooplankton-status-report, http://www.pices.int/projects/npesr/default.aspx

[2] http://www.reef.org/

[3] http://www.sahfos.ac.uk/

Fishery-dependent data includes catch records, dealer records, vessel monitoring systems, captain's logbooks, at-sea and port observers, and creel censuses. These data are collected globally and most if not all countries report catch data to the FAO. Catch data in an aggregated form has been used to study changes in fish distribution Cheung *et al*. 2013) based on the Sea Around Us project[4]. Accessing these data in less aggregated form for research purposes is often difficult (noted by participants from USA, Japan, Korea, and Canada) and data are often confidential. However, analyses of fishery dependent data on more regional levels is possible (e.g. Pinsky and Fogarty 2012). Such studies however must overcome a number of challenges including how to deal with effort estimation, proprietary nature of some catch data, and basic data availability.

A number of other data sources are available for examining shifts in fishery distributions, but these datasets are less complete spatially and temporally. Data from fisheries and oceanographic research programs are available but the data are held by numerous institutions and investigators and often do not focus on fishery species. Evaluating changes in distribution using project specific data – as opposed to survey or monitoring data - would be challenging, but the data can contribute as to the mechanisms shaping distributions or by combining data across projects to develop or augment longer regional time-series. Tagging data are available for many species and data aggregation is starting to occur (e.g. Ocean Tracking Network[5], Ocean Research Institute[6]). These data are unique as they provide information at the level of the individual. Thus, these data can contribute to the mechanisms shaping distributions and over the long term be used to examine changes in individual movement patterns. Fish biology studies as part of surveys are also unique. These can provide information on diets, population structure, and movements. In general, these studies are not thought of as providing information on distribution, but there is information available. There are also palaeo-ecological studies that can provide information on fish distributions (or production change at fixed stations, which could be a proxy for distribution change). These studies include strict palaeo-ecology (Baumgartner *et al*., 1992), and well as archeological studies (Van Neer *et al*., 2002). Finally, there are a number of point observations (e.g. museum collections) many of which have been aggregated in FishBase[7] and OBIS[8]. Site-specific species-lists also constitute another type of point observation.

In terms of availability of the above the data, there are several related questions. First, is the data available? Second, is the data useable? Third, is the data fit for purpose? The answers depend both on the data and on the person wanting to use the data. As an example, a dataset may be publically available, but it takes someone with the knowledge and tools to work with a netCDF to use the data. As another example, large differences in effort may diminish the value of a commercial fishery database for examining shifts in distribution, but this limitation may be known only to the individuals in the organization collecting the data. Thus, the questions of availability,

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[4] http://www.seaaroundus.org/
[5] http://oceantrackingnetwork.org/
[6] http://www.oritag.org.za/?orimember_unsecure
[7] http://www.fishbase.org/search.php
[8] http://www.iobis.org/

usability, and fit for purpose need to be addressed on a case-by-case basis from the perspective of specific users.

2.4.2 To what extent are the relevant datasets compatible in time and space scales to the physical observations and model datasets that define climate change?

The linkage of spatial distribution data to environmental data are central to attributing changes in distribution to climate and to projecting the future effect of climate change on species distributions. There are two basic methods for linking species distribution data with environmental data. First, is to use sample-specific measurements. For example, many fishery-independent trawl surveys make simultaneous environmental measurements (e.g. temperature, salinity, oxygen). These combined data allow abundance and distribution to be analysed with specific environmental variables. Second, is to interpolate environmental data to match fishery distribution data. Interpolation can involve varying degrees of aggregation on both the fishery and environmental side. A specific trawl catch can be assigned a temperature based on a data-derived or model-derived synoptic temperature field or a catch in a given region can be assigned to an average temperature in that same region. There are many sources of physical data that can be used for interpolation with fishery datasets and these types of physical data include: synoptic interpolations, climatologies, reanalyses, model output, and satellite-derived observations. The effect of the scale and source of environmental data on the examination of species distribution has not been evaluated.

2.4.3 In transboundary stocks, have methods been established to correct for differences in sampling methods? What options are available to make these corrections?

Transboundary stocks are particularly challenging because they are often assessed and managed by different teams using different methodologies. Few studies have assessed changes in fish distributions from single surveys or combined multi-surveys. The analyses completed to date are based on globally aggregated model data (e.g. Chueng *et al.*, 2013) or specific surveys that may be transboundary (e.g. Perry *et al.* 2005). Linking across surveys to conduct integrated analyses of distribution changes is challenging. Differences in catchability caused by gear, platform, season, and habitat are very difficult to overcome. Several approaches were identified for moving forward.

- Simply treat each survey independently and then combine the trends across surveys.
- Estimate environmental relationships for each survey separately and the project or infer distribution for integrated analyses of change.
- Analyse distribution by combining across stock areas; thereby using the stock assessment to combine multiple surveys into an estimate of abundance. This approach would result in a relatively course spatial scale analysis.
- Use methods like a stock assessment to estimate survey specific catchability and then apply to the raw survey data and combine across surveys.
- Use presence or absence in surveys rather than abundance as to dependent variable, thereby minimizing the effect of differences in catchability between surveys.

- Work to develop comparable surveys across broader regions. This would require calibration data between surveys.

An important issue is the combination of different taxonomic classifications. Each survey and each institution tend to use their own taxonomic classifications. Often these classifications have changed over time, as the ability to identify species has improved. Although this issue seems mundane, it is fundamental to integrating across surveys.

There are institutions that have developed methods for combing fishery-independent surveys. ICES uses survey data collected in a multinational effort. NOAA NMFS on the west coast of North American uses multiple commercial platforms to collect fishery-independent data. These and other organizations could provide technical expertise on the general problem of combining data among surveys to develop a more spatially extensive dataset for examining changes in distribution.

ICES/PICES needs to build relationships between experts in the different surveys. Such a group of survey experts would know the specifics of individual surveys. ICES/PICES should also entrain quantitative scientists who can develop or adapt the methods necessary to combine data across surveys. This is largely a problem of developing the right group of scientists with a common vision; a problem which ICES and PICES have a long-track record in solving. One goal of such an effort could be to develop a corrected, combined multi-trawl survey dataset. Another goal could be an aggregated dataset (e.g. IMR.NO Geo/data Map service).

2.4.4 Are protocols needed to allow international data sharing of fisheries or survey?

Sharing of data are more common place for fishery-independent data and research project data. Major obstacles exist for the sharing of fishery-dependent data, except at the global aggregated level. ICES and PICES are in an excellent position to foster more openness and availability of fishery-dependent data, but the issue will require effort, especially to work across traditional boundaries (e.g. combining Northwest and Northeast Atlantic fishery-dependent data to examine the distribution of Atlantic cod).

2.4.5 Do methods exist to allow integration and synthesis of different types of data (e.g. trawl, longline and acoustic)?

The answer to question 3 is relevant. Data are frequently combined across gear types in stock assessments. These same methods could be used to develop standardized species datasets across stocks. Taxonomic resolution of data becomes an issue when combining across fishery-dependent and fishery-independent (lower and higher taxonomic resolution) and across gears (trawl vs. acoustic).

2.4.6 What data display options should be considered?

No group spent much time on this question. The answer is very dependent on the question being asked and the audience being addressed. Clearly, studies of changes in fishery distribution could benefit from more improved data visualization methods.

2.4.7 What are the advantages or disadvantage of using existing National data centers as delivery nodes for distributed data access portal?

The advantage of using national data centers is continuity of funding and the ability to maintain a long-term archive. Any distributed data access system needs to be set up so that the same datasets are available in different regions – to create aggregate datasets. IODE (International Oceanographic Data and Information Exchange) under IOC is a network for oceanographic data sharing. World Ocean Database is one of good examples for oceanographic data integration project of IOC/IODE. To move fisheries data into this framework would require a similar network system of national data center for fish and fisheries. Other data centers are emerging related to the Global Ocean Observing System, collation of research project data (e.g. BCO-DMO[9]) and international agreements (e.g. ICES Data Centre). Distributed data networks also continue to emerge (e.g. LAS PMEL[10]). If the ICES/PICES community is serious about trying to coordinate access to fisheries data in a near 'raw' form, the attributes of such a 'data center' such be defined and then available options compared to the list of desired attributes. Given the nature of these datasets (e.g. non-standard, gear, region, design specificity), it is important that experts from the data collection side remain engaged. In other words, these data should not just be made available and then analysed 'user beware'; so level of coordination and standardization should be implemented or at least communicated.

2.4.8 Recommendations

Three approaches were discussed for moving forward. The three and not mutually exclusive and serve different users.

1) Develop an aggregated database of fishery-independent and fishery-dependent data that is at a higher-resolution in time and space than existing databases. This database would be supported by national or international institutions (e.g. ICES/PICES)
2) Develop approaches and metadata for specific datasets that specifically addresses the requirements of combining with other datasets.
3) Develop distributed data network for different datasets. A first-level effort could simply define the datasets and provide electronic access. A second level effort could include integration and visualization across multiple datasets.

2.5 Session 5: Vulnerability Assessment

Leaders: Jacquelynne King (Canada, PICES), Yury Zuenko (Russia, ICES), and Tarub Bahri (FAO)

One of the strengths of the workshop was the attendance of scientists within different disciplines. The diversity of backgrounds was apparent from discussions stemming from the questions posed by the workshop conveners for Session 5. There was a need for participants to agree on a common vocabulary and to approach these questions using common definitions. For instance, "risk assessment" and "vulnerability assessment" are different. Vulnerability is related to a threat while the risk is related to the impacts of that threat. Discussions of workshop participants focused on "biophysical" aspects of vulnerability and ignored social-economic vulnerability and adaptation.

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[9] http://bcodmo.org/

[10] http://ferret.pmel.noaa.gov/LAS

2.5.1 What are the core elements of fish vulnerability to climate change?

Workshop participants thought that it was important to distinguish between the vulnerability of 1) species / populations, 2) ecosystems and 3) fishers/communities to changing fish distribution. Within each of these categories, workshop participants defined Vulnerability V) as a function of Exposure (E) and Sensitivity (S) and adaptability (A) where V = S + E + A.

In terms of vulnerability assessment of single species the threats (drivers) include changes in physical habitat characteristics (temperature, water circulation patterns, sea level rise) sensitivity are key processes affecting habitat suitability and availability, while adaptability would be related to species traits (diets, life-history scheduling etc.).

A great deal of discussion focused on the sensitivity (S) of a species to changes in climate will depend upon a number of intrinsic attributes such as 1) body size (particularly in invertebrates), 2) adult mobility, and 3) the width of ranges in physiological tolerance to key environmental factors, and 4) the trophic level. Other intrinsic traits related to the life-history strategy of a species will also be important to sensitivity including 5) the degree of fidelity to spawning grounds and, more generally 6) the complexity in reproductive strategy and 7) plasticity in phenology of life-history scheduling. External pressures such as fishing will also affect a species sensitivity through changes in 8) stock size relative to B0, and 9) diversity in age structure. Particular facets of the environment interact with intrinsic traits of a species to affect factors that can be altered via climate change including 10) the extent of spawning and/or nursery areas, 11) prey specificity, 12) dispersal probability (retention / cross-shelf distribution), 13) the predator field, and, ultimately, 14) population growth rate. In general, the degree of exposure (E) of a species to other external stressors (hydrocarbons, pollution, over exploitation) will influence the severity (S) of climate impacts. A small population living within a discrete area likely has a much higher vulnerability to stressors such as fishing than do large populations.

In terms of exposure (E), not all areas are projected to experience the same degree of change in key abiotic factors due to climate change. For example, areas of high rate of change include polar and other (specific) regions such as south-eastern Australia (see Burrows *et al*. 2012). Shallow coastal areas are likely to be more affected than deeper, offshore areas where as subpolar and frontal systems appear less vulnerable. Areas which are particularly vulnerable include tropical reefs where habitat-forming species are being reduced (e.g. bleaching at warm temperatures) change). Also, it is important to distinguish changes in not only the mean parameters but changes in amplitude and frequency as well as the time-scale over which phenomena occur (seasonal, interannual, decadal, multidecadal). Finally, an appreciation is growing that hysteresis exists and pathways of change in one direction may not be reversible when conditions return to a previous state.

2.5.2 What types of vulnerability or (ecological) risk assessments have been developed in your region?

Workshop participants listed examples of ecological risk assessments performed in a number of different regions.

Marine Areas	Risk Assessment (RA) Notes
Arctic Ocean	Hollowed *et al*. (2013) recently prepared a vulnerability assessment
Bering Sea (US area)	Informal VA of fisheries related to movements of fish further away from ports

Marine Areas	Risk Assessment (RA) Notes
Canadian Waters	High level vulnerability assessments have been performed, regional assessments are in preparation
Australian Waters	Screening-level assessments (Pecl *et al*. 2010) and RA for corals
	Detailed, species-specific RA also performed (e.g. rock lobster)
UK Waters	Statutory requirement to conduct formal, metric based, risk assessments of climate change every 5 years
Norwegian and Barents Sea	RA being conducted by Norway
Russian Waters	Performing RA by subregion - probability of an outcome given a certain level of catch, not explicitly examining fish distribution
Korean Waters	VA will be part of the future, adaptive management but no formal VA of climate change on fish or fisheries has been completed
Japanese Waters	VA of aquaculture is conducted; ecosystem VA that includes fish is conducted for Seto Inland Sea focusing on degradation due to river inputs
Pacific Ocean	Corals within Pacific Ocean
	Vulnerability assessment of Small Island Developing States (tuna)
Benguela Current	Risk assessment of fisheries based upon climate impacts

2.5.3 What are the advantages and disadvantages of qualitative and quantitative risk assessment?

The advantages of qualitative assessments are that they are timely, have minimal data requirements and are not as expensive as quantitative risk assessments. Thus qualitative assessments may make the most efficient use of resources in areas with a limited range of tactical management tools. Qualitative assessments can provide first-order guidance to managers on priorities for research and they are easily understood and accepted by stakeholders and managers. The disadvantages of qualitative assessments are that they only include an informal treatment of uncertainty based on professional judgment and they only provide guidance on course temporal and spatial scales. Furthermore it is difficult to detect formal biological reference points linked to management action and to compare results obtained in different regions.

2.5.4 What research is needed to improve vulnerability assessment?

Workshop participants agreed that it was critical **to** identify multiple stressors and develop tools that allow scientists to disentangle the effects of specific stressors (to better understand the cumulative impacts from co-stressors). This implies an improved capacity to accurately predict the effects of climate change on physical properties such as temperature, O_2, advective corridors, and the location and magnitude of ocean features (fronts, eddies, mixed layer depth…) important to species distribution and productivity.

More emphasis should be placed on understanding the biology of the species including gathering improved information on actual movement responses to environmental change (fish behavior and movement studies; e.g. tagging), comparative physiology studies (e.g. thermal tolerance surfaces under changing environmental conditions, and species interactions and behavioral responses to changing environmental conditions. An area where knowledge is considerably lacking is in the adaptive capacity of species either due to genetic diversity and selection or phenotypic plasticity as well as colonization probabilities (members vs. vagrants).

The better knowledge of physical and ecological changes should allow one to better quantify the probability of threats and benefits accruing from climate change but rigorous testing of methods and assumptions is needed. For example, evaluations are needed of observed traits of species and how those are related to historical and expected future (projected) responses. Risk assessments need to be developed that can evaluate the potential benefits of climate change. In this regard, there is a need for improved forecasts of expected trends in socio-economic responses both in terms of changes in marine resources and to changes in societal demands for resources. It should be noted that in depth discussions of the vulnerability of communities relying on fish and fisheries did not take place at this workshop. Finally, quantitative modelling should be used to make comparisons of vulnerability assessments across regions and qualitative modelling can be used to test expert judgment.

2.5.5 Should ICES and PICES strive to publish regional vulnerability assessments on a periodic basis?

There was debate regarding the answer to this question. In two of the three breakout groups, the answer was "Yes". Reports produced by both ICES and PICES contain information useful for the development of vulnerability assessments and the work would dovetail well with the goals and ongoing initiatives of these organizations. It is important to note that there are several existing environmental assessments and any new vulnerability / risk assessments could be incorporated into these reports or modelled after them. Examples of these reports include:

- Annual or biannual ICES reports (e.g. Ocean Climate Status Report, Plankton Status Reports)
- PICES North Pacific Ecosystem Status Reports
- OSPAR quality status report
- ACIA – Arctic Climate Impacts Assessment
- Stated of the California Current (CalCOFI)
- Ecosystem Considerations Chapter (US – Alaska)
- DFO State of the Ocean
- National Climate Assessment (USA)

On the other hand, the availability of other vulnerability assessments from other organizations demands that those created by ICES and PICES provide both unique and complimentary information. The frequency of these assessments should match the pace of development of physical and biological climate science. Ideally these vulnerability assessments would be conducted such that they are available for consideration by IPCC writing teams. From a practical perspective, the (frequency of the) preparation of these vulnerability assessments is normally related to changes in environmental / fisheries policy / legislation.

2.6 Session 6: Communicating outcomes to inform decisions regarding management of living marine resources under changing climate.

Leaders: Phillip Mundy (USA, PICES), John Pinnegar (UK, ICES), Motomitsu Takahashi (Japan, PICES)

2.6.1 Who are the decision-makers and by whom are they directed or influenced?

Decision-makers include regulatory bodies at national and international levels. For example:

Country	Decision-makers
Canada	DFO for endangered species
	Ministry of Fisheries (national level)
USA	Dept of Interior (Endangered freshwater)
	Dept of Commerce (Endangered anadromous and marine)
	First nations make own regulations
Japan	Environmental Agency (all endangered species – tuna)
	Coastal fisheries (prefectures), Fisheries Ministry in all offshore waters
UK	No Endangered Species Act some conservation from individual agencies, marine species underrepresented
	Fisheries managers, environmental compliance, other conservation agencies
EU	All member states: Common Fisheries Policy, Marine Strategy framework Directive

Decision-makers are directed and/or influenced by a number of different mechanisms including

- US political bodies, national, international
- Fishing industry (including fishers, seafood companies, etc.)
- First nations (Canada)
- Stakeholders (general public)
- Environmental groups
- Financial interests, i.e. local financiers, World Bank
- International Treaty Organizations (tuna, salmon, halibut, eventually Pollock?) and multinational/bilateral agreements
- ICES provides advice to the EU

2.6.2 How can ICES/PICES capture the different management perspectives?

There was consensus that both groups need to invite "outside" participation (e.g. industry and management). An important distinction is the lack of an advisory branch within PICES and the well-established advisory capacity in ICES. Within PICES a poll could be taken of the chairs of committees and working groups (although these people may not have the required perspective, background, or interest for a thorough response. The governing council in PICES can also be consulted. There is a need to review national and international conservation laws (regulations, treaties). Within ICES, the Science (SCICOM) and Advisory (ACOM) Committees can be consulted. There are also various national and EU initiatives on the ecosystem approach to management.

ICES and PICES might develop a white paper outlining the development of a spatial database for distribution, analysis and summarization of the information. Both groups provide a logical forum for the discussion and review of analytical methods that could be adopted by national governments. Finally, ICES and PICES should develop a clear overview of key research products and approaches that could utilized by managers / governmental agencies. This could be part of an ICES/PICES science plan with clear, common deliverables.

2.6.3 What are the management objectives (e.g. building sustainable fisheries, preserving diversity) and how can climate change projections inform strategies to achieve these objectives?

At the national level, management objectives and priorities will depend upon the country (e.g. to "maximize" or "stabilize", etc.) but three main categories were considered: 1) Utilization for food, recreation, commerce (economic development, livelihood), cultural heritage, food and nutrition security, 2) Sustainability and conservation (for biodiversity or to improve/maintain adaptive capacity), and 3) preservation (e.g. by using exclusive Marine Protected Areas). At the International level, a potentially different set of objectives exist including those related to transboundary species (migratory or transient species) such as their allocation (catches) or conservation). Also, objectives may be focused on conflict avoidance. It was noted that FAO is responsible for negotiating conflicts associated with management objectives.

Climate change can provide strategic information (e.g. adaptation planning) but there is a need to match the relatively long-term climate horizon with the relatively short planning horizon of the audience. Within thee short-term political process, one may not need climate advice (2 – 3 year planning horizon), however CC projections will be critical for legislation with a longer term planning horizon. CC projections can also inform on the risk of *not* attaining objectives and provide recommendations on adaptation options. Long-term commitments (MPA's, stock rebuilding plans, etc.) as well as short-term actions needed to reduce vulnerability of long-term goals (e.g. reduce quotas now for long-term benefit, moving processing plants) need information stemming from CC projections. This will be particularly relevant to conducting management strategy evaluations for marine spatial planning.

When providing projections, it was considered important to: 1) incorporate deviation from equilibrium assumptions (changes in mean and trends in errors), 2) differentiate between different levels of vulnerability, 3) identify emerging opportunities, and 4) provide advice on how to apply the precautionary approach to management – exploitation rate proportional to level of certainty (climate projections, predictions vs. forecasts). In the long-term, models could be linked to provide a global assessment of the implications of climate change on marine fish and shellfish production to inform decisions regarding food security and international trade.

2.6.4 What products can ICES and PICES deliver to decision-makers and their constituencies? If products are delivered, how will the quality and effectiveness of the products be assessed?

First and foremost, it is important to ask decision-makers what they want and what form will make produced more effective. ICES and PICES can create and share variety of products including publishing articles in the peer-reviewed literature or science articles in the popular press. Social networking is also an important endeavor. Decision-makers can also be provided forecasts, predictions or projections (Outlooks) and report cards (e.g. UK Marine Climate Change impacts annual report series). Status reports (e.g. North Pacific Ecosystem Status Report – PICES, State of Oceans – Canada) can be delivered. Additionally, evaluations that summarize suites of products can be effective.

In terms of the control of quality and effectiveness, peer-review of individual products (forecasts, predictions, projections or outlooks and status reports) was considered important. Conduct analysis of the skill of the projections in projecting observed conditions to gain confidence in model output. It will be important to communicate that long-term projections may be more accurate than short-term forecasts. The success ultimately depends upon whether following advice achieves management objectives. In this regard, conducting post hoc evaluations of adequacy and efficiency of advice (e.g. Common Fishery Policy of the EU) will be important.

2.6.5 What form of information is needed for decision-making? (e.g. decision tables, risk analyses, decision theoretic approach, verbal models, interdisciplinary explanations)

A range of both qualitative and quantitative is required (see #4). Novel products are also needed such as interactive game theoretical approaches. In terms of the communication of results, ICES already has a press office, PICES does not have one. Offering public communication courses to scientists would be helpful.

2.6.6 What range of management actions could be considered? How could information products be designed to help managers to make informed choices in the future?

There will be limits imposed by different nations, international agreements as well as biological and physical limits (See above)

2.6.7 What are the implications of climate change impacts on fish and fishery distributions for making management decisions on resources that cross international boundaries?

Information on the effects of CC on the spatial distribution and productivity of species will be particularly important to support the structuring treaties relating to transboundary plans that are adaptive with respect to CC. An example was provided by Link *et al*. (year fish and fisheries) on managing stocks under changing stock distributions. Within existing treaties, allocation rules may need to change (e.g. Pacific salmon treaty, Vessel Day scheme in Pacific SIDS for tuna that has flexible structure). There will also be a need for new treaties. In areas where effects of climate change evident, need for surveys and assessments is increased.

Papers Stemming from Workshop Discussions

There was considerable interest in publishing a special volume containing papers stemming from discussions in each of the six sessions. A tentative list of participants willing to lead these efforts and notes on the contribution are listed below:

Theme Session	Topic	Lead Participants (alphabetical order)
Session 1: Analytical methods for detecting changes in spatial distribution.	Analytical methods for detecting changes in distribution (2 to 3 papers)	Cheung, Meuter, MacKenzie
Session 2: Skill assessment and model intercomparison	Synthesis papers will be written (1 or 2 papers)	Curchister, Ito, Jones, Payne
Session 3: Quantifying uncertainty	Empirical model of spatial variability and/or paper on data uncertainty was suggested	Barange (for Bograd), Certain, Di Lorenzo, Pavlova, Reid
Session 4: Design specification for database of observations of distribution of living marine resources (including filling data gaps).	White paper to ICES and PICES and a paper on linking datasets	Hare, Suzuki, Sydeman
Session 5: Vulnerability Assessment	A methods paper describing different approaches	Bahri, de Young, King, Pecl, Zuenko

Session 6: Communicating outcomes to inform management decisions	A transboundary paper and/or a paper highlighting case studies	Mundy, Pinnegar, Takahashi,

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Figure 1. Group photo of participants of the ICES-PICES SICCME-Spatial workshop (top) as well as small breakout group discussions (bottom left and middle), A welcome address and wrap up summary of the workshop was provided by Anne Hollowed (bottom, right photo). Pictured in the bottom left photo (R to L: John Stein (Canada), Naesun Park (Korea), Toru Suzuki (Japan), Bill Sydeman (USA), Mike Foreman (Canada), Chan Joo Jang (Korea)). Pictured in the bottom middle photo (L to R: Anne Britt Sandø (Norway), unknown, Lorna Teal (Netherlands), Myron Peck (Germany), David Reid (Ireland)).

Annex 2: Agenda

Day 1 (Wednesday, 22 May 2013)

09:00 **Welcome, introductions.**
09:15 Overview of goals and objectives of WKSICCME-Spatial

09:30 **Session 1: Analytical methods for detecting changes in spatial distribution**.
09:30 Session 1: Invited speaker 1: **William Cheung (Canada) "Projecting climate change effects on the distribution of global fish stocks"**
09:50 Session 1: Invited speaker 2**: Franz Mueter (USA.) "Quantifying spatial variability of species distributions: The roles of density, temperature and advection"**
10:10 Session 1: **Breakout group assignments** (Session leaders: Franz Mueter (USA), William Cheung (Canada), Brian MacKenzie (DK))

10:20 Coffee Break
11:00 Session 1 Breakout groups (1 hour 30 minutes)
12:20 Lunch
14:00 Plenary discussion action plan, key data gaps and key recommendations (10 minutes each)
14:30 **Session 2: Skill Assessment and model intercomparison.**
14:30 Session 2: Invited speaker 1**: Miranda Jones (UK) "Applying a multi-model approach to predicting species' distributions"**
14:50 Session 2: Invited speaker 2: **Shin-ichi Ito (Japan) "How to model fish migration and distribution under future climate?"**
15:10 Session 2 **Breakout group assignments** (Tentative session leaders: Miranda Jones (UK), Mark Payne (UK), Enrique Curchitser (USA))
15:10 Coffee Break
15:30 Session 2 Breakout groups (1 hour 30 minutes)
17:00 Session ends

Day 2 (Thursday, 23 May 2013)

09:00 Plenary Discussion action plan, key data gaps, and key recommendations (10 minutes each)
09:30 Poster Introduction – (2-3 minute presentations) 40 minutes
10:10 **Session 3: Quantifying uncertainty**
10:10 Session 3: Invited speaker: **Tatiana Pavlova (Russia) "Climate simulations and projections over Russia and the adjacent seas: a CMIP5 update"**
10:30 Session 3: Invited speaker: **Certain Grégoire (Norway) "Trying to measure what we don't know: Examples in ecology and management"**
10:50 Session 3 **Breakout group assignments** (Tentative session leaders: David Reid (Ireland), Emanuele Di Lorenzo (USA), Steven Bograd (USA))
10:50 Coffee Break
11:10 Session 3 Breakout groups (1 hour 30 minutes)
12:40 Lunch
14:00 Plenary discussion action plan, key data gaps and key recommendations (10 min each)
14:30 **Session 4: Design specification for database of observations of distribution of living marine resources (including filling data gaps).**

14:30	Session 4: Invited speaker: **William Sydeman (USA) "Database considerations for global meta-analyses of climatic impacts on distribution: the NCEAS-MarClim experience"**
14:50	Session 4: **Breakout group assignments** (Tentative session leaders: Jon Hare (USA), Toru Suzuki (Japan), William Sydeman (USA))
14:50	Session 4: Breakout groups (1 hour 30 minutes)
16:20	Coffee Break
16:40	Plenary Discussion action plan and key recommendations (10 minutes each)
17:10	**Vulnerability Assessment**
17:10	Session 5: Invited speaker 1: **Cassandra de Young (Italy) "Vulnerability assessments in fisheries and aquaculture socio-ecological systems: some experiences in their development and use in adaptation planning"**
17:30	Session 5: Invited speaker 2: **Gretta Pecl (Australia) "Approaches for assessing species vulnerability to climate change in an ocean warming hot spot"**
17:50	Session 5 **Breakout group assignments** (Tentative session leaders: Jacquelynne King (Canada), Yury Zuenko (Russia), Tarub Bahri (FAO))
17:50	Session ends

18:00 Reception at Courtyard Marriott Hotel

Day 3 (Friday, 24 May 2013)

09:00	Session 5: Breakout groups (1 hour 30 minutes)
10:30	Coffee Break
10:50	Session 5: Plenary Discussion action plan, key data gaps and key recommendations (10 minutes each)
11:20	**Session 6: Communicating outcomes to inform decisions regarding management of living marine resources under changing climate**
11:20	Session 6: Invited speaker: **John Pinnegar (UK)** *"Answering the "so what" question: communicating with policy-makers, members of the public and the media"*
11:40	Session 6: Invited speaker: **Motomitsu Takahashi (WG 28, Japan) "Approaches for identifying ecosystem responses to human activities and natural stressors**"
12:00	Lunch
13:30	Session 6: **Breakout group assignments** (Tentative session leaders: John Pinnegar (UK), Phillip Mundy (USA), Motomitsu Takahashi (Japan))
13:30	Session 6: Breakout groups (1 hour 30 minutes)
15:00	Session 6: Plenary discussion: action plan, key data gaps and key recommendations (10 minutes each)
15:30	Coffee Break
15:50	Plenary Discussion synthesis action plan and recommendations
16:00	Options for Global Partnerships and proposal writing
16:20	Summary
17:00	Workshop ends

Annex 3: WKSICCME-Spatial Terms of Reference

2012/2/SSGEF11 The **Workshop on Global Assessment of the Implications of Climate Change on the Spatial Distribution of Fish and Fisheries** (WKSICCME-Spatial), chaired by Myron Peck* (Germany, ICES), Anne Hollowed* (USA, PICES) and Suam Kim* (Korea, PICES), will meet in St Petersburg, Russia, 22–24 May 2013 to:

a) Develop and test analytical methods for detecting changes in distribution;

b) Assess the skill of different modelling approaches;

c) Develop methods for quantifying uncertainty in projected changes;

d) Produce design specifications for a global database of marine observations;

e) Evaluate the influential factors governing vulnerability to shifting distributions.

WKSICCME-Spatial will report by 1 July 2013 (via SICCME and SSGEF) for the attention of SCICOM.

Supporting Information

Priority	High. The workshop is a joint PICES/ICES initiative and a contribution to the implementation of the SICCME plan. It contributes to several parts of the ICES Strategic Plan, with particular reference to climate change impacts on marine populations and species.
Scientific justification	Climate change will impact the spatial distribution of fish and fisheries around the globe. These changes are expected to disrupt current fisheries, alter species interactions, and may result in conflicts over quota allocations. Previous studies have demonstrated that fish and fisheries are responding to shifts in environmental conditions in selected regions. Future projections from a number of bio-climatic window models, individual based models and coupled biophysical ecosystem models show climate change will impact spatial distributions of fish and fisheries, but differ in their estimation of impact. An Atlas of observations and model projections is needed to start developing a global synthesis of the implications of climate change on fish and fisheries. Participants will review the available observations and model output to: 1) develop and test analytical methods for detecting changes in distribution; 2) assess the skill of different modelling approaches; 3) develop methods for quantifying uncertainty in projected changes; 4) produce design specifications for a global database of marine observations; 5) evaluate the influential factors governing vulnerability to shifting distributions. Products of this effort will be used to develop regional and latitudinal differences in the vulnerability of species or species groups to climate change induced shifts in ocean conditions. The synthesis will be used to inform future decisions regarding the governance and management of marine resources.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	Ca. 20-25 scientists involved in observation and modelling of fish species distributions and climate change research from the ICES and PICES communities..
Secretariat facilities	None.
Financial	No financial implications.

Linkages to advisory committees	None.
Linkages to other committees or groups	This workshop is a direct result of the SICCME Implementaton Plan approved by SCICOM and the PICES Science Board in 2011. It is relevant to ICES WGIPEM, WGIAB, and WGINOSE, and PICES WG-28 and TCODE. This project builds on th findings of ICES/PICES WKBCASAS and the workshop on "Climate change and range shifts in the ocean: Detection, prediction and adaptation". This project will complement the proposed ICES Theme Session focused on this issue for fall of 2013. Meeting to be held back-to-back with PICES intersessional Science Board.
Linkages to other organizations	PICES

Annex 4: Recommendations

Recommendation	Adressed to
1. Compile existing skill assessments of the ability to model climate-driven changes in the migration of marine fish species and to disentangle shifts in distribution due to behaviorally driven migration and changes in local productivity	WGIPEM
2. Explore the ability of Integrated Assessment Working groups to perform vulnerability assessments of species to climate – driven changes in distribution	WGBIODIV and SIBAS
3. Explore how to combine ICES fishery-dependent and fishery-independent datasets with those of other national and international organizations to create merged datasets allowing explorations of changes in the distribution of marine species	ICES Data Centre

Annex 5: Abstracts of Keynote Speakers

The following section provides the abstracts of the 11 keynote presentations given during the WKSICCME-Spatial. They are listed in chronological order.

Presentation 1 (Session 1)

Projecting climate change effects on the distribution of global fish stocks

William Cheung

Marine fish and invertebrates respond to ocean warming through distribution shifts, generally to higher latitudes and deeper waters. Consequently, fisheries should be affected by 'tropicalization' of catch (increasing dominance of warm-water species). However, a signature of such climate-change effects on global fisheries catch has so far not been detected. Here we report such an index, the mean temperature of the catch (MTC), that is calculated from the average inferred temperature preference of exploited species weighted by their annual catch. Our results show that, after accounting for the effects of fishing and large-scale oceanographic variability, global MTC increased at a rate of 0.19 degrees Celsius per decade between 1970 and 2006, and non-tropical MTC increased at a rate of 0.23 degrees Celsius per decade. In tropical areas, MTC increased initially because of the reduction in the proportion of subtropical species catches, but subsequently stabilized as scope for further tropicalization of communities became limited. Changes in MTC in 52 large marine ecosystems, covering the majority of the world's coastal and shelf areas, are significantly and positively related to regional changes in sea surface temperature Projections of future distributions of exploited species and their potential catches suggest that fisheries stocks in the tropics will be negatively impacted by continuous ocean warming and changes in primary production, resulting in reduction in catch potential in the tropics. Ocean warming has already affected global fisheries in the past four decades which will continue into the future. The studies highlight the immediate need to develop adaptation plans to minimize the effect of such warming on the economy and food security of coastal communities, particularly in tropical regions.

Presentation 2 (Session 1)

Quantifying spatial variability in species distributions: an example from the eastern Bering Sea

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Empirical indicators that quantify the spatial distribution of a species or population on land or in the sea include the center of distribution, the northern- and southern-most range limits, the spatial spread of a population (inertia), the fraction of a survey area occupied, measures of spatial structure (patchiness), and many others. Such descriptors based on either presence/absence or measures of abundance provide simple summary measures of central location or spread, but may not adequately capture relative changes that affect the spatial pattern of distribution without necessarily affecting the central location or the overall spread. Here an alternative measure of distribution is proposed that is sensitive to complex distributional changes without being strongly affected by measurement variability. The proposed measure is based on what is known as an Empirical Orthogonal Function (EOF) analysis in oceanography or as a Principal Components Analysis (PCA) in statistics and is based on an eigen-analysis of the variance-covariance matrix of multiple time-series of abundance (catch per unit of effort) obtained at a fixed set of survey stations that have been consistently sampled over time. The resulting primary mode(s) of variability (EOF modes or Principal Components) provide both a map of major spatial anomalies in the distribution of a species or group of species across the survey area (spatial loadings) and a time-series (Principal Component scores) that captures the sign and magnitude of the anomalies (Figure 5.1, a,b).

To examine the influence of climate variability on spatial distribution, measures of spatial distribution are often correlated with or modelled as a function of temperature and other environmental drivers. Here we show that direct effects of temperature and measures of advection on the spatial patterns of distribution of 46 taxa sampled consistently from 1982 to 2012 in the eastern Bering Sea were often much smaller than the apparent effects of changes in the abundance or density of a given taxon (intraspecific density-dependent effects; Figure 5.2). The response of some species, such as rock sole (Figure 5.1), is consistent with MacCall's (1990) basin hypothesis, which suggests that an increase in abundance leads to increases in density in the core area as well as an expansion into marginal habitats (Figure 5.3a). The hypothesis can be modified to allow for a geographic boundary, such as a coastline, that limits the expansion of the population from their center of distribution (Figure 5.3b). Under the basin model, an increase in abundance leads to a proportionally larger increase in local densities in marginal habitats compared to core habitats, hence the presence of a physical boundary will result in a pronounced shift in the center of distribution, as well as the edge of the range, away from the boundary. When attributing distributional shifts to climate variability or climate change, it is important to account for the effects of changes in abundance, which may occur independently of changes in climate. Moreover, in addition to intraspecific density-dependence, there are strong interspecific effects on the distributions of all species as evident in the high average absolute correlations ($|r| =$) among the first principal component scores across 46 taxa in the eastern Bering Sea.

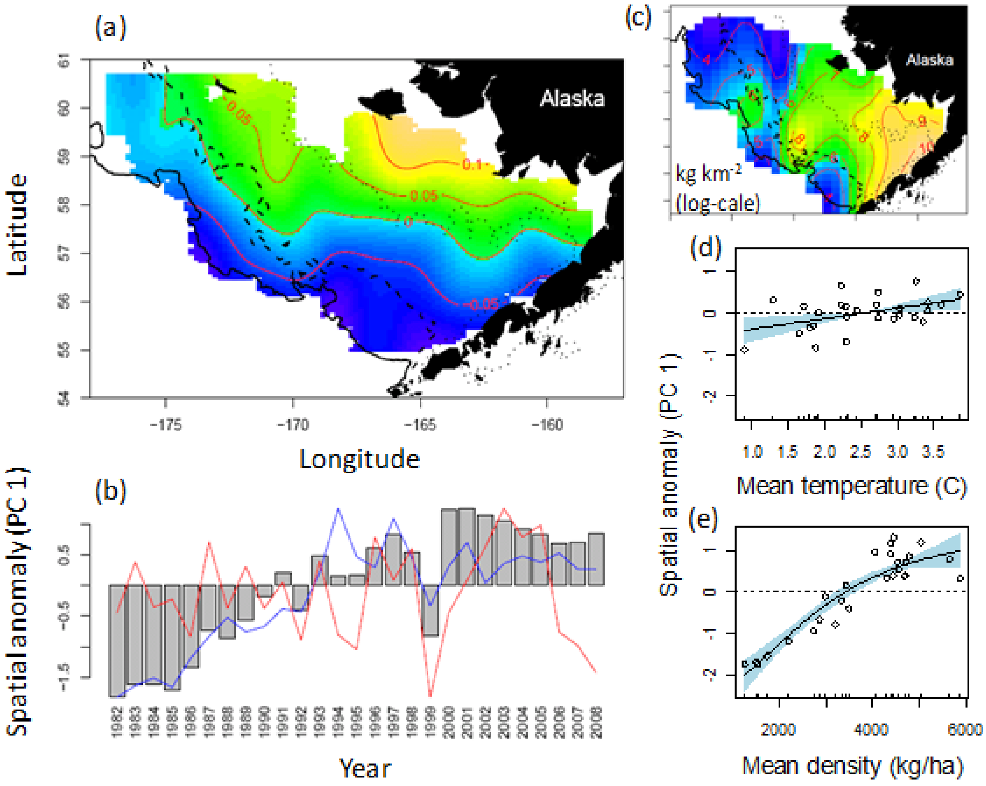

Figure 5.1. (a) Spatial loadings and (b) time-series (grey bars) of the first principal components from a PCA of catch-per-unit effort time-series for rock sole (*Lepidopsetta* spp.) at 284 stations sampled consistently between 1982 and 2012 in the eastern Bering; (c) Mean spatial patterns of log-transformed catch-per-unit-effort of rock sole (kg ha-1). Estimated effects of (d) mean bottom temperature and (e) mean rock sole density on the spatial anomaly (PC1) based on a multiple, non-parametric regression of PC 1 on temperature and density. The spatial loadings in (a) depict relative anomalies from the mean spatial pattern (c) during periods when the PC1 loadings (b) are positive. Red and blue lines in (b) show standardized time-series of mean bottom temperature (red) and density (CPUE, blue).

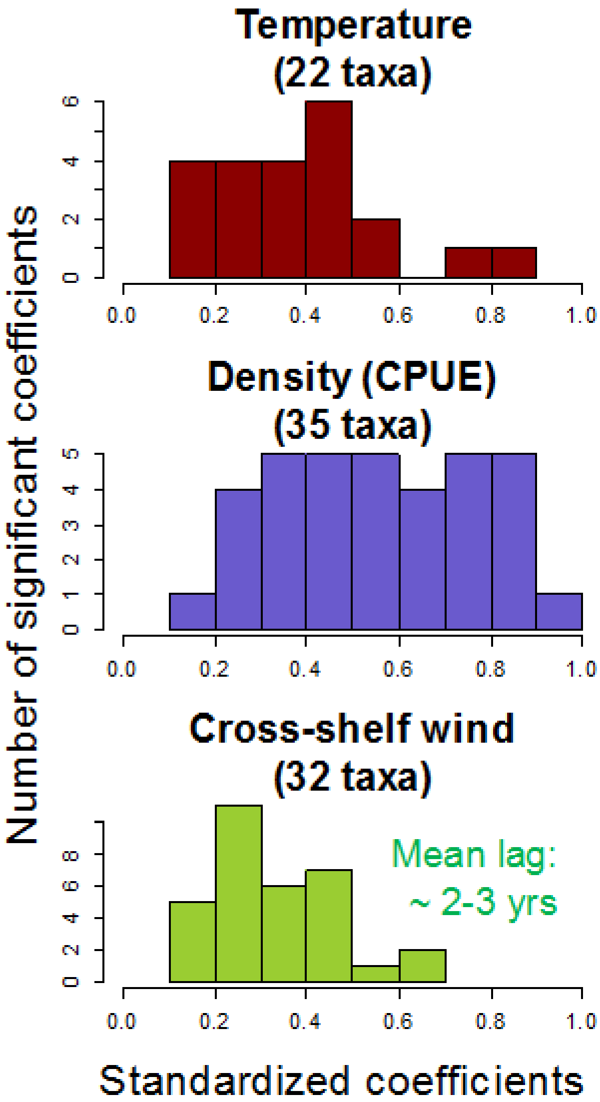

Figure 5.2. Histograms of the estimated effects of temperature, density (CPUE) and cross-shelf winds on spatial distribution based on a multiple linear regression of PC1 for 46 taxa (see Figure 1 for example). Variables were standardized to mean 0 and standard deviation 1 prior to regression, hence coefficients are comparable across variables. Only coefficients that were individually significant at the 95% significance level are shown and the number of taxa with significant coefficients is noted.

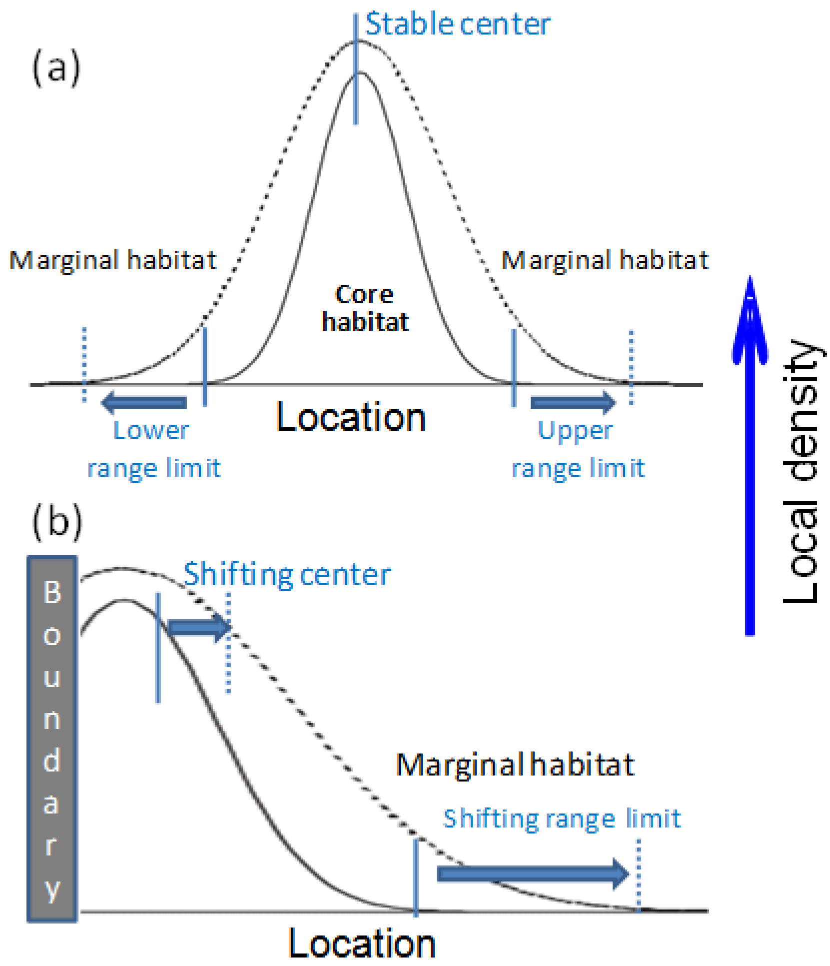

Figure 5.3. (a) Local density of a species under Mac Call's (1990) basin model at low (solid line) and high (dashed line) abundances (top). Range limits (vertical bars) expand when the abundance increases, while the center remains stable; (b) Modified basin model in the presence of a geographical boundary. Both the center and the range limits shift in the presence of a boundary when the abundance increases.

Presentation 3 (Session 2)

Applying a multi-model approach to predict species' distributions

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Species distribution models are important tools to explore the effects of future global change on biodiversity. AquaMaps, Maxent and the Sea Around Us project algorithm are three approaches that have been applied to predict distributions of marine species. They were designed to cope with issues of data quality and quantity common in species distribution modelling. However, the characteristics of model projections for marine species from these different approaches have rarely been compared. Such comparisons provide information about the robustness and uncertainty of the projections, and are thus important for spatial planning and developing management and conservation strategies. We therefore applied the three species distribution modelling methods to predict the current distributions of a set of commercial fish in the North Sea and North Atlantic, with the aim of drawing comparisons between the approaches. Predicted current distributions were tested following data partitioning and selection of pseudo-absences and the effect of different assumptions within each approach on the predicted current relative environmental suitability was assessed. As indicated by the test statistics, each modelling method produced plausible predictions of relative environmental suitability for each species, with subsequent incorporation of expert knowledge generally improving predictions. However, because of the differences between modelling algorithms, methodologies and patterns of relative suitability, comparing models using test statistics and selecting a 'best' model are not recommended.

The models were subsequently used to make projection of species' potential distribution shifts under climate change. Figure 5.4. shows an example of the range of results obtained for the predicted shift in latitudinal centroids of a set of threatened species predominantly inhabiting the North Sea. Results were obtained using the three species distribution models and data from two global climate models, both modelled under the SRES A2 emissions scenario (GFDL ESM2.1, (Dunne *et al*. 2010) and the World Climate Research Program (WCRP) Coupled Model Inter-comparison Project phase 3 (CMIP3) multi-model dataset (http://esg.llnl.gov:8080).

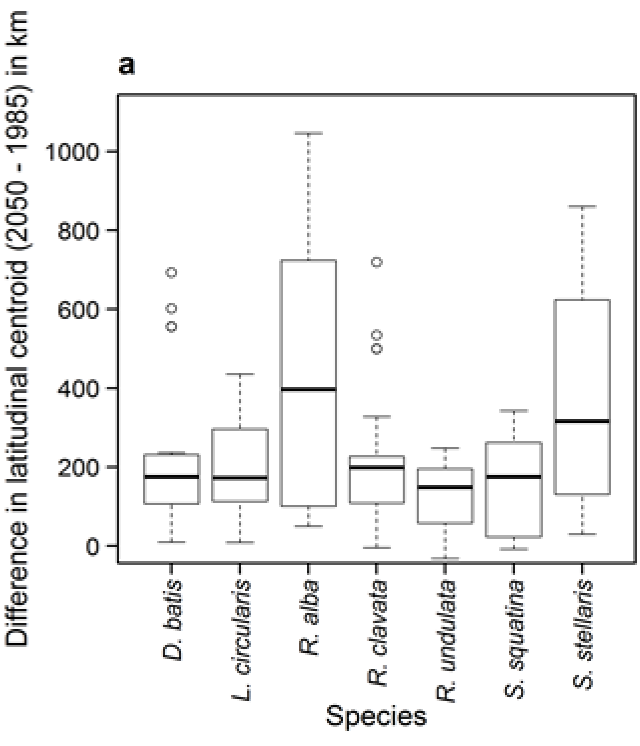

Figure 5.4. Projected change (in km) in latitudinal centroid from 1985 to 2050 across the six SDM and climatic dataset combinations for threatened species. (Jones *et al.*, 2013).

Thus although we proposed that a multi-model approach should be preferred and a suite of possible predictions considered to minimize biases due to uncertainty in data and model formulation, considering predictions from alternative models, the intractability and uncertainty resulting from a suite of predictions may hinder the application of science in policy, where a single prediction with little ambiguity or uncertainty would be most desirable. We therefore applied an ensemble prediction to assess the distribution of suitable environmental space for the invasive Pacific oyster, *Crassostrea gigas*, in UK waters both currently and in the future. The ensemble incorporates predictions from three species distribution models, using data from two global climate models. We develop a method highlighting the agreement of the ensemble, further applying threshold values to retain information from constituent predictions in the final map of agreement.

Further information on this work and the modelling procedures used can be found in Cheung *et al*. (2011), Jones *et al*. (2012 and 2013).

Presentation 4 (Session 2)

How to model fish migration and distribution under future climate?

Shin-ichi Ito and Takeshi Okunishi

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Climate change effects on fish migration and distribution have been examined in several studies (e.g. Okunishi *et al*., 2012a; Ito *et al*., 2010; 2013). To make mechanistic projection of fish distribution under future climate, at least, three types of models 1) growth model, 2) reproduction model, and 3) migration model are essential in addition to environmental conditions (Figure 5.5). Incorporating movement behavior of fish in models is essential to predict spatial distribution of fish under future climate. Spawning behavior (place and season) may also be modulated under the future climate. For the closure of target species life history, a reproduction model is required. Modification of the spawning ground and migration route may alter the match–mismatch of fish with prey/predator and hence growth and survival of fish.

For growth model, bioenergetics model (Wisconsin model, e.g. Ney, 1993) is a major solution. The growth is defined by the difference between consumption and dissipations including respiration, specific dynamic action, egestion, excretion, and egg production in the bioenergetics model. Each term is a function of weight, temperature, prey density, etc. Therefore, it is usually impossible to know all the parameters even for one target species under natural condition. In addition, it is not unusual that parameters estimated under laboratory experiments are far from those speculated under natural conditions (e.g. because of different prey). Another big issue in the growth model is that accuracy of prey plankton models is usually immature to predict fish growth. This is because bottom–up focusing scientists start from phytoplankton and top–down focusing scientists start from fish (Figure 5.6). Therefore, zooplankton resolution or accuracy often becomes an weakness of marine ecosystem models (Ito *et al*., 2010).

Bioenergetics models sometime include a production term (e.g. Hanson *et al*., 1997). Income-breeder, who immediately utilize energy inputs from prey to egg production, is simple to be modelled (e.g. Pacific saury: Ito *et al*., 2004; Japanese anchovy). However, capital-breeder, who reserve energy inputs from prey for specific duration, is difficult to be modelled (e.g. Japanese sardine: Okunishi *et al*., 2009). Therefore, sometime a simple spawner-recruitment model is applied for the closure of the life cycle (e.g. herring: Megrey *et al*., 2007). Anyway, it is essential to close the life cycle of the target species in the model. Another issue for reproduction models is that many species have spawning grounds in narrow coastal regions where needs high resolution ocean circulation model. For physical models to provide useful information for the estimation of nearshore fish production, the physical model needs to resolve the shelf and coastal morphology (bathymetry and coastline) on relatively fine temporal and spatial scales (Ito *et al*., 2010). Decadal to centurial simulations are necessary in order to make projections of fish distribution under future climate. Such kind of simulations needs tremendous computer power and is a big challenge of the physical-chemical models.

For migration models, fish behavior determines their migration, however, fish behavior is not usually well elucidated (e.g. Hamston *et al*., 2004). We don't know how clever fish is (period of information memory, searching area, searching frequency, 2D or 3D recognition; Figure 5.7). We do not know the motivation of the fish / the environmental cues (temperature, salinity, oxygen, ocean color, light, prey, magnetic, tide, conversation, etc.). We do not know the response of fish (random search or gradient search for bad condition; keep going or slow down for good condition). An example is provided for modelling Japanese sardine migration. Okunishi *et al*. (2009) reasonably reproduced migration of Japanese sardine using NEMURO.FISH (Ito et al., 2004; Megrey et al., 2007) as a growth model. Okunishi *et al*. (2009) applied a fitness algorithm for the feeding migration. However, recent observation showed fish distribution in the northern area across the Subarctic Boundary. We applied three types of migration algorithm to the feeding migration and compared the results. First is the fitness algorithm in which the fish is assumed to move toward the optimal growth direction. The second is the kinesis model algorithm in which the fish movement is denoted by two components including movement depending on the previous migration and random movement. The third is the extended kinesis model in which a component to keep the direction but slow down the speed is added for a better condition compared with previous (Okunishi *et al*., 2012b). Compared three types of migration algorithms and only the extended kinesis was able to reproduce northward migration of sardine across the Subarctic Boundary (Okunishi *et al*., 2012b).

The result seems to mean that the slowdown behavior with better condition is a crucial mechanism of sardine migration. However, if an escaping behavior from predatory fish was included, the fitness algorithm was also able to reproduced the northern migration across the Subarctic Boundary. Therefore, a pattern matching does not seem enough skill assessment. Different mechanisms can reproduce a similar pattern. In meteorology, Taylor diagram (Taylor, 2005) is often used for model skill assessment. However, to draw the diagram, fish distribution data are too sparse in space and time. For large species, fish behavior (e.g. archival tag data) seems feasible for the skill assessment. For small species, since it is difficult to conduct tag observations, synoptic surveys (e.g. acoustic survey) seem feasible for the skill assessment. Since data are insufficient, model comparisons seem good strategy to improve models. Model portability may be a good index for the skill assessment.

In conclusion, to project fish distribution under future climate, improvements of growth, production and migration models are essential. We listed big challenges of these three model components, 1) improvement of biological growth information, 2) improvement of zooplankton prediction, 3) modelling of reproduction process of capital breeders, 4) long integration of biological oriented high resolution models, 5) modelling of fish behavior, 6) modelling species interaction, and 7) skill assessment of models. In addition, 8) modelling density-dependent effect and 9) modelling spawning migration are also big challenges. Model intercomparison seems key process to improve the model skills. High technical observation methods (compact tags, contacting buoys, etc.) to observe fish behavior are essential. Laboratory experiments are also needed to improve the model skills.

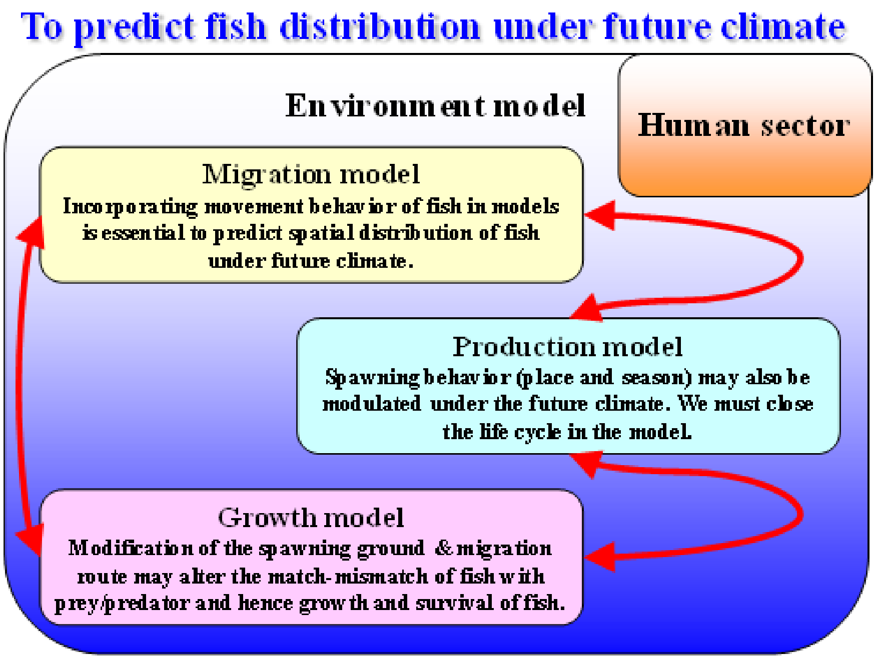

Figure 5.5. Three components of models to make mechanistic projection of fish distribution under future climate.

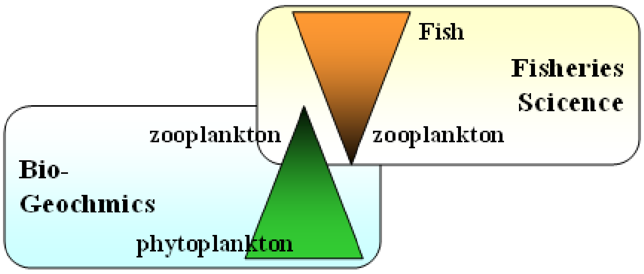

Figure 5.6. A weakness of marine ecosystem models in zooplankton resolution or accuracy. This is because bottom–up focusing scientists start from phytoplankton and top–down focusing scientists start from fish.

Figure 5.7. Unknown fish behavior in migration models.

Presentation 5 (Session 3)

Climate Simulations and Projections over Russia and the Adjacent Seas: A CMIP5 Update

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Within the framework of the preparation of the IPCC Fifth Assessment Report (AR5), the fifth phase of Coupled Models Intercomparison Project (CMIP5) was initiated by the World Climate Research Programme. CMIP5 simulations are performed by more than 20 modelling group using more than 50 models *(Taylor et al., 2012).* Our report includes an assessment of climate simulations over Russia and its adjacent seas in CMIP5 model ensemble compared to CMIP3 simulations and observations. Projected climate changes for the territory of Russia are considered as well.

Special attention is paid to the Arctic Sea ice simulations and projections. Ice cover of the Arctic seas directly influences the marine economic activity, including fishery. Sea ice extent is the most reliably measured characteristic of sea ice to evaluate models. Compared to CMIP3, CMIP5 ensemble mean is in better agreement with the observed mean climatological state of the sea ice cover and the rate of decline ice extent over the satellite observation period. It should be noted, however, that linear trends in September sea ice extent simulated by most of CMIP5 models remain smaller than the observed value. Nevertheless some models reach nearly ice-free state (sea ice extent in September less than 1 million km^2) in the first half of 21st century (Figure 5.8).

Projected changes in surface air temperature and precipitation over Russia under RCP4.5 and RCP8.5 scenarios by the middle of 21st century are presented as well.

The detailed assessment of climate simulation and projections over Russia will be done in the Second Assessment Report on Climate Change and Its Consequences in Russian Federation. The Report will be published in 2014. Special chapters of the Report are devoted to the impact of climate change on marine ecosystems in the Russian Arctic Seas, Baltic Sea, Russian Southern Seas and Far Eastern Seas.

The use of climate model outputs in practical applications is a significant scientific challenge. The key questions of using model data projections in applications have been discussed recently at the Arctic Monitoring and Assessment Program (AMAP) workshop "Adaptation Actions for a Changing Arctic" which was held in St Petersburg, Russia, 22–24 April, 2013. As was pointed out at the workshop, model data can be useless or even misleading if used improperly. Improper use of model data are a result of both unsatisfactory communication between providers and users and existing major gaps in the scientific knowledge. The scientific problems of model data use in impact studies and risk assessments include approaches to model discriminations, dealing with model ensembles and associated probabilities and uncertainties, added value and added uncertainties of downscaling techniques, different confidence in model projections of different climate variables, etc.

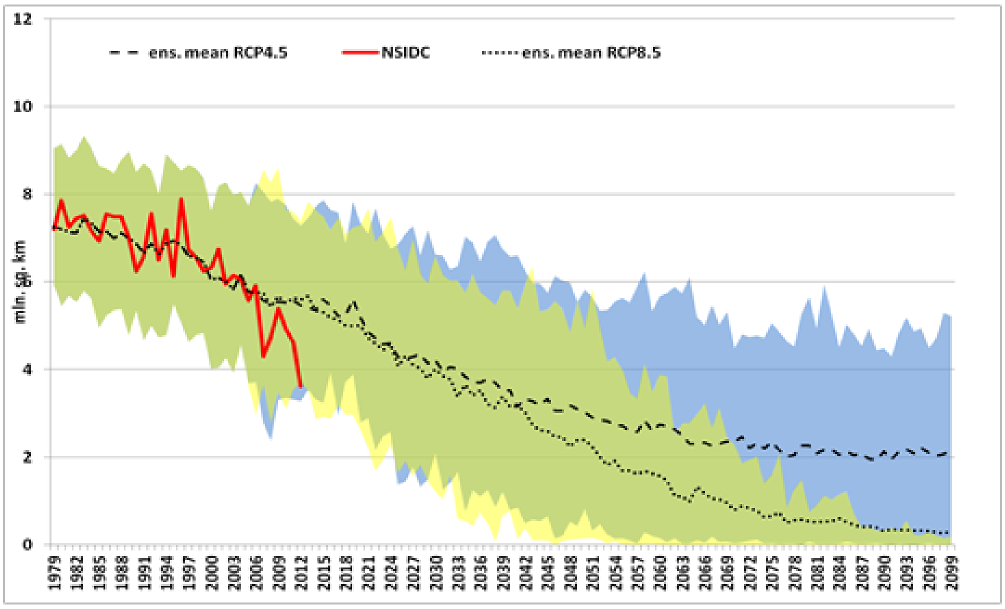

Figure 5.8. Arctic September sea-ice extent from observations (NSIDC, solid red line), CMIP5 multi-model ensemble mean for RCP4.5 (dark dashed line) and RCP8.5 (dark dotted line) emission scenarios, and inter-quantile ranges (10th to 90th percentiles) of the model estimates for RCP4.5 and RCP8.5 scenarios (blue and yellow shadings, respectively). ***(Pavlova and Kattsov, 2013).***

Acknowledgements

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modelling groups for producing and making available their model output. For CMIP the US Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals

Some of the results presented in our report were obtained under projects supported by the Russian Foundation for Basic Research (grants 11-05-00734 and 12-05-01069) and The Russian Humanitarian Scientific Foundation (grant 12-32-06001)

Presentation 6 (Session 3)

Uncertainty in forecasts of Species Distribution Models: a brief overview

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Species Distribution Models (SDMs) are statistical models linking the presence or abundance of a given species to environmental parameters such as temperature, salinity, rainfall, productivity, bathymetry, etc. They may also include mechanistic components modelling explicitly ecological processes such as dispersion or reproduction (Mokany and Ferrier 2006), and they can be used to forecast the possible distribution of species under diverse global change scenarios. These forecasts assume that the shape of the modelled species-environment relationships remains the same although environmental conditions are changing.

To forecast the distribution of a species under a global change scenario, first a SDM must be fitted and then a scenario must be chosen, with which SDM predictions will be produced. In the case of marine species, these scenarios will be issued from the coupling between climatic and oceanographic models that will predict the fate of water masses under atmospheric warming. Various sources of uncertainty are associated to this process (Figure 5.9).

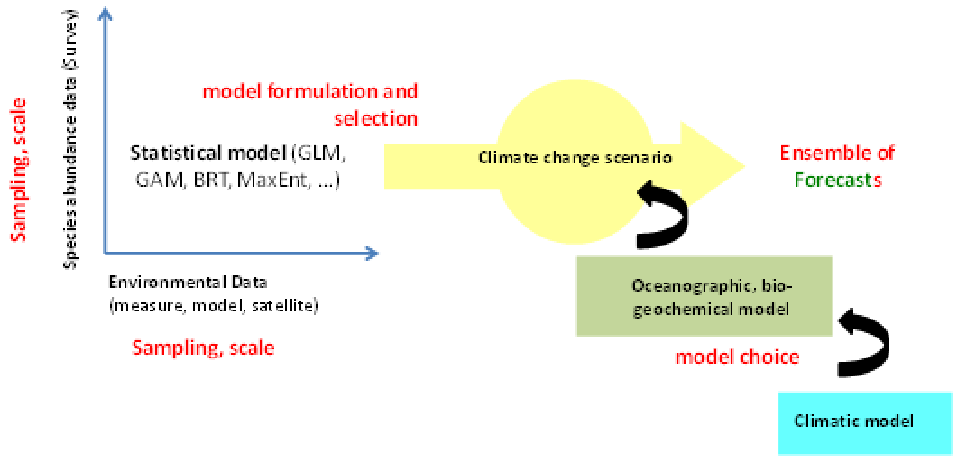

Figure 5.9. Forecasting Species Distribution, and associated sources of uncertainty in red.

First, sampling and scale-related uncertainties affect classically the input (both response and predictors) of the species distribution model. Uncertainty and scale are often inversely related, as model predictive performance can decrease with increasing spatial or temporal resolution Levin (1999). When designing a SDM, the input data are often assembled from various sources (survey, model, satellite, etc…) and may not be available at the same spatial or temporal scale. Choices need to be made on the scale on which the analysis is performed, which can influence the results and therefore introduce uncertainty. Second, different statistical framework can be used to build the SDM, either generalized linear and additive models, boosted regression trees, entropy-based methods, etc. The choice of the method is another source of uncertainty, which can be dealt with through ensemble forecasting (Thuiller *et al.* 2009). A third source of uncertainty can be found in climatic model. These are deterministic models that mimic the behavior of the atmosphere and oceans through a series of differential equations representing physical processes. However, the way these processes are formulated might greatly influence forecast outputs, as demonstrated in Popova *et al.* (2012). Again, ensemble forecasting is a way to account for these uncertainties (Littell *et al.* 2011).

One challenge of applying ensemble forecasting to both SDMs that predict species distribution and the oceanographic models that produces climate change scenario is that the resulting ensembles might be overwhelming and when fully propagating all sources of uncertainty across the modelling chain pictured in figure 1, getting conclusive results might be difficult. Personally, I think that trying to propagate all these uncertainties when forecasting the distribution of a given species under climate change scenarios might well be an endless and uninformative exercise. However, carrying out modelling experiments to identify the largest uncertainty sources, and being explicit about which uncertainty is dealt with and which is not, can certainly produce useful and interpretable results.

Presentation 7 (Session 4)

On the move: database considerations for synthesis and meta-analysis of climate change impacts on fish/fisheries distributions

NCEAS Working Group on Marine Climate Impacts (presented by William J. Sydeman, Farallon Institute, 101 H. Street, Suite Q, Petaluma, CA 94952; www.faralloninstitute.org; wsydeman@faralloninstitute.org)

Working under the auspices of the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California, a group of marine scientists from across the globe prepared a database to conduct a meta-analysis on the effects of recent climate change on marine life (hereafter MarClim; see Brown *et al*. 2011 in *Global Change Biology*, Burrows *et al*. 2011 in *Science*, Richardson *et al*. 2012 in *Biology Letters*, and Poloczanska *et al*. 2013 in *Nature Climate Change*). In this presentation, one of the group members, WJ Sydeman, described the decisions made in developing the structure and functionality of the database. To implement the database, the MarClim working group conducted a search of the primary literature using keywords: climate change, warming, acidification, expansion, contraction, abundance, calcification and phenology. The group also conducted systematic (page by page) searches of 6 journals: *Global Change Biology, Marine Ecology Progress Series, Progress in Oceanography, Journal of the Marine Biological Association of the UK, Global Ecology and Biogeography* and *Journal of Fish Biology*. Finally, studies to be included in the database were obtained through direct communication with colleagues. The MarClim database includes climate change studies published through January, 2012.

Initial concerns of the group were: 1) that single-species studies are more likely to have publication bias (Parmesan and Yohe 2003 – i.e. single species studies can be published only if results are positive); 2) short time-series may misrepresent long-term trends, and/or overestimate responses due to confounding with interannual/decadal climate variability; and 3) a voluminous literature on climate variability could make database construction unwieldy and difficult to interpret relative to climate change impacts. These initial concerns led to the following decisions regarding data extraction from the published literature: a) papers should be focused on regional climate change; studies explicitly concerning "climate variability" only were excluded from the database; b) authors must infer or test for trends and connections between biological and climatic variables; c) papers must include data after 1990, that is be associated with "recent" climate change; and d) observations must span at least 19 years (both continuous and "between period" studies were included).

For each publication, observations were defined as single biological response variables that were, at a minimum, discussed by a paper's authors in relation to *expected* impacts from recent climate change. Observations were broadly grouped into the response categories: phenology, distribution, abundance, community composition, demography and calcification.

Based on these preliminary criteria for data extraction, the NCEAS MarClim database includes 208 peer-reviewed studies on 857 species and species-assemblages, representing 1735 observations of marine biological responses to climate change. The median time span of observations is 41 yrs with a range of 19–343 yrs; overall, the database contains ~27,000 "observation-years". Observations of larval and adult fish distribution and abundance dominate the database (~850/1735 observations). Most observations came from the California Current, NE and NW Atlantic (including North Sea), Mediterranean Sea, and Eastern Australia, with a preponderance of observations obtained in mid-latitudes (30°–50° N). For each observation, we scored whether the authors interpreted the result as being consistent (1) with expectations under regional climate change (e.g. poleward shift relative to ocean warming) or inconsistent (0) with such expectations. ~80% observations were consistent, but using multispecies studies only (to minimize publication bias), gave a similar consistency (78%).

Regarding distributional shifts, a decision was made to include information concerning study location relative to the range of the species under consideration. In particular, each observation was scored as being central to the distribution or at the leading or trailing edge of the species' range. This decision was made because different processes determine leading and trailing edges, and population growth /abundance often declines at trailing edge but increases at leading edge. Moreover, leading edges are often characterized by greater demographic stochasticity due to colonization effects. This scoring allowed us to examine both distribution and abundance together. We found that trailing-edge range contractions were slower than leading-edge expansions, but could be due to slower temperature velocities in regions where trailing edges were studied (Poloczanska *et al*., 2013).

Extraction of other data from papers was based on a variety of expectations. For example, we extracted information on lifespan because other studies have shown that species with shorter life-histories may move more rapidly than long-lived species. We included information on trophic level because it is hypothesized that planktivorous species may move more rapidly than picsivorous ones. We extracted and included information on whether a species was exploited because these species may be more sensitive to climate change, so their rates of change should be greater than that of unexploited species. We also captured information in the database on the climate variables considered, and whether these showed significant change over the time period of the study. We included fields concerning the robustness of statistical analyses. For example, were there statistical tests for trends in climatic or biological variables, and were variable linked using correlation or regression approaches. Was temporal or spatial autocorrelation considered by the authors?

Ultimately, the NCEAS MarClim database includes 6 fields that specify and describe details of the data source, 16 fields that specify study location and time period**,** 12 variables that describe the biological characteristics of each study, 18 variables, including quantitative measures of distribution change, that concern each observation in each study, and 15 variables that describe the climate variables under study, the authors' attribution of the biological change to climate change, and statistical considerations. These variables were reviewed and discussed. The NCEAS MarClim database is open for use by any interested party and is available from the NCEAS public data repository (www.nceas.ucsb.edu).

Presentation 8 (Session 5)

Vulnerability assessments in fisheries social-ecological systems: some experiences in their development and implementation for adaptation planning

Cassandra De Young (FAO), Eddie Allison (UEA), Cécile Brugère (FAO consultant)

Vulnerability assessments play an important role in the climate change adaptation process in that they link physical changes (either current or projected) with the ability of aquatic and human systems to cope or benefit from such change. In general, a vulnerability assessment helps to target adaptation actions by better understanding who are the vulnerable people\species and how their vulnerability can be reduced, where the vulnerable ecosystems are and whether resource management can improve their capacity to adapt, where the economic consequences of vulnerability of fishery systems will be felt most and how we can plan to minimize those consequences and where climate change will create new opportunities and bring benefits and, importantly, for whom.

In 2001, the Intergovernmental Panel on Climate Change (IPCC) developed a generic model to assist in understanding the multiple facets of vulnerability as "a function of the *sensitivity* of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), *adaptive capacity* (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of *exposure* of the system to climatic hazards" (Figure 5.10).[11] The specific vulnerability questions asked (i.e. vulnerability of whom/what to what changes and why) and the methodologies used to answer these questions will often be influenced by the historical background and disciplinary training of the assessor. That is, an assessment stemming from risk/hazard, resilience or political economy traditions may place different emphasis on the various elements underlying vulnerability, such as whether the hazard itself and its impacts are the main elements of concern or, perhaps, whether differentiate susceptibility to such change is important or whether there are tipping points to such susceptibility. In addition, different disciplines (i.e. natural or social sciences) within these traditions may also frame the vulnerability assessment diversely, such as focusing on the vulnerability of the natural system or of the human system or whether underlying and existing vulnerability to change determines a system's ability to adapt to a climate related driver (focusing on the why of vulnerability) vs. a more linear impacts assessment approach, etc.. Understanding the array of different perspectives and methodologies would support any future vulnerability assessment.

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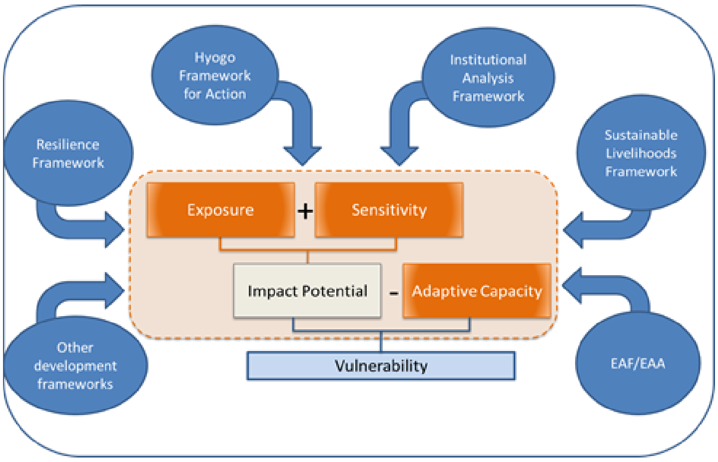
[11] IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC. (also available at http://www.grida.no/publications/other/ipcc_tar/www.grida.no/publications/other/ipcc_tar/)



Vulnerability = f(Exposure, Sensitivity, Adaptive Capacity)

Figure 5.10. The basic IPCC Vulnerability framework supported by other frameworks.

The fisheries and aquaculture sector is gaining experience in applying the IPCC framework as can be seen through an annotated bibliography of recent assessments in the sector (Barsley et al., 2013)[12]; allowing for the development of initial guidance on vulnerability assessment processes for the sector (FAO, 2013).[13] Three examples in marine capture fisheries are provided below:

Example 1:[14]

Vulnerability Question:

How are national economies vulnerable to potential climate change impacts arising through their fisheries (Figure 5.11)?

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[12] Barsley, W., De Young, C & Brugère, C. 2013. Vulnerability assessment methodologies: an annotated bibliography for climate change and the fisheries and aquaculture sector. FAO Fisheries and Aquaculture Circular No. 1083. Rome, FAO. 43 pp. (also available at www.fao.org/docrep/018/i3315e/i3315e.pdf).

[13] FAO. 2013. Report of the FAO/PaCFA Expert Workshop on Assessing Climate Change Vulnerability in Fisheries and Aquaculture: Available Methodologies and their Relevance for the Sector, Windhoek, Namibia, 8–10 April 2013. FAO Fisheries and Aquaculture Report No. 10473. Rome.

[14] Allison, E.H., Perry, A.L., Badjeck, M.C., Adger, W.N., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. & Dulvy, N.K. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries, 10(2): 173–196.

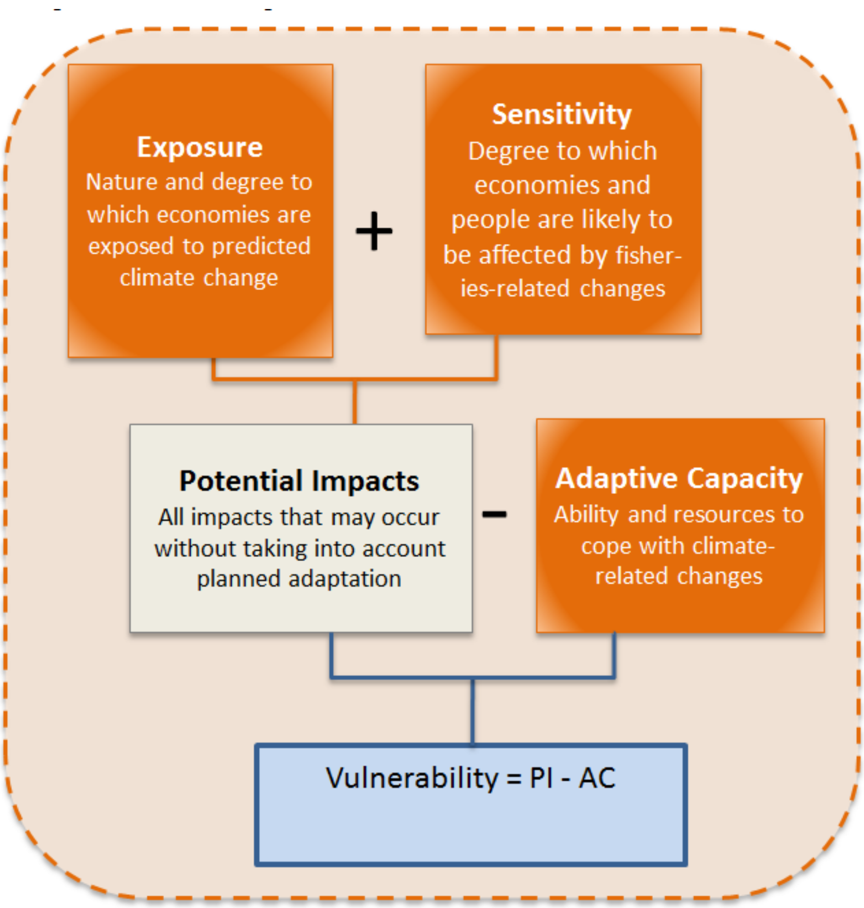

Figure 5.11. Vulnerability framework for Example 1.

Data and methods:

Indicator based for 132 nations

Exposure - 2050 surface temperatures (HadCM3 model, 2 scenarios)

Sensitivity (Fisheries dependency – marine and inland) - Landings and contribution of fisheries to employment, exports and dietary protein (FAO, World Bank)

Adaptive capacity - Human development indices (health, education, governance, and economy size)

Presentation of results:

Global mapping of relative vulnerability of national economies is shown in Figure 5.12

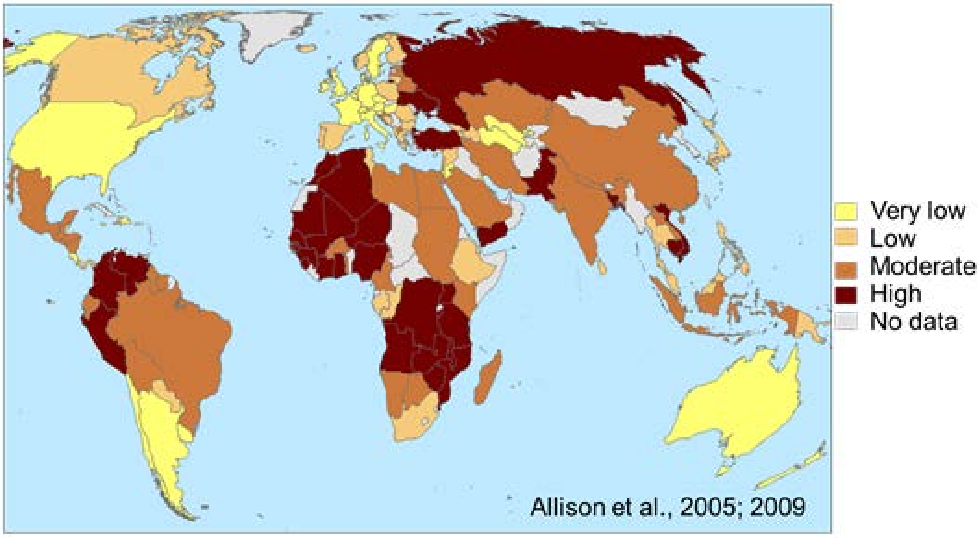

Figure 5.12. Vulnerability of national economies in Example 1.

Example 2:[15]

Vulnerability Question: How are Pacific SIDS economies vulnerable to CC through potential changes in tuna fisheries?

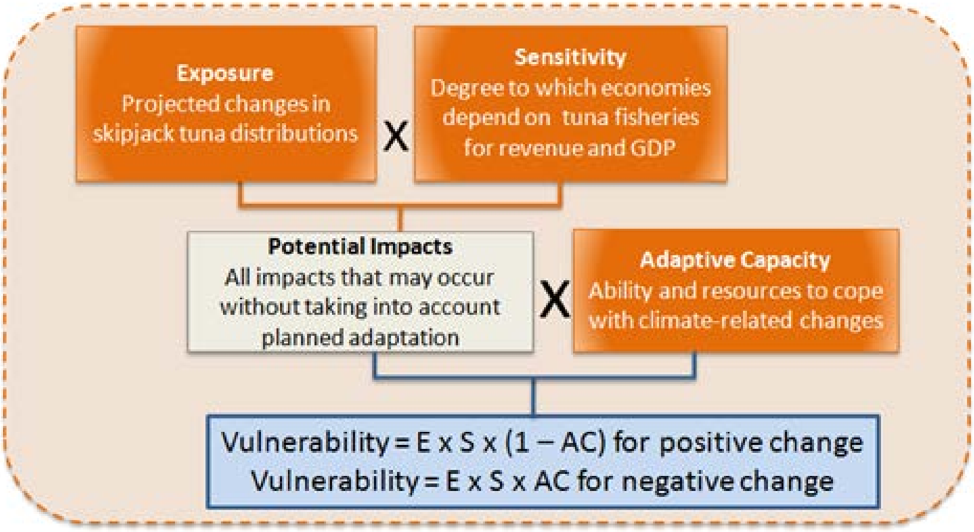

Figure 5.13. Vulnerability framework in Example 2.

Data and methods:

Exposure estimated from projected change in tuna catch

Sensitivity estimated as average contribution to government revenue and GDP

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[15] J.D. Bell, J.E. Johnson & A.J. Hobday, eds. *Vulnerability of tropical pacific fisheries and aquaculture to climate change*, pp. 647–731. Noumea, New Caledonia, Secretariat of the Pacific Community. (also available at http://www.spc.int/climate-change/fisheries/assessment/e-book/).

Adaptive capacity estimated from four indices – health, education, governance and the size of the economy

Presentation of results:

Comparative benefits and vulnerabilities of selected Pacific Island countries and territories

PICT	2035	2050	2100
PNG	+ Very low	- Very low	- Very low
Solomon Islands	+ Very low	- Very low	- Low
FSM	+ Low	+ Very low	- Low
Kiribati	+ Very high	+ Very high	+ Very high
Marshall Islands	+ Low	+ Low	+ Low
Nauru	+ Moderate	+ Moderate	- Very low
Palau	+ Very low	+ Very low	- Very low
Tokelau	+ High	+ High	+ Very high

Example 3:[16]

Vulnerability Question: What is the Social-ecological vulnerability of coral reef fisheries to climate change?

[16] Cinner, J., McClanahan, T., Wamukota, A., Darling, E., Humphries, A., Hicks, C., Huchery, C., Marshall, N., Hempson, T., Graham, N., Bodin, Ö., Daw, T. & Allison, E. 2013. Social-ecological vulnerability of coral reef fisheries to climatic shocks. FAO Fisheries and Aquaculture Circular No. 1082. Rome, FAO. 63 pp. (also available at http://www.fao.org/docrep/018/ap972e/ap972e.pdf)

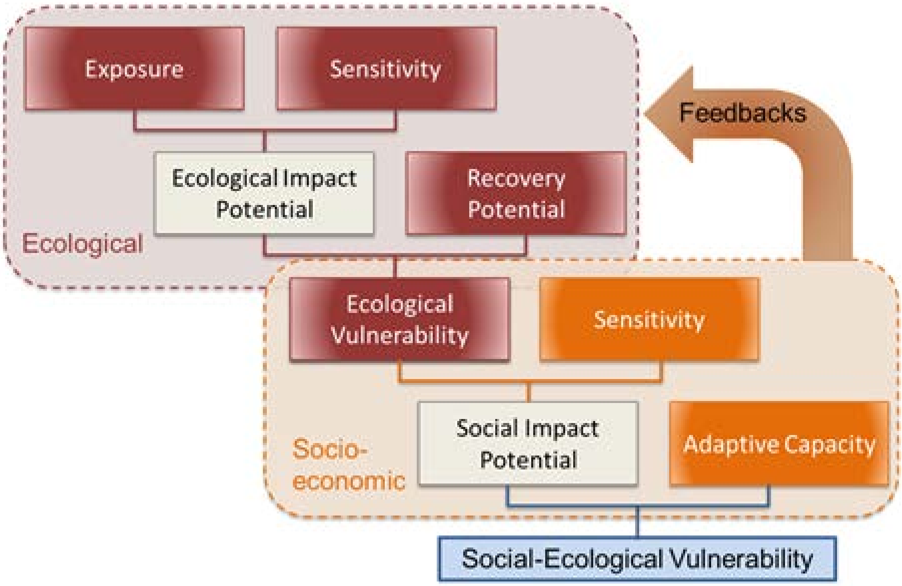

Figure 5.14. Vulnerability framework for example 3.

Data and methods:

Ecological exposure – based on temp, currents, temperature, light, tidal variation, chlorophyll, water quality - Site-specific index of bleaching stress

Ecological Sensitivity – 2 indicators

Susceptibility of coral community to bleaching

Susceptibility of fish community to population declines associated with coral habitat loss from bleaching

Ecological Recovery Potential

5 indicators for corals, 6 indicators for fish species

Social Exposure = Ecological Vulnerability

Social Sensitivity - 2 indicators:

Livelihood sensitivity: dependence on marine resources

Gear sensitivity: data on how susceptible the catch composition of different gears is to coral bleaching

Social adaptive capacity – 11 indicators:

1) Recognition of causal agents impacting marine resources

2) Access to credit

3) Occupational mobility

4) Occupational multiplicity

5) Social capital

6) Material assets

7) Technology

8) Infrastructure

9) Debt levels

10) Trust of community members, local leaders, police, etc

11) Capacity to anticipate change and to develop strategies to respond

Presentation of results (Figure 5.15):

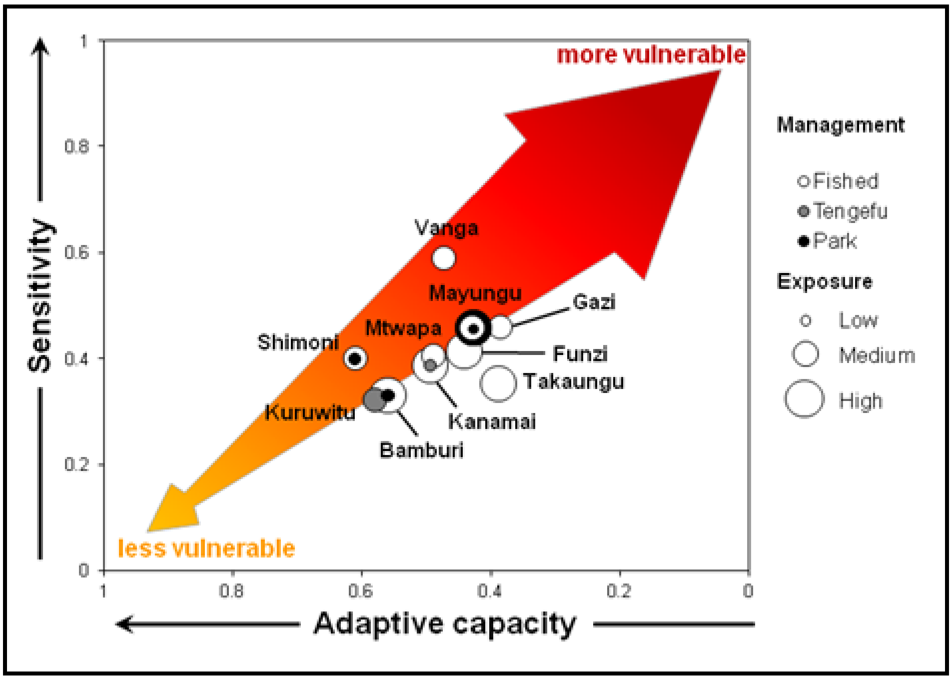

Figure 5.15. Results of the vulnerability assessment in Example 3 showing the social-ecological vulnerability for 10 Kenyan communities.

A few recommendations stem from existing experiences and include the importance of defining clearly the vulnerability questions needing to be answered in a particular assessment, the understanding that the scale, approach and method of vulnerability analysis used should be determined by its purpose but will be influenced by resources, time, expertise and availability of data, the benefits of combining top–down and bottom up analyses, keeping indicators simple, pathways of impact clearly defined and policy/practice objectives in focus, the acknowledgement that a vulnerability assessment is a means to an end and, therefore, may not require huge investments to resolve all questions.

Presentation 9 (Session 5)

Assessing species-specific responses to marine climate change in south-east Australia

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[4] **Simon Fraser University, British Columbia, Canada**

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Marine waters off south-eastern Australia produce more than 50% of the country's wild-caught seafood and are recognized as a global "hot spot" for marine climate change, with ocean warming in some areas at 3-4 times the global average. The region provides a useful a case study for developing a framework for prioritizing research to inform fisheries adaption to climate change, and for assessing species responses. Long-term fisheries datasets are available, considerable warming has already occurred, fisheries target a wide range of species and use a diversity of methods, there are complex social considerations (e.g. access by commercial, recreational and indigenous sectors), and there are five jurisdictions, each with different environmental and fisheries management legislation and systems.

We conducted a high-level screening risk assessment to identify the physical and chemical parameters that may determine impacts, the life-history stages of key fisheries species likely to be impacted and to highlight critical data gaps, relevant to future assessment and adaptation (Pecl *et al*., 2011). Literature reviews were conducted to develop 'assessment profiles' for key species; the likely physical drivers of climate change stressors were identified for each species and the economic and social values of each fishery were assessed. Innovative risk assessment methodologies were developed and applied to identify the relative vulnerability (i.e. sensitivity and exposure) of key species and the future research needs were prioritized and used to inform the development of a research program to inform future adaptation required in the management realm. Substantial effort had already been made to develop a rigorous methodology for the Ecological Risk Assessment for the Effects of Fishing (ERAEF; Hobday *et al*., 2007). In the ERAEF methodology, an approach for estimating the relative productivity of species had been developed where biological attributes of the species' life cycle are used (combined) to yield a productivity score (or measure of the potential to increase in abundance), which is the approach adopted in this work. We extended the ERAF methodology to recognize that climate change impacts can be expressed by a change in a species' abundance, distribution, or phenology. With regard to abundance, higher productivity species are considered to be less sensitive (more resilient, can recover more quickly) to climate change stressors; low productivity species are considered more sensitive (and less resilient, and slower to recover). Similarly, attributes were developed to estimate the sensitivity of species to realize changes in distribution. The third measure of sensitivity incorporated in the risk assessment was to develop attributes for estimating the sensitivity of species to changes in the timing of their life cycle events (phenological changes, such as spawning, moulting and migration). Fisheries species assessed as the highest risk were also the regions most valuable, i.e. blacklip and greenlip abalone and southern rock lobster. Temperature was the most commonly cited driver of current or potential climate change. Potential changes in currents, freshwater inflows and salinity were also identified as important and impacts of ocean acidification were highly uncertain. Major data gaps included: environmental tolerances, population linkages, ecological relationships (i.e. predator–prey), factors controlling timing of life cycle events and likely responses to lowered pH.

Attributes, criteria and risk categories used to assess climate change risk for each species.

Sensitivity attribute		Risk category (sensitivity and capacity to respond to change)		
		High sensitivity (3), low capacity to respond (higher risk)	**Medium (2)**	**Low sensitivity (1), high capacity to respond (lower risk)**
Abundance	Fecundity – egg production	<100 eggs per year	100–20,000 eggs per year	>20,000 eggs per year
	Recruitment period – successful recruitment event that sustains the abundance of the fishery.	Highly episodic recruitment event	Occasional and variable recruitment period	Consistent recruitment events every 1–2 years
	Average age at maturity	>10 years	2–10 years	≤2 years
	Generalist vs. specialist – food and habitat	Reliance on both habitat and prey	Reliance on either habitat or prey	Reliance on neither habitat or prey
Distribution	Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk-sac re-adsorption (pelagic species).	<2 weeks or no larval stage	2–8 weeks	>2 months
	Capacity for adult/juvenile movement – lifetime range post-larval stage.	<10 km	10–1000 km	>1000 km
	Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance.	<10º latitude	10–20º latitude	>20º latitude
	Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range.	No unoccupied habitat; 0 – 2º latitude or longitude	Limited unoccupied habitat; 2–6º latitude or longitude	Substantial unoccupied habitat; >6º latitude or longitude
Phenology	Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows.	Strong correlation of spawning to environmental variable	Weak correlation of spawning to environmental variable	No apparent correlation of spawning to environmental variable

	Environmental variable as a phenological cue for settlement or metamorphosis	Strong correlation to environmental variable	Weak correlation to environmental variable	No apparent correlation to environmental variable
	Temporal mismatches of life cycle events – duration of spawning, breeding or moulting season.	Brief duration; <2 months	Wide duration; 2–4 months	Continuous duration; >4 months
	Migration (seasonal and spawning)	Migration is common for the whole population	Migration is common for some of the population	No migration

As with many regions around the globe, the south east region of Australia has already had major distributional shifts recorded for several dozen taxa, however, the rate of range extension or contraction varies in both space and time. To minimize negative impacts and maximize opportunities, we ultimately need to 1) understand the mechanisms behind such shifts, 2) develop the capacity to predict species responses into the future and 3) monitoring infrastructure in place to capture distributional changes within reasonable time frames and with a degree of certainty.

Variation among species responses may be attributable, at least in part, to variation in intrinsic traits that differentially promote range expansions. We combined range shift observations of 150 fish and invertebrate species with a database of ecological traits, and asked if variation in range shifts was related to probabilities of arrival and establishment using available morphological and life-history data to represent each hypothesis (Sunday *et al* in prep). Whilst life-history traits were not useful in predicting species that shiftedvs.those whose distribution remained stable, species traits could be related to the degree of shift among those species that exhibited a change in distribution. However, the traits that were related to the rate of shift differed between fish and invertebrates, and some taxa exhibited much greater variation in the extent shifted compared to others, even under same degree of warming.

Although shifts in species distributions are one of the major responses recorded here, and globally, monitoring at the necessary temporal and spatial scales is challenging. We have developed an initiative that serves as a communication and engagement mechanism with our marine stakeholders, as well as a citizen science' monitoring platform. Redmap (Range Extension Database and Mapping project, www.redmap.org.au, (Figures 5.16 and 5.17)) is a multi-award winning online database and mapping resource allowing members of the public to submit observational data (including photographs) of marine species occurring outside their known distribution (i.e. species that may be undergoing range shifts). A successful pilot in Tasmania has now expanded to an Australia-wide long-term biodiversity monitoring system, designed to be a low-cost and sustained approach to assessing changing marine species distributions. Australia has over 3.5 million fishers and divers - many equipped with consumer electronics and the capacity to record verifiable observations. However, one challenge to the adoption of such datasets is the perception of bias or low quality. In addition to extracting geo-tag information from photographs (validating location), species identifications are verified by essentially 'crowd-sourcing' from a large panel of expert scientists using a semi-automated validation workflow. This initiative has the potential to generate large amounts of valuable information for researchers, engage communities, including Indigenous coastal communities, fishers and industry, in climate science (using their own data), and raise awareness of climate change impacts and consequences. Redmap is an early warning system for changes occurring in the marine environment, and has the potential to play a pivotal role in directing management decisions and actions. Importantly, Redmap is involving Australia's marine industries in the actual creation of the knowledge base that is being used to assess how our marine ecosystems are responding to a changing climate.

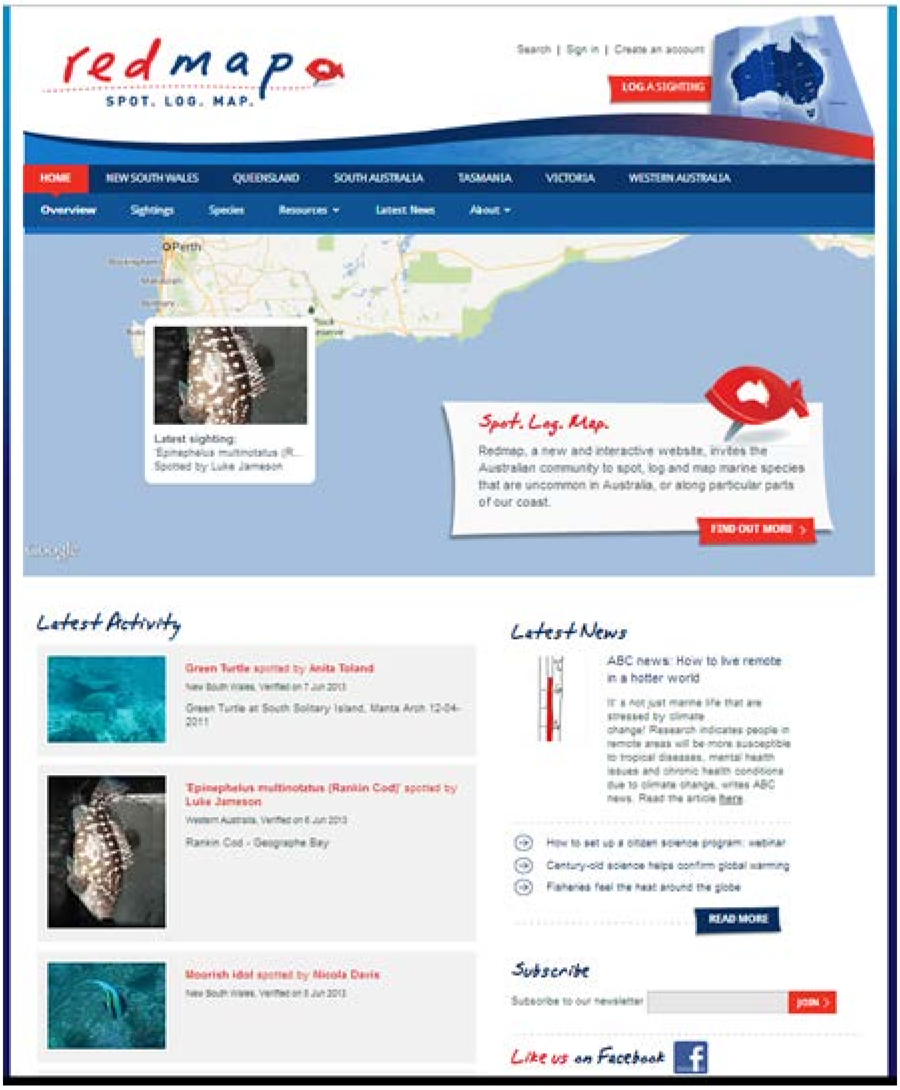

Figure 5.16. The Redmap home page.

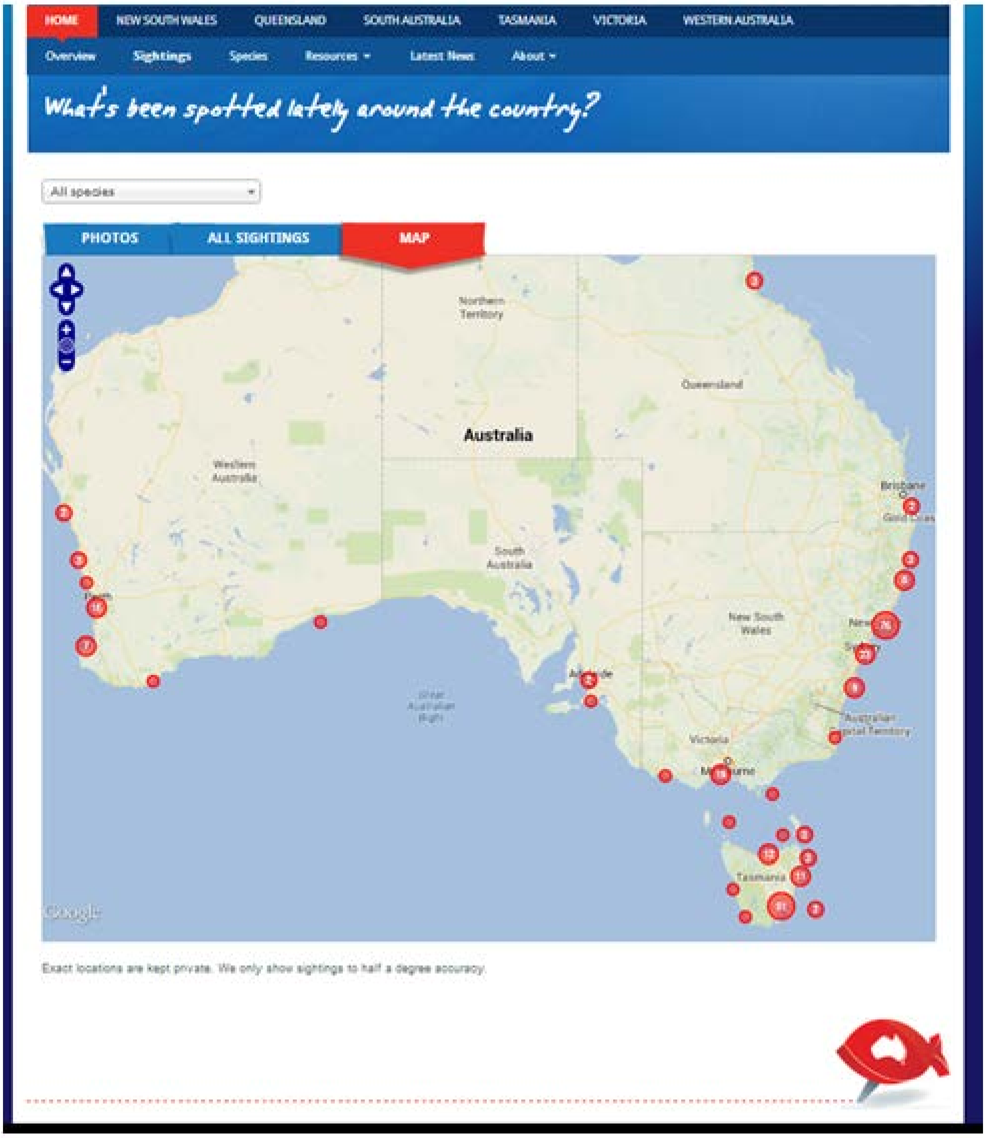

Figure 5.17. Verified out-of-range observations submitted to Redmap since the National launch in December 2012.

Presentation 10 (Session 6)

Answering the "so what" question: communicating with policy-makers, members of the public and the media

John K. Pinnegar (Cefas, UK)

This presentation reflected upon recent experience in the UK of communicating with policy-makers, members of the public and the media. Fish distribution shifts have been widely reported for the Northeast Atlantic, with 70% of the fish species having responded to warming by changing distribution and abundance (Simpson *et al*. 2011) 2011). Centres of distribution have generally shifted by distances ranging from 48 to 403 km (Perry *et al*., 2005) and the North Sea demersal fish assemblage has deepened by ~3.6 m per decade between 1980 and 2004 (Dulvy *et al*., 2008).

Within the UK, a new law was introduced in 2008 that requires a **climate change risk assessment (CCRA)** every five years. This has necessitated that consideration be given to possible consequences of **climate** change on maritime industries including fishing and aquaculture. The first CCRA was published in January 2012 and included many metrics relating to shifting distribution of seabirds, benthic invertebrate species, non-native invasive species and commercial fish. Some of this information has subsequently been used in the *Economics of Climate Resilience* assessment of whether or not the UK fish catching sector can adapt to future opportunities and threats.

A major ongoing initiative in the UK and Ireland is the Marine Climate Change Impacts Partnership (MCCIP). The primary aim of the MCCIP is to transfer high quality evidence on marine climate change impacts, from scientists to policy advisors and decision-makers. The 2010 Annual Report Card, involved contributions from 100+ scientists from 40 separate institutes. It aimed to determine the level of consensus and uncertainty of each topic, and to identify research gaps with regard to changes that have happened in the past and projections for the future. A very similar Annual Report Card (following the MCCIP model) was produced by scientists in Australia in 2009 and together these assessments have elicited considerable media interest all around the world.

Key issues for fisheries management were discussed, including the fact that species distributions may migrate across international boundaries where quotas belong to different nations. A notable example has arisen recently as a result of mackerel quota allocations between Norway, the EU, Iceland and the Faroe Islands. Such disagreements may become more commonplace with climate change in the future. In 2011 Link *et al*. wrote a review paper that provided guidelines for incorporating climate-associated fish distribution shifts into fisheries management. The management response will be different, depending on whether a cohesive stock has simply moved from one locality to another, or a stock is expanding its distribution – but not necessarily declining anywhere. The possible consequences of shifting distributions on the effectiveness of spatial management measures (marine protected areas etc.) was also examined.

In 2011, as part of the EU FP7 project CLAMER, a professional polling company was commissioned to conduct a quantitative survey of the awareness of marine climate change issues among citizens in 10 European countries. The views of 10,000 citizens were sought and this revealed varying levels of awareness and concern across the continent. With regard to sources of information and trust, the survey revealed that most European citizens obtain their information about marine climate change issues via television, but they do not necessarily trust this form of media. Scientific articles in journals were used less but the most trusted, whereas newspapers and social-media websites were the least trusted. When asked about 'who' they trust to provide accurate information concerning marine climate change impacts, citizens expressed the most trust in scientists working for universities or NGOs, less trust in the IPCC and government scientists and the least trust in scientists working for industry.

Presentation 11 (Session 6)

Approaches for identifying ecosystem responses to human activities and natural stressors

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Approaches for identifying ecosystem responses to anthropogenic activities and natural stressors as expert elicitation and empirical approach were introduced from presented talks in session/workshop by the PICES Working Group 28, which focuses on development of ecosystem indicators to characterize ecosystem responses to multiple stressors. Expert elicitation using the stressors-habitats matrix (Halpern *et al*. 2008) was conducted in roughly half of the studies reported in the PICES Annual Meeting 2012. Based on published scientific reports, vulnerabilities were scored as spatial scale, frequency, functional impact, resistance, recovery time and certainty and identified most influential activities/stressors in the ecosystems. Empirical approaches have been conducted in most of the studies reported in the PICES Annual Meeting 2012. Relevant indicators were identified based on long-term datasets of abiotic and biotic indices. Expert elicitation would be a solution when no data are available but it includes insufficient information for specific responses (see Table below). Empirical approaches could track emerging stressors, which experts had little prior experience, but it is difficult to find datasets at appropriate scales. Another advantages and disadvantage of the empirical approach is that, on the one hand, it could tailor the appropriate indicators but, on the other hand, the outcome could be the least common denominator of various indices. Therefore, combined approaches of expert elicitation with empirical approach would be a powerful procedure for identifying ecosystem responses to climate change among multiple stressors.

Table. Pros and cons between approaches for identifying ecosystem indicators.

Approach	Pros	Cons
Expert elicitation	Solution to the no data problem Appropriate for global/regional visualization	Not enough info for specific responses
Empirical approach	Track emerging stressors untested Appropriate indicators can be tailored	Hard to find data sets at appropriate scales Least common denominator issue

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