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Modelling ocean acidification impacts: from biological experiments to economic assessments and social impacts

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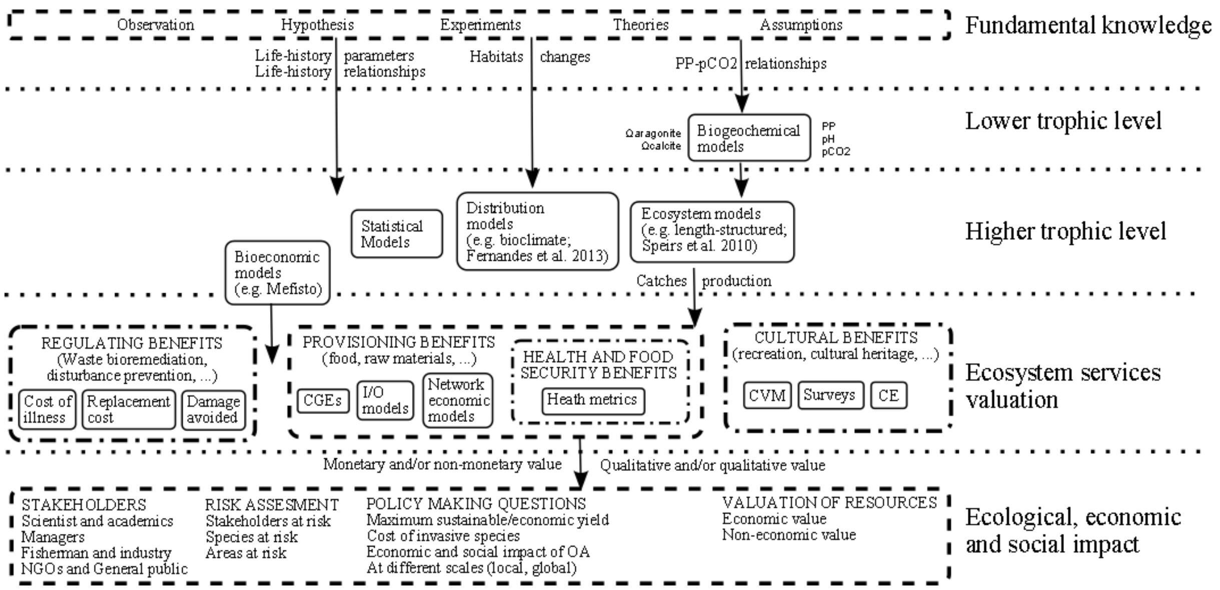
Summary
Assessing the potential biological and socio-economic consequences resulting from climate change (CC) and ocean acidification (OA) impacts on marine ecosystems is necessary for the sustainable utilisation and management of the oceans' resources and services. This requires interdisciplinary collaborations between experimental biologists, oceanographers, ecosystem modellers, social scientists and economists. Common assessment frameworks to integrate these interdisciplinary approaches are needed to bridge the methodological and scale challenges between sciences. We present such an assessment framework to assess the impacts of CC and OA on marine ecosystems and their services, with a view to develop an economic analysis that considers the needs of stakeholders. This framework aims to bring experiments focused on the potential impacts of OA into models, producing a solid basis for socio-economic analysis concentrating on three key areas: 1) species' life-histories (e.g. survival, development, growth); 2) primary production and biogeochemical processes; and 3) species' habitats availability (e.g. increased seaweed and seagrass production). The validity of this framework is demonstrated using case studies from research on commercial fish species and invertebrates.

Introduction
Rising CO_2 levels are expected to affect ocean conditions (OA, ocean acidification) and consequently distribution, productivity and abundance of fishery resources (Cheung et al., 2010) with societal implications for dependent communities and industries (Merino et al. 2012). Recent studies have focused on the effects of OA on the life history of commercial species such as growth, larval and adult mortality (Branch et al., 2013). Other studies have looked at habitat changes induced by OA including reduced seafood production from coral reefs, but increased production from seagrass and seaweed (Hendriks et al., 2010). Primary production (PP) is also expected to be affected by OA (Riebesell et al., 2011). Thus there are different pathways though which OA influence can be observed and modelled to support broad impact studies. Here we present an integrative modelling framework which is able to link laboratory and in situ experiments on OA impact to the economic and social impacts through multiple paths. The aim of this framework is to use the best knowledge available; but identifying the uncertainties and assumptions which demand the results to be interpreted accordingly.

Material and Methods
The proposed assessment framework (Fig. 1) considers the pathways of OA impacts which are represented by the arrows originating from the first level (fundamental knowledge) into subsequent levels. The lower and higher trophic levels are represented by a range of models, often coupled in combined models interacting (online) or using each other outputs as inputs (offline). The lower trophic level models provide estimates of the environmental variables (e.g. temperature, pH) and PP (Artioli et al., 2013). The higher trophic level models can provide biomass and/or potential catches that can be used for economic and social impact assessments and/or ecosystem services valuation. The bioeconomic models mix biological and economic models with simplified processes, whilst ecosystem services valuation produce a more holistic synthesis of impacts. The figure below represents a simplification of the framework, providing examples of the wide range of models available.



The framework is being tested for a case study using a bioclimate envelope model (Fernandes et al, 2013) to consider all the identified pathways for OA impacts on commercially exploited species (under different emission scenarios). This is based on the limited number of fish and shellfish species for which experimental data is available (at several temperature and pCO2 levels: 380, 750 & 1000 ppm).

Results and Discussion

Preliminary results of the case study suggest that subsistence fisheries are potentially impacted more than larger, commercial fisheries. Some specific species or groups (such as shellfish) are predicted to be impacted more than others. Therefore, at a global scale the effect of OA might not be significant, but at local scales the effect on employment and communities could be significant. Societally impacts will be difficult to quantify and results will need to be communicated carefully to indicate the large uncertainties and assumptions in the models, and the limited data available. For example, these models have only included parameters that have already been directly investigated experimentally, with the assumption that all untested parameters are unaffected by OA. In addition, many identified effects are proving difficult to incorporate into models (e.g. implications of shell degradation). Nevertheless, the findings of this framework suggest that local communities may be particularly vulnerable to the OA. This work has been funded by UK Ocean Acidification research programme and EURO-BASIN of the European Union's 7th Framework Program (Grant Agreement No.264933).

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