ECOSYSTEM OCEANOGRAPHY: UNDER-STANDING A RAPIDLY CHANGING OCEAN

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Introduction

Oceanography has progressed over the last 150 years from a mainly descriptive science to a modern, synthetic discipline aimed at understanding and predicting large-scale patterns and processes in the sea. Similarly, ecology has matured from description to experimentation and more recently to a macroecological approach aimed at understanding general patterns and deriving unifying laws, such as models explaining the striking patterns of species diversity around the globe [1, 2]. My research has explored the interface of these two fields, by analyzing large-scale ecological patterns in the oceans and their drivers, including the role of human activities. Over the past five to ten years we have seen a dramatic shift in perception, towards the realization that rapid human-induced changes are occurring all around us and that ocean ecosystems are reorganizing on regional to global scales as a result. These topics have long been at the core of my research interest and are now growing focus of marine science laboratories around the world. Moreover, this research has proven vitally important in addressing concerns about biodiversity loss in the oceans and its consequences for human well-being.

Following these developments, the new discipline of 'ecosystem oceanography' has emerged (Fig. 1), with a focus on understanding and predicting global change in the oceans from the bottom to the top of the food web [3]. Traditionally, most oceanographers have concentrated on ocean physics, chemistry and plankton dynamics, which are shaping major biogeochemical cycles on this planet. Fisheries scientists, in contrast, have mostly focused on the upper trophic levels that fuelled rapidly expanding fisheries. My research is at the forefront of integrating these approaches, and has demonstrated simultaneous long-term (decades to centuries) global changes at the top as well as the bottom of the food web [4-6].

Several key questions have emerged from this (i) Under which conditions are changes in fish stocks causing cascading changes at lower trophic levels, (ii) How do the effects of climate change on plankton affect fish stocks, and (iii) How do any such changes impact biogeochemical processes, such as nutrient and carbon cycles? Answers to these questions will help in predicting global changes in the oceans and devising adaptive management and conservation strategies.

My students and I focus on these questions by combining meta-analysis of large-scale data sets, field experiments, and modeling, in collaboration with major research initiatives at Dalhousie University (CERC in Ocean Sciences, Ocean Tracking Network), Kiel University (GEOMAR, Excellence Cluster Future Oceans) and the Universities of Washington and British Columbia (two major initiatives on understanding global fisheries dynamics). Below I highlight some recent advances stemming from this work.

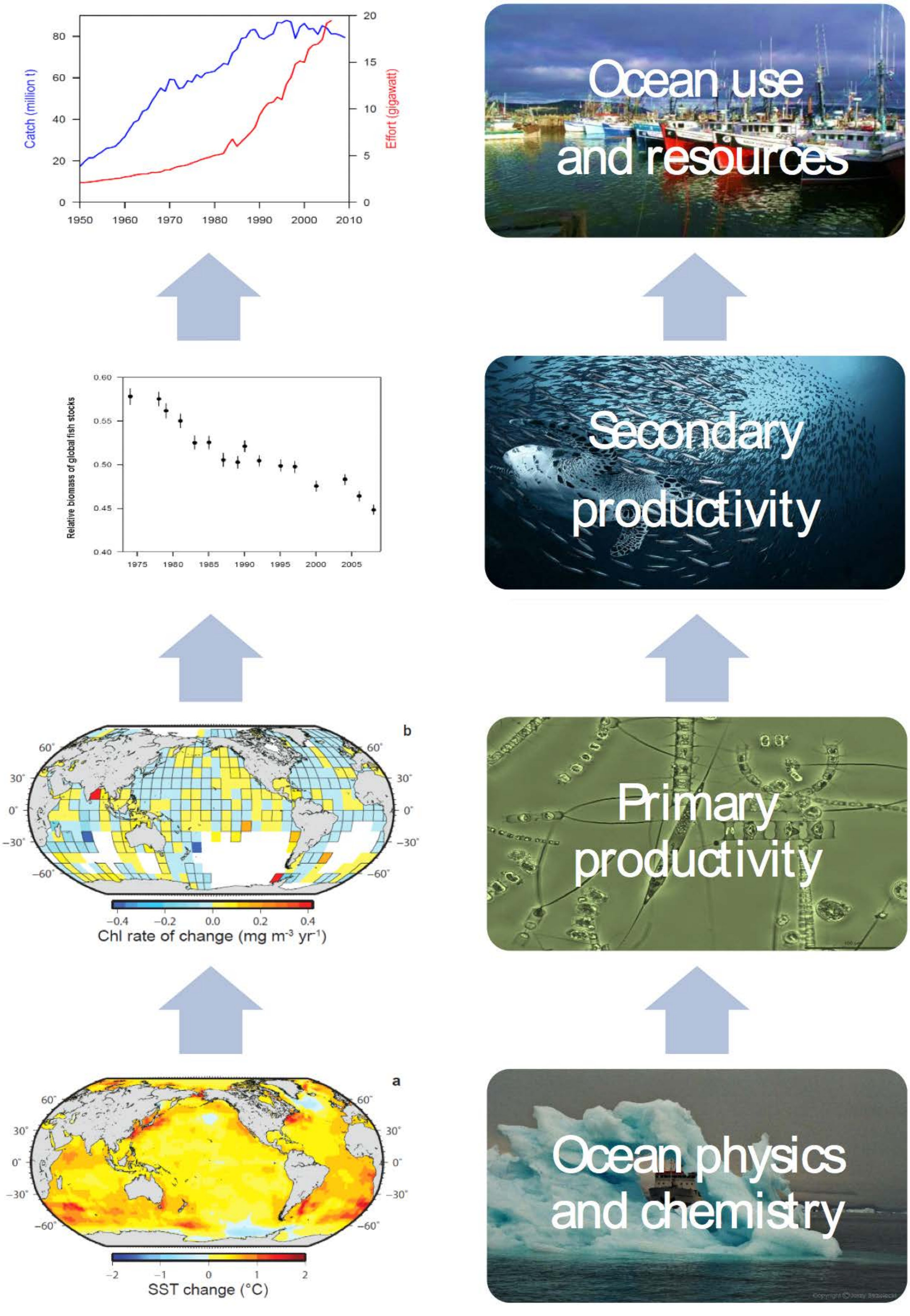

Figure 1: Ecosystem oceanography. Shown are linkages between changes in ocean physics and primary producers (bottom panels: changes in sea surface temperature, SST, and phytoplankton chlorophyll concentration, Chl, over the last century; from ref. [4]) to fish stocks and human use patterns (top panels: relative biomass of globally assessed fisheries, fish catch and fishing effort, from ref. [7]).

1. Meta-analysis

In an NSF-funded interdisciplinary working group that I co-led with R. Hilborn (U Washington), we assembled an unprecedented database on biomass, recruitment and fishing mortality of more than 400 available stocks, trawl survey data from 25 large marine ecosystems, global fish catches (Fig. 2, in collaboration with The Sea Around Us Project, University of British Columbia), and ecosystem models from 31 regions around the world [6]. We showed that on average, most stocks were overfished, but trends in exploitation rate were positive in a number of regions, allowing for the rebuilding of depleted resources where proper management frameworks are in place [6]. In a separate effort, my laboratory has compiled and analyzed plankton data reaching back to the beginning of oceanographic measurements [4, 8, 9], and demonstrated for the first time long-term plankton declines in eight of ten large ocean regions, partially driven by increasing temperature and ocean stratification (see Fig. 1, bottom panels). Combining these databases has recently allowed us to evaluate empirically the effects of declining plankton abundance on the productive capacity of fisheries [10]. To this end, we have adapted statistical 'state-space' approaches used to track weather patterns, to track fish recruitment and productivity; these innovative tools are now being expanded to be used in the management of fisheries in a rapidly changing environment.

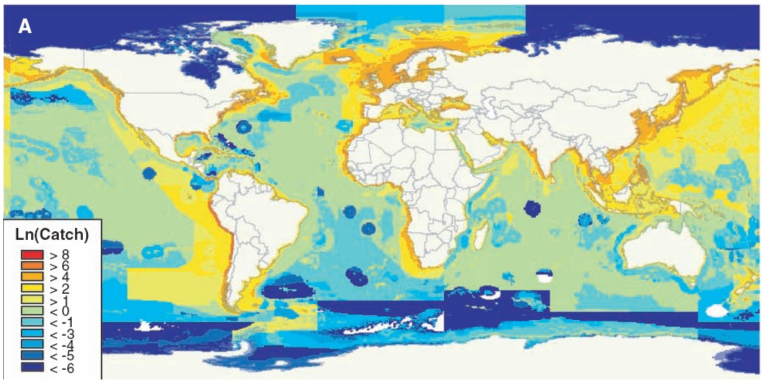

Figure 2: Global distribution of marine fish catches in t km¬¬-2 yr-1 (1950-2004, from ref.[6]).

2. Experiments

During my 2010 Petersen Excellence Professorship at Kiel University I have built collaborations that gave my research group the opportunity to run realistic ocean-warming experiments in plankton mesocosms in 2012. Researchers at GEOMAR in Kiel have built and tested exceptionally robust indoor mesocosms where changes in temperature and nutrient content were experimentally induced and controlled (Fig. 3). This allowed us for the first time to evaluate the mechanisms that shape food web responses to ocean warming and examine in great detail experimentally induced phytoplankton declines. Results show that surface ocean warming affects phytoplankton via two fundamental mechanisms, specifically increased metabolism and grazing by zooplankton, and lower nutrient delivery via increased stratification of the water column. We were able to show that the first mechanism is particularly important in colder, well-mixed ecosystems, where the latter appeared more important under warm, stratified conditions [11].

Figure 3: Collaborative mesocosm experiment at GEOMAR. Graduate student D. Boyce checking one of 12 experimental facilities analyzing the effects of ocean warming on phytoplankton.

3. Modeling

Both Dalhousie and GEOMAR feature world-leading expertise in the modeling of ocean ecosystems, with particular emphasis on plankton dynamics and biogeochemical cycling. My research is positioned to integrate these strengths in a dynamic ecosystem context, tracking changes from the bottom to the top of the food web, as shown in Fig. 1. The ultimate goal is to develop predictive models that allow us to forecast how changes at lower and upper trophic levels will influence each other, and how this interaction may shape ocean ecosystems and biogeochemical processes in the future. While some of this is still the focus of future work, my collaboration with GEOMAR and PIK in particular have begun to establish a scientific dialogue whereas model results inform empirical data analysis and controlled experiments, and vice versa. For example, we have integrated models, experiments and data analysis in the examination of global plankton declines, past, present and future [11-13].

Summary

My research program aims to integrate key topics from oceanography, macroecology, and conservation biology into a new synthetic discipline called 'ecosystem oceanography'. This rapidly developing and innovative field of research has important implications for the sustainable management of ocean ecosystems, and the rebuilding of depleted marine resources.

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