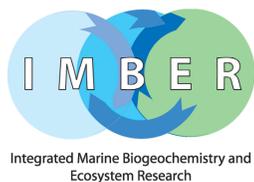


# Developing integrated analyses of Southern Ocean ecosystems: status, change and future projections

Nadine M. Johnston, Rachel D. Cavanagh, Eugene J. Murphy  
British Antarctic Survey, High Cross, Madingley Road, Cambridge, England, CB3 0ET, UK



**ICED Scientific Steering Committee**  
Richard Bellerby, Norwegian Institute for Water Research  
Andrew Constable, ACE-CRC, Australia  
Dan Costa, University of California at Santa Cruz, USA  
Eileen Hofmann, Old Dominion University, USA  
Walker Smith, Virginia Institute of Marine Science, USA  
Dieter Wolf-Gladrow, Alfred Wegener Institute, Germany  
Jose Xavier, University of Coimbra, Portugal



## INTEGRATING SOUTHERN OCEAN ECOSYSTEM SCIENCE

Southern Ocean ecosystems provide globally important ecosystem services: maintaining biodiversity, influencing biogeochemical cycles and in supporting fisheries they affect global food security. They are also being affected by rapid climate driven changes, with impacts being observed at every trophic level in the ecosystem. Understanding the impacts of change in these ecosystems requires integrated (end-to-end) ecosystem analyses at regional and circumpolar scales. Developing those analyses has been the focus of the Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme. This 10 year programme has three major scientific objectives: 1) understand how climate processes affect ecosystem structure and dynamics, 2) understand how ecosystem structure and dynamics interact with biogeochemical cycles, and 3) determine how ecosystem structure and dynamics should be incorporated into management approaches for sustainable exploitation. These are being achieved through three key activities; circumpolar data synthesis and mining, field coordination and modelling. Here we highlight our recent progress, particularly in the development of end-to-end analyses and models. An ICED-led assessment of the status of Southern Ocean ecosystems has highlighted the urgent need for better observational data to allow the evidence of change to be rigorously tested. That work led to the development of the ICED-Sentinel programme that aims to generate the observational systems required to monitor change in Southern Ocean ecosystems. We also highlight a major current ICED activity focussed on the development of scenarios and models for the projection of the impacts of future change.

## IMPLEMENTATION PHASE

Since publication of the ICED Science Plan and Implementation Strategy (Murphy et al. 2008), ICED has developed extensive coordination and planning, mobilising the international research community (across a range of disciplines) to jointly address key scientific challenges in understanding the impact of climate and anthropogenic forcings on the Southern Ocean. ICED is currently represented by >80 researchers from 14 countries. In 2012, the British Antarctic Survey was awarded a significant Natural Environment Research Council grant to lead the coordination of ICED from its International Programme Office in the UK and conduct a range of science. ICED is now focussed on its 3 main implementation activities- data synthesis and mining, field coordination, and model development- to deliver its scientific goals and objectives

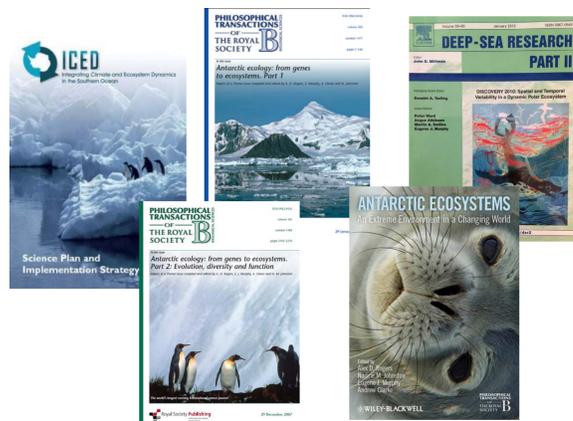


Fig 1. Recent ICED syntheses

## ACTIVITY HIGHLIGHTS

**Data synthesis & mining.** ICED scientists have led and contributed to a number of major syntheses of Southern Ocean ecology from the molecular to the ecosystem level (Fig 1). These have included two special issues in *Phil. Trans. Roy. Soc. B* (Antarctic ecology; from genes to ecosystems, Parts 1 & 2, Rogers et al., 2007), a special issue of *Deep Sea Res. Part II* (DISCOVERY 2010: Spatial and temporal variability in a dynamic polar ecosystem, Tarling et al., 2012) and an edited Wiley-Blackwell book (Antarctic ecosystems: An extreme environment in a changing World, Rogers et al., 2012). See [www.iced.ac.uk](http://www.iced.ac.uk) for further publications.

**Field coordination.** ICED Sentinel has been developing an integrated adaptive field programme for monitoring essential variables in the Southern Ocean to assess status and trends of key habitats, productivity, biota and ecosystems and estimate the likelihood of future states (Fig 2).

**Modelling.** ICED recently held a workshop 'Southern Ocean Food Webs and Scenarios of Change' focused on exploring plausible quantitative scenarios of how the Southern Ocean may change in the future based on the latest available climate models, ecological data and models, and information on fisheries. This united ecologists, fisheries and climate scientists. Critical challenges were discussed, and these are explored in a community paper (Cavanagh et al., in prep) and a detailed study of sea ice scenarios (Fig 3).

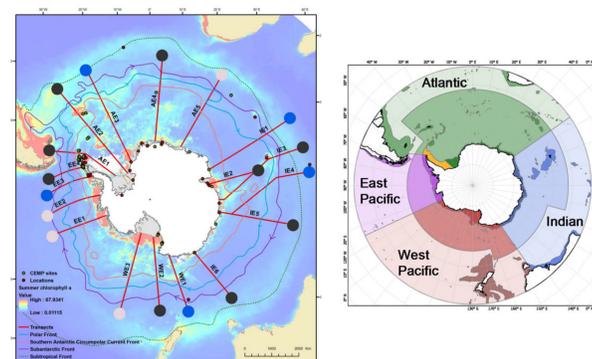


Fig 2. ICED Sentinel map of possible transects to benchmark habitats, key species and ecosystems by ~2020.

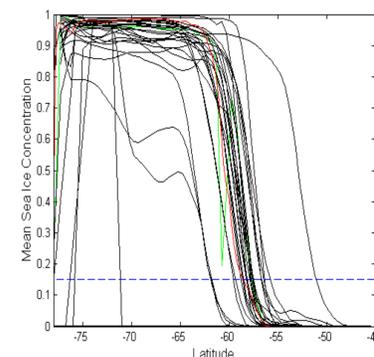


Fig 3. British Antarctic Survey scientists are currently examining scenarios of sea ice concentration from CMIP5 models (Sep through 45°W). Detail in the Marginal Ice Zone (below blue line) is the most ecologically relevant. Timing of arrival/retreat and regional variation are also important.

## FUTURE DIRECTIONS

Key future ICED priorities include **change, scenarios and projections:** given the knowledge gaps and uncertainties inherent in studies of change, the use of future scenarios to explore drivers and potential responses to and consequences of change is an area we are exploring. This has proved a useful introduction to the challenges of integrating physics with biology, and work is now beginning to bring more meaningful application of climate data and models to ecological change. This work will naturally lead on to projections of change and is highly relevant to the requirements of IPCC, CCAMLR and IPBES. **Towards end to end ecosystem models:** a long-term ICED goal is to develop a coupled end-to-end model of Southern Ocean ecosystems to examine the effects of change. We have several shorter-term aims: (a) develop a generic food web model, (b) explore modelling approaches used in combination to resolve the relative importance of process interactions at different scales, (c) develop coupled models focused on the central role of zooplankton and linking with biogeochemical models, and (d) develop multi-scale models towards circumpolar operation of Southern Ocean ecosystems. **Informing policy and society:** recent interactions in providing information to policy makers has highlighted a key challenge- to work towards a more effective way of informing policy. There is increasing recognition that directly submitting scientific papers or workshop reports to policy meetings does not necessarily generate the required impact. The results need to be translated appropriately into messages that resonate with policy makers. ICED is now committed to improving this area, and will work particularly with CCAMLR, CEP and IPCC to achieve this. **Novel data systems and emerging technologies:** ICED has made progress towards collating historical datasets for use in circumpolar analyses and developing ecological observing networks in the Southern Ocean. A rapid expansion is occurring in remote analyses through satellite observations, fixed sensor platforms, use of autonomous vehicles and the application of biosensors for animal tracking and activity analyses. This presents major challenges of data communication, storage, management and analysis. There is an urgent need to ensure the community has the management and analysis systems, and skills, required to fully utilise this data. **Biodiversity and genomics:** Through our links with SCAR's AnT-ERA and other groups we intend to further our involvement with biodiversity and genomics research in the Southern Ocean.

ICED is a regional programme of the International Geosphere-Biosphere Programme's Integrated Marine Biogeochemistry and Ecosystem Research programme. ICED is also jointly sponsored by the Scientific Committee on Oceanic Research and the Scientific Committee on Antarctic Research. To become part of the ICED community please visit [www.iced.ac.uk](http://www.iced.ac.uk)

