Project information

Project title

UndersTanding and PRedicting the acidification of northern waters and its iMpacts on marine ecosystems and biogeochemistry (TRUMP)

Year

2019

Project leader

Philip Wallhead (NIVA), Solfrid Hjøllo (IMR)

Geographical localization of the research project in decimal degrees (max 5 per project, ex. 70,662°N and 23,707°E)

Task 1&2: Pan-Arctic (everywhere north of ~ 60N); Task 3: Laptev Sea (76.5–77.5N, 121–132E); Task 4: Barents Sea (68.5-82.58N, 8.0-68.4E)

Participants

Trond Kristiansen, Andre Staalstrøm, Evgeniy Yakushev, Elizaveta Protsenko, Richard Bellerby (NIVA);

Morten Skogen, Cecilie Hansen, Erik Mousing (IMR);

Gary Griffith (NPI)

Flagship

Ocean Acidification

Funding Source

FRAM

Summary of Results

Task 1: Understanding regional OA using models. Testing model output against historical and recent field data is essential for understanding the drivers of OA/climate change, for reconstructing the environmental history of organisms, and for reducing uncertainty in model projections. During 2019 we identified an important bias common to several downscaling and global models: an excessive seasonal melting and retreat of sea ice during summer. For the new pan-Arctic ROMS-ERSEM model developed under the OA Flagship ("A20"), this bias was reduced during 2019 by refining the parameterization of ice/snow albedo and shortwave attenuation by ice (Fig. T1.1). We also developed a new high-resolution OA model for Kongsfjorden, using the NORWECOM.E2E ecosystem model (including the OA module) forced by a 160m-resolution ocean circulation model for the period March 1 to September 30, 2009. Carbon system dynamics were compared to observations from spring 2014 and 2017. Some large discrepancies were found (including an overestimation of TA, DIC and pH, apparently driven by the forcing salinity) but general patterns showed a promising level of agreement (Fig. T1.2). A new ocean circulation model is now available (Torsvik et al., 2019) with a better implementation of glacial smelting and less vertical bias in both salinity and temperature, and we expect use of this improved physics to yield better results in 2020.

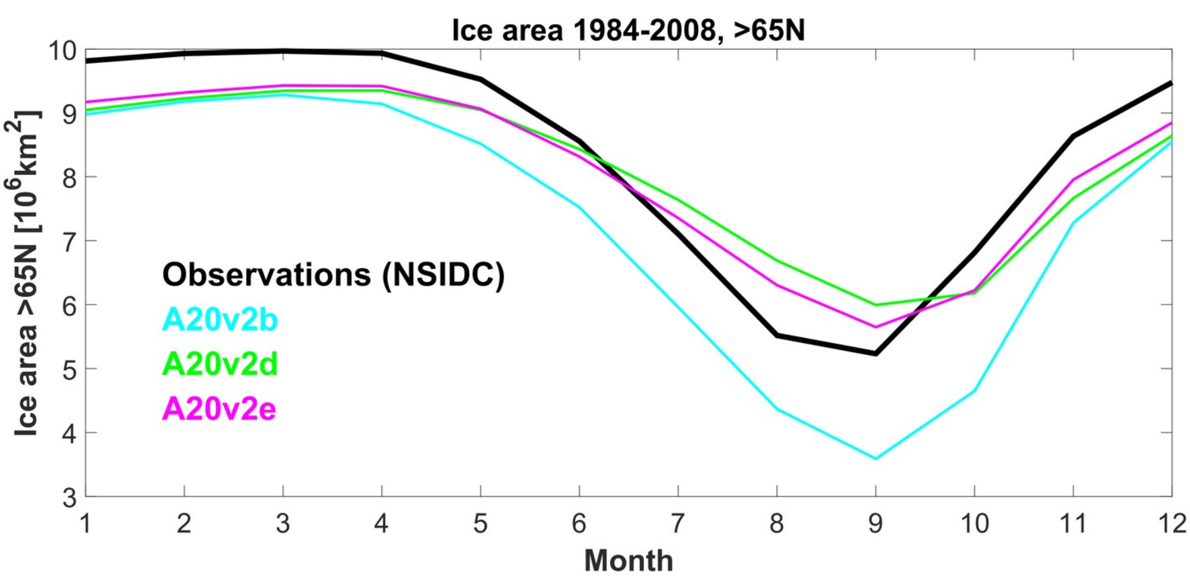

Fig. T1.1. Climatological comparison of modelled seasonal sea ice coverage (>65N) with observations from NSIDC,

showing improvement from refined A20 model versions (v2d, v2e).

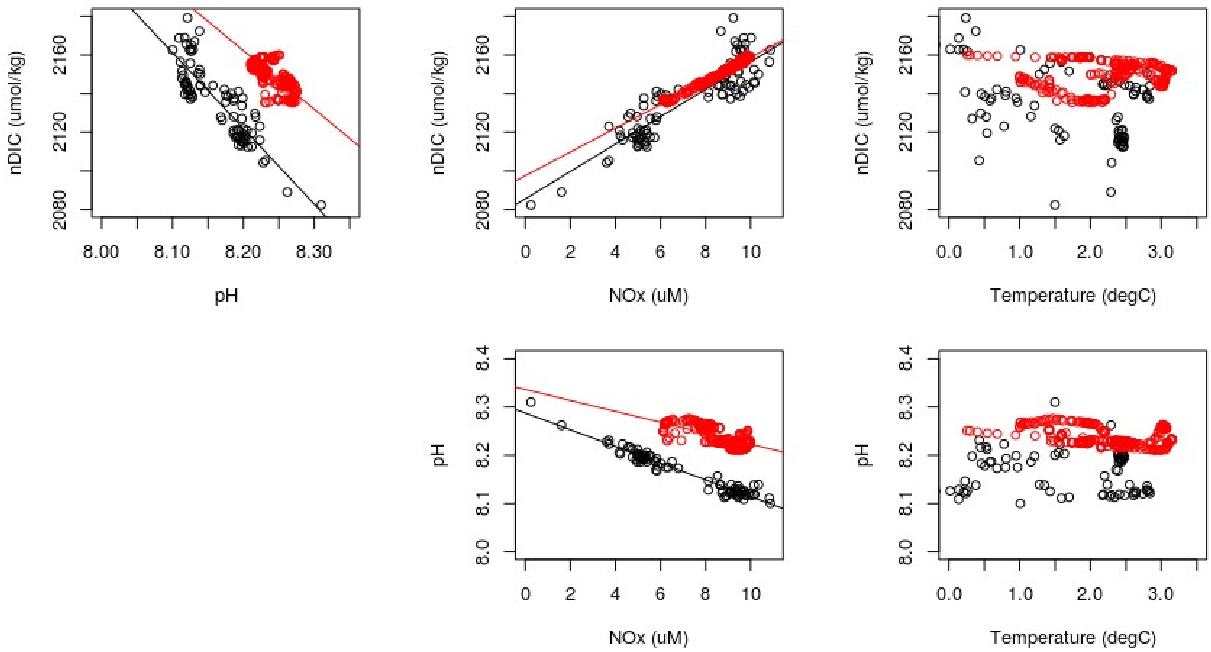

Fig. T1.2: Normalized dissolved organic carbon and pH versus dissolved nitrogen and temperature for observed (black) and modelled (red) values from the new high-resolution Kongsfjord model.

Task 2: Projecting ecosystem response and feedbacks to OA. Task 2 attempts to project the impacts of OA and climate change on Arctic ecosystems, combining data from sensitivity studies with ecosystem models. During 2019 we projected the combined impacts of warming and OA on habitat area for Arctic benthic fauna, and found only weak impacts at group level that were, surprisingly, not significantly more severe for Arctic or calcifying taxa (Fig. T2.1, results published in Renaud et al., 2019).

We also examined future changes in water-column primary productivity projected by three downscaling ecosystem models (NORWECOM, NORWECOM.E2E and SINMOD) and applied a statistical model to infer major drivers and directions of relationships. The directions of impacts of the environmental variables were relatively consistent between models: future changes in productivity were primarily correlated to changes in temperature and ice-cover/light, acting directly or indirectly by modifying nutrient and mixed layer dynamics (Fig. T2.2). This suggests that the disagreement in productivity projections is mainly caused by the choice of the underlying physical forcing, and in particular, the non-linear impacts of other physical variables which modulate the impact of warming in different ways.

Through a comparative modelling study, the sensitivity of the Barents Sea ecosystem to changes in the higher trophic levels was explored. The recruitment function for Northeast Arctic cod, as used in the AMAP report from 2018, includes effects of OA. It was implemented into the ecosystem model Atlantis to explore how this recruitment-option, in combination with a set of management regimes, will impact the Barents Sea ecosystem and cod stock in a future climate. These simulations will be compared to the outcome from the already implemented and applied recruitment function within the Atlantis framework.

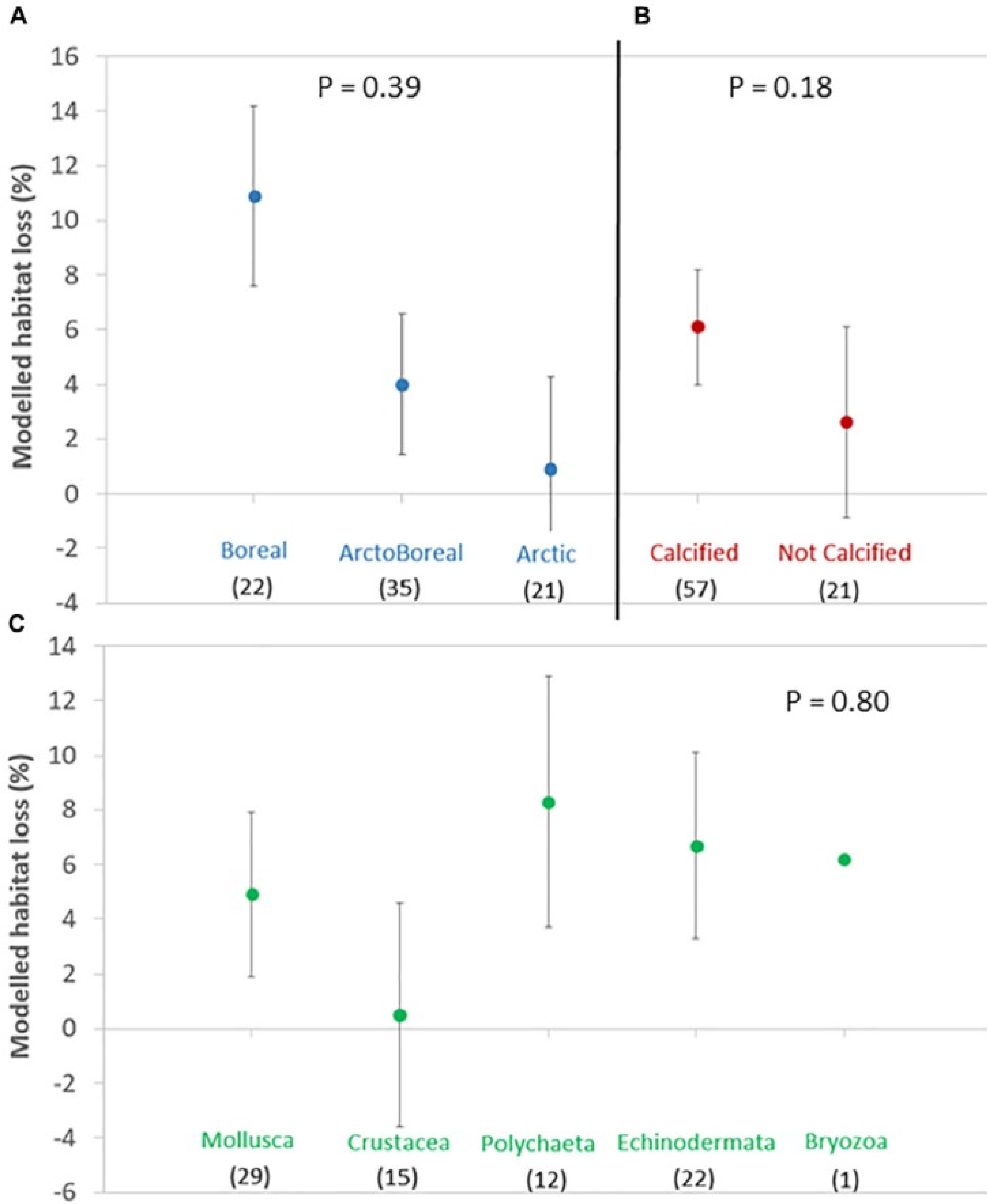

Fig. T2.1. Projected % habitat loss (present day vs. 2090-2099 under SRES A1B) for different groups of benthic fauna, classified by biogeographic region (A), calcified vs. non-calcified (B), and different taxonomic groups (C).

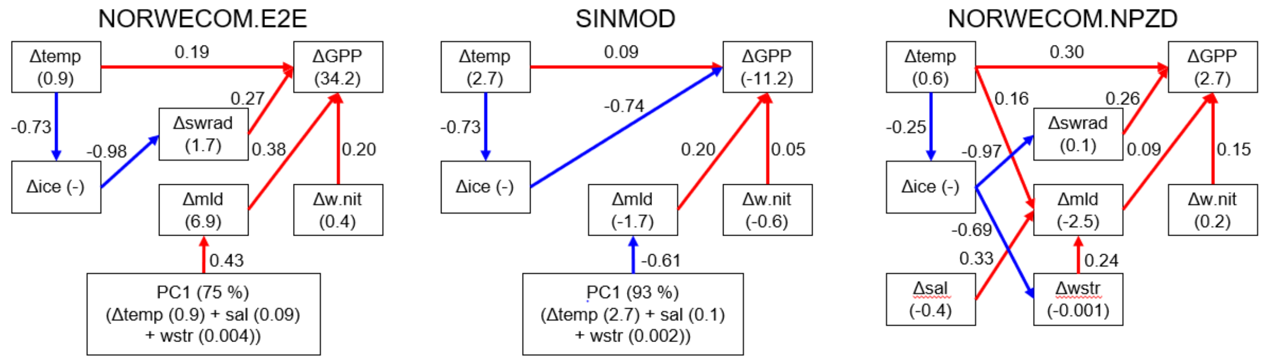

Fig. T2.2: Direct and indirect relationships between changes (future minus present) in the forcing variables and changes in Gross Primary Production for the Barents Sea. Red and blue arrows represent positive and negative relationships, respectively. Numbers on lines are relationship strengths expressed as beta-coefficients. Numbers in boxes are median changes.

Task 3: Local OA impacts from benthic drivers. Task 3 studies the effects (including OA) of permafrost thawing and benthic methane/alkalinity emissions on local marine biogeochemistry. During 2019 we published a new model, the Sympagic-Pelagic-Benthic transport Model (SPBM), that enables the integrated simulation of biogeochemical responses in sea ice, seawater, and sea sediment domains, thus providing a useful tool for studying the impacts of OA and climate in Arctic systems where these three domains are often strongly coupled (Fig. T3.1; Yakubov et al., 2019). We also revised the parameterization of horizontal mixing in our SPBM model for studying the impacts of methane seepage in the Laptev Sea (using BROM model biogeochemistry); this model now simulates methane concentrations in the water column that are consistent with observed ranges (Fig. T3.2).

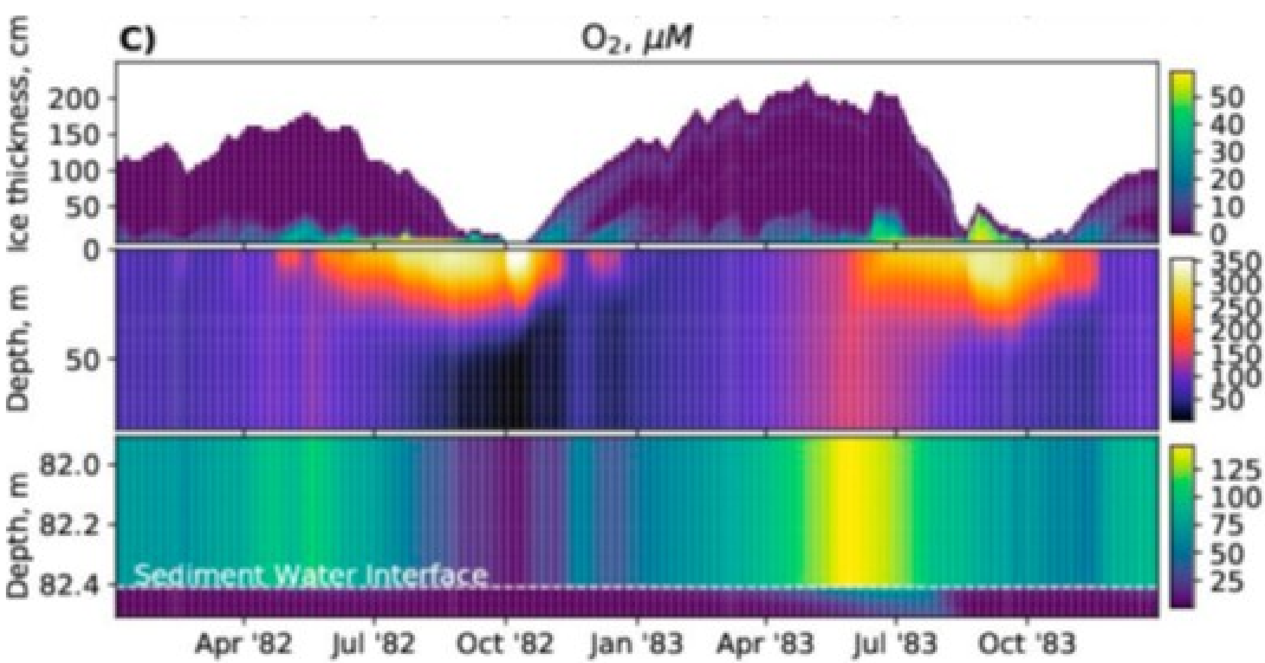

Fig. T3.1. Example output from the new Sympagic-Pelagic-Benthic transport model developed under the flagship, showing output for dissolved oxygen in the three simulated domains (ice, water, sediments).

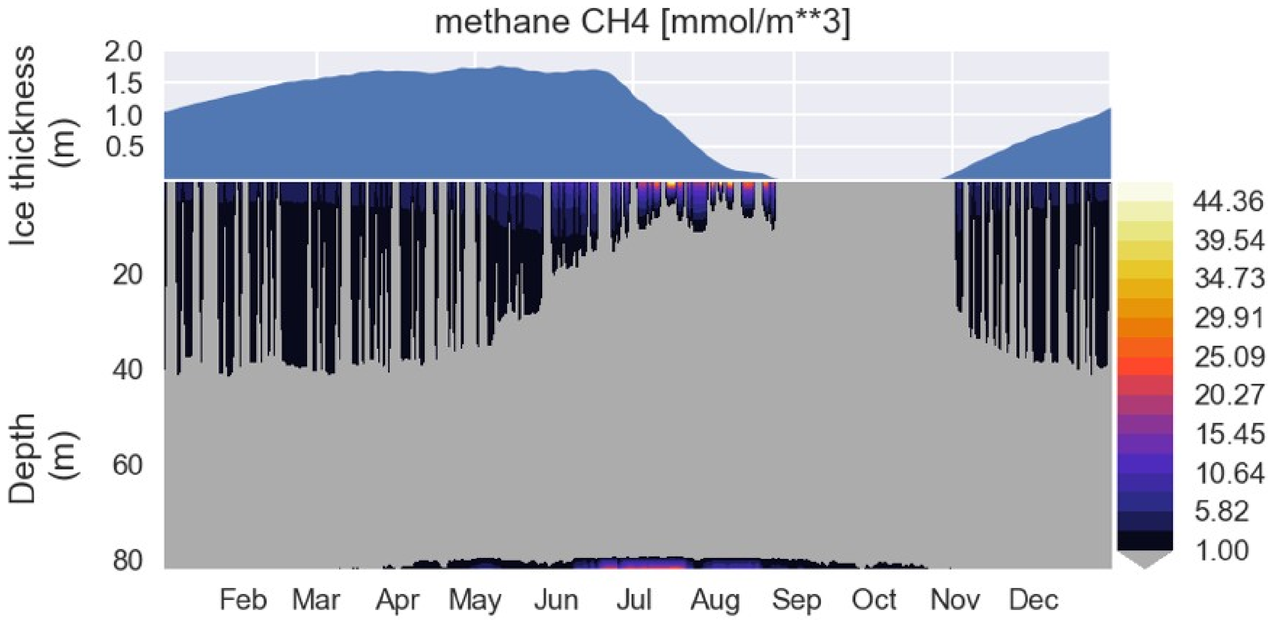

Fig. T3.2. Example model output for concentrations of dissolved methane (a contributor to local OA) in the Laptev Sea.

Task 4: Tracking and forecasting OA impacts on complex multi-species interactions. How real-world marine food webs absorb change, recover and adapt (that is, ecological resilience) to climate change remains problematic. We apply a novel approach to show how the complex changes in resilience of food webs can be understood with a small core set of self-organizing configurations that represent different simultaneously nested and multiple-species interactions (Fig. T4.1). We identified a recent emergent pattern of an improving but possibly short-lived resilience of a highly observed Arctic marine food web (2004–2016), considered a harbinger of future Arctic change (Fig. T4.2, results published in Griffith et al., 2019). The changes can be explained by continuing subsidiary inputs of Atlantic species that repair (self-organize) interactions within some configurations. Despite significant environmental perturbation (including ocean acidification), we found that the core ecological processes are maintained. We conclude that Arctic marine foodwebs can absorb and begin to adapt to ongoing climate change (infographic summary, Fig. T4.3).

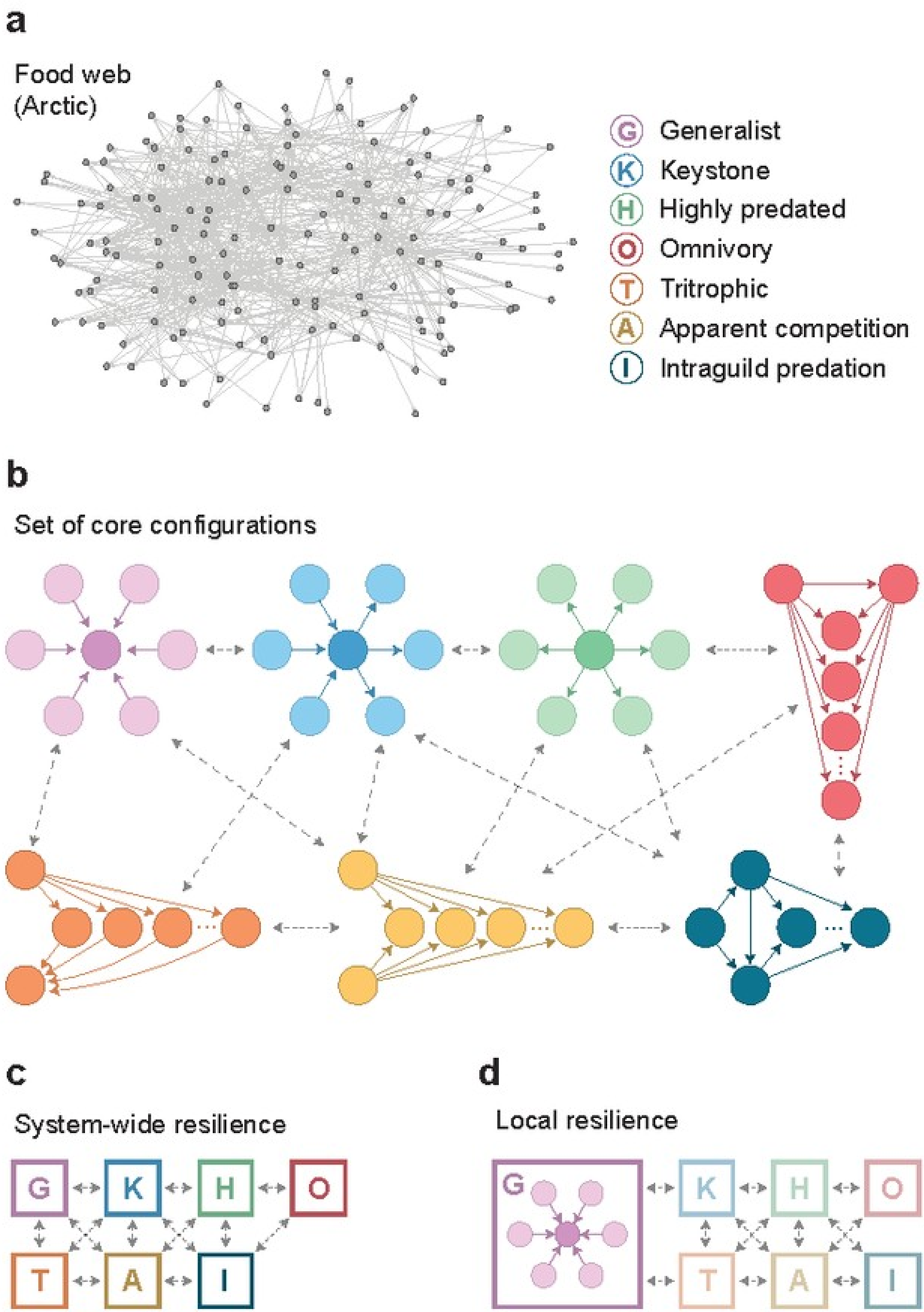

Fig. T4.1. Multi-species interactions approach

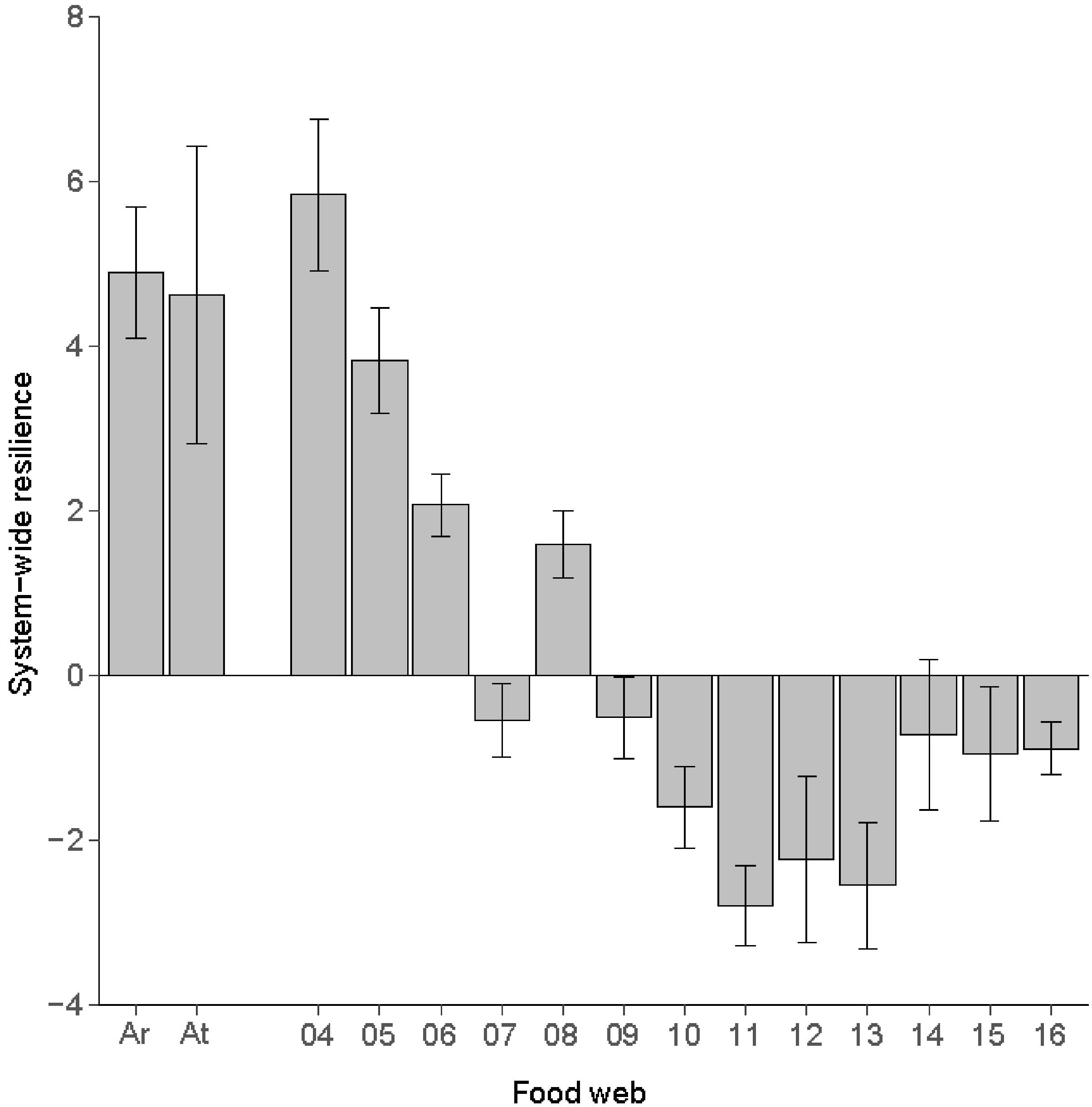

Fig. T4.2. Changes in Kongsfjord system-wide resilience

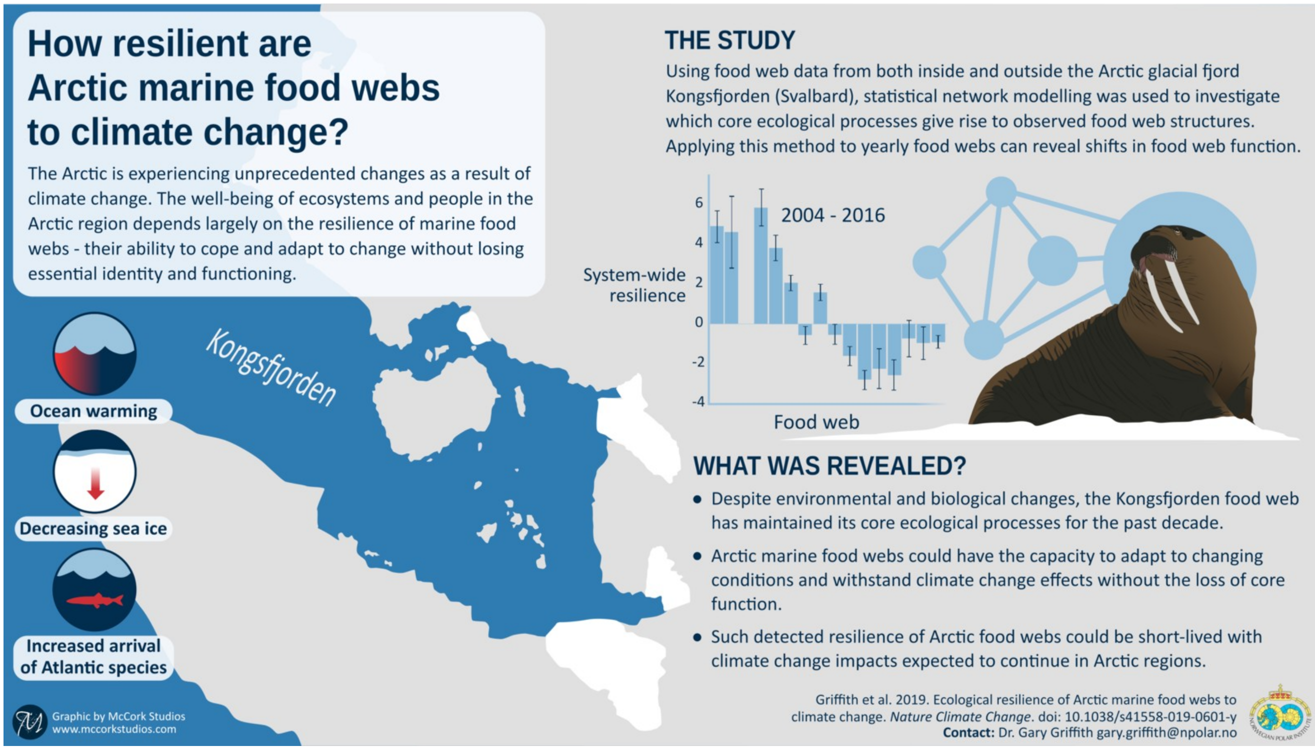

Fig. T4.3. Infographic summary of impact study on Kongsfjord multi-species interactions

For the Management

As climate change advances, many people have their eyes on the Arctic region. The Arctic is warming two to three times faster than the global average, and high northern latitudes are especially vulnerable to ocean acidification, requiring us to understand and mitigate the effects of climate change there earlier than elsewhere in the world. During this unprecedented change, the well-being of the ecosystems and people of the polar regions depends on Arctic resilience: the ability of the Arctic to cope with the change and adapt to it without losing the essential identity and function of the region. Writing in Nature Climate Change, Gary Griffith and colleagues report that Arctic marine communities are able to adapt to considerable environmental change, suggesting resilience to climate change impacts (see infographic Fig. T3.3). Also, writing in Frontiers in Marine Science, Paul Renaud and colleagues suggest that the area of suitable habitat for bottom-dwelling animals in the Arctic Ocean, when considered as a group, may be little-affected by ocean warming and acidification, although individual species may experience substantial losses and gains in suitable habitat.

Published Results/Planned Publications

Published 2019 (and acknowledging Fram funding where possible):

Griffith, G.P., Hop, H., Vihtakari, M. *et al.* 2019. Ecological resilience of Arctic marine food webs to climate change. *Nature Climate Change* 9, 868–872doi:10.1038/s41558-019-0601-y

Renaud, P.E., Wallhead, P., Kotta, J., Włodarska-Kowalczuk, M., Bellerby, R.G.J., Rätsep, M., Slagstad, D., Kukliński P., 2019. Arctic Sensitivity? Suitable Habitat for Benthic Taxa Is Surprisingly Robust to Climate Change. *Front. Mar. Sci.* 6:538. doi: 10.3389/fmars.2019.00538

Yakubov, S., Wallhead, P., Protsenko, E., Yakushev, E., Pakhomova, S., Brix, H., 2019. A 1-Dimensional Sympagic–Pelagic–Benthic Transport Model (SPBM): Coupled Simulation of Ice, Water Column, and Sediment Biogeochemistry, Suitable for Arctic Applications. *Water* 11(8):1582. doi:10.3390/w11081582.

Yletyinen, J. 2019. Arctic climate resilience. *Nature Climate Change* 9, 805–806 doi:10.1038/s41558-019-0616-4

Planned:

Griffith, G.P., Science in support of a nonlinear, non equilibrium world. *ICES Journal of Marine Science*

Griffith, G.P et al. Marine species to conserve will change with cumulative stressors. *Science* (In review Nov)

Mousing, Ellingsen, Willby, Skogen, Hjøllo. Primary drivers of changes in productivity in a future warmer Barents Sea - a comparison of 3 downscaled ecosystem models (in prep).

Protsenko et al. Modelling the local effects of methane seeping on Arctic water column biogeochemistry. *Front. Mar. Sci.*

Wallhead et al. AERSEM: a new adaptation of the European Regional Seas Ecosystem Model for modelling high northern latitudes. *Geoscientific Model Development*.

Communicated Results

Svalbard Science Conference 5-6th November, Oslo, Norway. Talk: Griffith, G.P. Ecological Resilience of Arctic marine food webs to climate change.

Food Web Workshop, Tromso, Norway. Series of talks and workshop: Griffith, G.P.

Conservation Optimism Summit, 2-4th September, Oxford University, UK. Plenary Session Griffith, G.P. Considering cumulative stressors for adaptive marine management.

IMBeR Future Oceans Conference 15-21 June, Brest, France. Griffith, G.P. Visioning Global Futures workshop

Results from *Nature Climate Change* paper (Griffith et al) communicated internationally via Nature Press Office, and Institutions. Ranked in 95th percentile of 215,000 published articles in October/November 2019. International press coverage. The results have been presented at national and international workshops/meetings.

Interdisciplinary Cooperation

TRUMP has benefited from extensive interdisciplinary cooperation, with only positive aspects. For example, in Task 1, comparisons of numerical modelling results with biogeochemical field observations disclosed weaknesses in the physical model forcing.

Disciplines included: Marine Biology, Marine Chemistry, Marine Physics, Bubble Hydrodynamics, Marine Statistical Physics, Computer Science, Oceanography, Modelling, and Complexity Science.

Budget in accordance to results

- **In which way has the funding from the Fram Centre helped the project?**

The TRUMP project is at present the only project within any of the participating institutions that is specifically aimed at modelling and projected OA changes and impacts on ecosystems. The Fram funding has also served to trigger and complement internal institutional funds that are crucial for progress in the field. The development and application of ecosystem models within TRUMP enhances the ability of the participating institutions to win funding from other sources and to contribute in future projects. Fram funding has also allowed the exploration of novel approaches, and has assisted in covering computer costs and the employment of a talented young Norwegian Researcher.

- **Did the Fram Centre funding act as a sufficient boost for completing the project through other sources of funding?**

Yes, although the project was still quite strongly dependent on additional funding from non-Fram sources.

Could results from the project be subject for any commercial utilization

No

Conclusions

a) Indicate future research and/or perspectives which the project results have led to

b) List and describe new methods or techniques that have been developed during the project or that the project has revealed a need for

a) Project results have led to a new approach/paradigm for understanding how real-world food webs absorb change, recover and adapt to climate change (including cumulative effect of ocean acidification with other stressors, see Task 4). They have also given us new perspectives on weaknesses/biases in Arctic biogeochemical models (e.g. ice albedo, glacial smelting, Task 1) and sensitivities to physical forcing (e.g. of primary productivity, see Task 2) and to subsea permafrost emissions (Task 3) that in turn suggest profitable areas for future research and further improvement of model projections.

b) TRUMP has developed several new methods and analysis techniques e.g.: structural equation modelling of biogeochemical model output for understanding drivers of change (Task 2), a new, integrated ice-water-sediments transport model for assessing impacts on Arctic marine biogeochemistry (Task 3), new analytical techniques based on complexity theory for studying multi-species interactions and OA/climate change impacts in marine ecosystems (Task 4).