Arctic Ocean Acidification (AOA) Assessment

AMAP Report to Senior Arctic Officials for meeting in Lulea, Sweden, November 8-9, 2011

Recent Activities

There have been good linkages to the research community in general and significant progress made in preparation of the AOA by 2013. The AOA Expert group under the AMAP WG met in Villefranche-sur-mer September 6-8, 2011. They also met several other leading experts, including experts leading an ocean acidification (EPOCA) project that work out of the Villefranche-sur-mer Oceanographic institute, as well as experts from the International Atomic Energy Agency (IAEA) laboratory in Monaco that are engaged in assessment of economic aspects associated with ocean acidification.

The list of contributing authors was also up-dated, and calls made for some additional experts to be involved in the drafting of several sections of the report. SAOs and AMAP HoDs are asked to look into providing additional support for experts to be engaged in the AOA drafting work. An up-dated time schedule for the production of the assessment report was agreed (see below). At present the scientific report is estimated to be approximately 150 pages plus figures and photos, meaning that the printed version will be around 100 pages.

Outline of Assessment Report

See attached draft list of content, appendix 1.

Time Schedule and Peer/National Review

According to the new time schedule, the 2nd draft of the science report will be circulated December 15, 2011 for National review. Comments to the draft, and new data from national activities should be reported back to the AMAP Secretariat by February 1, 2012.

The 3rd draft that will be prepared after an AOA expert meeting that is currently planned for second half of February 2012 and will be circulated for international peer-review. It was decided that it might not be advisable to hold this meeting in conjunction with the IPY 2012 Conference in Montreal as originally planned, due to the many side meetings already being connected to

that meeting. Amsterdam or Copenhagen were suggested as alternative possibilities to minimize travel. Ideally we would like to have 2-3 reviewers per chapter, and two reviewers for the entire report. AMAP has to decide on a workable strategy for the selection and ranking of peer-reviewers.

A 'Layman' style summary report will be prepared by a professional science writer and AMAP HoDs and others are being requested to nominate possible writers for this task.

In addition to producing the reports, there is a plan to produce a short video presenting the main results of the assessment and its conclusions to a wider audience. Some funding for this has already been allocated, but the Arctic countries are welcome to sponsor this production.

Products

1) Scientific Assessment Report (100-150 printed pages)
2) Layman style Summary Report
3) Film – 3 min and longer version

SAOs guidance is being sought on the following:

1) Report outline.
2) Timeframe for production.
3) Final products, including science and summary reports and film.

Appendix 1

Arctic Ocean Acidification (AOA) Assessment
Draft list of contents

Chapter 1. Introduction

Chapter 2. Arctic Ocean Acidification

Policy relevant questions

What are the dominant processes forcing OA
Which regions are most sensitive to OA
What timescales are relevant?
What processes are sensitive to OA

Newly defined sections

1. Carbonate system in seawater
    a. CO2 chemistry
    b. Carbon pumps
    c. Buffer capacity (resilience)
2. OA Sensitive processes
    a. Integrate nutrient and metal sections
    b. Sedimentary processes (CaCO3, S, N,
    c. Calcification and production
    d. Speed of sound
3. Sources and sinks in present day arctic
    a. Standing stocks of C
    b. Carbon fluxes (air-sea exchange and transport)
    c. River sources
    d. Methane and CO2 seeps, volcanoes
4. Contemporary OA
    a. Natural OA (circulation)
    b. Anthropogenic OA including NOx SOx
    c. Acidification highways (Nordic highway, North American Arctic and Siberian Shelf)
5. Future OA
    a. Model scenarios
    b. Return to biogeochemical sensitivity
    c. Return to flux studies
    d. Processes defined
        i. Polynas and leads
        ii. River alkalinity
        iii. Biogeochemical feedbacks
    e. (bring in paleo “evidence”)
6. Databases and monitoring strategies
    a. Combining metadatsets
        i. CARINA
        ii. Geotraces_Melina_CFL

iii. CASES
iv. NSF
v. SOCAT
vi. Ferrybox
vii. Defining new monitoring strategies
viii. New instrumentation required

Chapter 3 – Biological responses to OA [30-40 pages]

Policy questions

These are intended for use in organizing the manner in which the information is presented in the extended-length executive summary.

- How will Arctic ecosystems change under OA
- What's the relative importance of OA compared to other stressors
- Which Arctic ecosystems are most sensitive to OA?

1. Arctic environment & biological hypotheses [1-2 pages]
- Biogeochemistry (link to Chapter 2) + high productivity (seasonal, food/energy)
- Future ocean -> multiple stressors (salinity, ice melt, temperature, pCO_2)
- Hypotheses & paradigms (e.g. under-saturation -> negative impact on calcifiers, stress->nutrition)

Short species-process review for the Arctic then compare and contract with Antarctic. Gaps and challenges in the Arctic.

Connect the species presentations with the processes.

Policy-orinted approach rather than strictly scientific

2. Biological response – General [1 page]
Brief summary of the topic (number of species studied in the light of life diversity, species-specific even in closely related species, even within population, range of responses, different experimental approach, etc.)
Highlight the lack of information (quantify) for polar and Arctic regions (? Word on practical limitation in working in these regions?)

3. Biological response – Taxa [2-3 pages]
For each major studied taxa, one paragraph summarizing the whole literature, then emphasize what is known for polar and Arctic (?make a template for contributors?)
- Viruses
- Bacteria
- Phytoplankton

- Macroalgae
- Cold water corals (with reference to other corals)
- Molluscs (several sub-groups: cephalopods, pteropods, shells)
- Echinoderms
- Crustaceans (several sub-groups: barnacles, others?)
- Fish
- Mammals (whales, sound?)

4. Biological response – Processes/endpoints [2-3 pages]

Same approach than for Taxa

- Fertilization
- Growth
- Physiology (respiration, feeding, etc.)
- Survival
- Reproduction
- Calcification
- Behaviour, acoustic, smell, etc.
- Etc.?

5. Species response - Uncertainties [4-5 pages]
All experiments are abstraction of reality, no species with the full story.
- **Time of exposure** [*most studies short terms, over- (acclimation, selection) and under-estimate (late mortality, carry-over effects) the real impact*]
- **Abrupt vs Gradual changes**
- Lack of **link to fitness** [change ≠ negative, plasticity, etc.) -> danger of over-interpretation of the data (+ unrealistic pCO_2 should not be used in a OA context but only for physiological values).
- **Natural spatial-temporal variability** (daily, seasonal, yearly)
- **Ecological interactions** (e.g. natural analogs highlight importance of interactions) – food webs
- **Synergy between biotic and abiotic stressors**. (Invasives)
- **Life-history** bottleneck + carry-over/latent effects.
- **Evolutionary processes** (multi-generation, adaptation potential, natural selection)
- **Surprises**: new field, lot of "unexpected" observations -> space for exploratory research
- **Proximal factors**? (pCO_2, pH, carbonate chemistry, etc.)

6. What we do know for sure [1-2 page]

- *Not much for the Arctic, can we answer issues from Chapter 2?*
- *Effect certain, can be negative but cautious, species-specific, paradigms should be revisited*
    - ➔ *can only be sure of extreme negative impacts (extinction, no change of adaptation, etc.)*
    - ➔ *not possible (so far) to make any large scale prediction*

7. What is needed for meaningful and well-founded predictions [2-4 pages]

Some keys for large scale predictions (how to explain inter-specific variability)

- Taxonomy/Phylogeny? -> not supported by data for most taxa, does not work at the species level
- calcifiers vs non-calcifiers?, CaCO3 forms, etc -> not always supported by data, does not work at the species level
- region (Arctic vs others) -> ?
- Historical natural variability experienced by the species
- Life-history strategies (fecundity, larval strategy, selection potential, etc.), ontogeny + evolutionary potential (generation time, gene flow, etc.)
- physiology, pH regulation, metabolism
- energy acquisition (e.g. symbiosis, heterothrophy, autotrophy, etc.)

8. Conclusions [1 page]

Chapter 4. Ocean Acidification's Economic Impacts on Arctic Fisheries

1. Modeling catch impacts of ocean acidification
2. Modeling economic impacts on commercial fishing
3. Indigenous peoples' availability of food supplies due to the food chain
4. Recreational value of arctic ecosystems
5. Marine management plan suggestions

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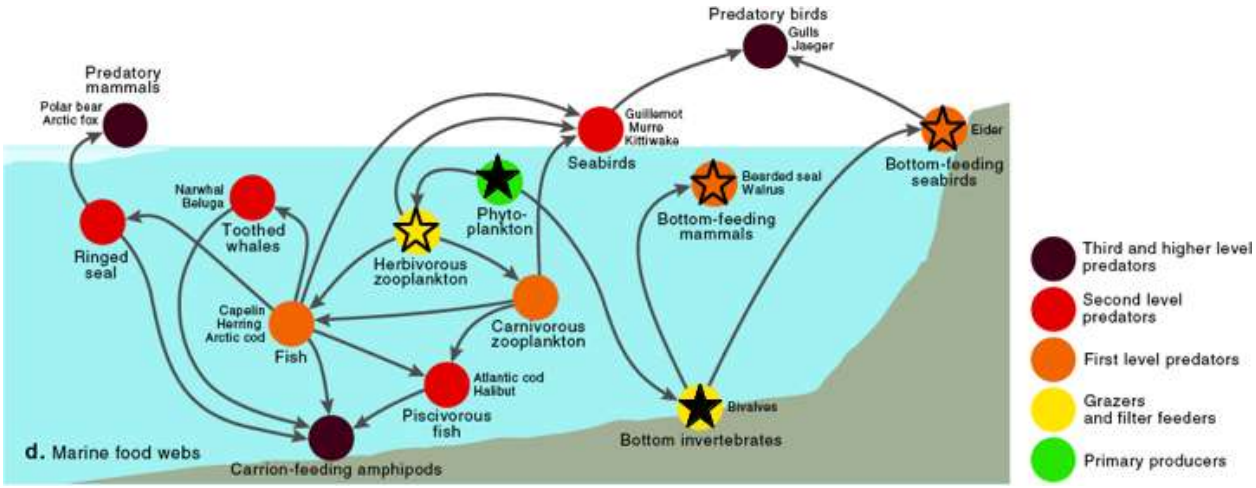

Figure F1. Generalized Arctic food web, with trophic levels very likely to be directly affected by ocean acidification noted with a filled star, and species likely to be indirectly affected (e.g. via a predator-prey relationship with a directly affected species) noted with an open star. Adapted from AMAP Ch. 4.

Table T1. Arctic organisms harvested by indigenous peoples (AMAP Ch. 5).

Organisms listed in bold are at highest risk of ocean acidification either due to direct or indirect risks.

Major category	Organism harvested	Major prey	Directly at risk of OA?	Indirectly at risk of OA b/c prey at risk?
Fish	Unspecified	Any below	Not known	Somewhat likely
	Arctic char	insects, mollusks, small fish	Not known	Somewhat likely
	Atlantic cod/Cod	krill, crustaceans, young fish	Not known	Somewhat likely
	Atlantic wolffish/ocean catfish	mollusks, crustaceans, echinoderms, crabs, urchins	Not known	Very likely
	Blue ling	fish, crustaceans, benthic invertebrates	Not known	Somewhat likely
	Blue whiting	amphipods, appendicularians, krill	Not known	Not likely
	Capelin	plankton, krill, crustaceans	Not known	Somewhat likely
	Coalfish	young fish	Not known	Not likely
	Greenland cod	shrimp, crab, young fish	Not known	Not likely
	Greenland halibut/Halibut	shrimp, plankton, krill, young fish	Not known	Somewhat likely
	Greenland shark	fish, marine mammals	Not known	Not likely
	Haddock	crustaceans, echinoderms, fish	Not known	Somewhat

Major category	Organism harvested	Major prey	Directly at risk of OA?	Indirectly at risk of OA b/c prey at risk?
				likely
	Herring	phytoplankton, copepods, small crustaceans	Not known	Somewhat likely
	Ling	krill, copepods	Not known	Not likely
	Mackerel	copepods, young fish, krill, shrimp	Not known	Not likely
	Muksun	planktonic crustaceans, plankton, benthic invertebrates	Not known	Somewhat likely
	Nelma/inconnu	plankton, small fish,	Not known	Not likely
	Plaice	invertebrate worms	Not known	Not likely
	Redfish	shrimp, small mollusks, invertebrates, shrimp	Not known	Somewhat likely
	Rockfish	plankton, copepods, fish eggs, small crustaceans	Not known	Somewhat likely
	Rough dab	small crustaceans, worms, mollusks, young fish	Not known	Somewhat likely
	Saithe	fish	Not known	Not likely
	Salmon	Insects, young fish, shrimp, pteropods	Not known	Somewhat likely
	Siberian sturgeon	crustaceans, worms	Not known	Somewhat likely
	Tusk	crustaceans, soft invertebrates, mackerel	Not known	Somewhat likely
Shellfish	Unspecified	Any below	Somewhat likely	Not likely
	Clams	plankton	Very likely	Not likely
	Crab	Crustaceans, mollusks, worms, urchins, benthic invertebrates	Somewhat likely	Somewhat likely
	Norway lobster/langoustine	worms and fish	Somewhat likely	Not likely
	Scallops	plankton	Very likely	Not likely
	Shrimp	planktonic organisms	Somewhat likely	Not likely
Marine Mammals	Unspecified	Any below	Not known	Somewhat likely
	Bearded seals	Crustaceans, mollusks, fish	Not known	Somewhat likely
	Beluga whales	Fish, marine invertebrates	Not known	Not likely
	Bowhead whales	Plankton, krill, copepods	Not known	Somewhat likely
	Common seals	Fish	Not known	Not likely
	Fin whales	Fish, krill	Not known	Not likely
	Fur seals	Fish, squids	Not known	Somewhat likely
	Harbour seals	Fish, crustaceans, mollusks	Not known	Somewhat

Major category	Organism harvested	Major prey	Directly at risk of OA?	Indirectly at risk of OA b/c prey at risk?
				likely
	Harp seals	Fish, crabs	Not known	Somewhat likely
	Hooded seals	Fish, mollusks, crustaceans	Not known	Somewhat likely
	Minke whales	Small fish, krill	Not known	Not likely
	Narwhal	Squid, fish, shrimp	Not known	Somewhat likely
	Pilot whales	Squid, fish	Not known	Somewhat likely
	Polar bears	Ringed and bearded seals	Not known	Not likely
	Ringed seals	Fish, shrimp, crustaceans	Not known	Somewhat likely
	Sea lion	Fish, cephalopods	Not known	Somewhat likely
	Walrus	Shrimp, crabs, worms, mollusks, clams	Not known	Somewhat likely
Seabirds	Unspecified	Any below	Not likely	Somewhat likely
	Arctic tern	Fish, crustaceans, mollusks, insects	Not likely	Somewhat likely
	Black guillemot	Fish, crustaceans	Not likely	Somewhat likely
	Cranes	Fish, insects, plants	Not likely	Not likely
	Dovekie	Crustaceans and zooplankton	Not likely	Somewhat likely
	Ducks	Fish, insects, plants, mollusks	Not likely	Somewhat likely
	Eider	Benthic invertebrates, mollusks	Not likely	Somewhat likely
	Geese	Fish, insects, plants	Not likely	Not likely
	Kittiwakes	Marine invertebrates, plankton, fish	Not likely	Not likely
	Sea gulls	Fish, mollusks, invertebrates	Not likely	Somewhat likely
	Swans	Plants	Not likely	Not likely
	Thick-billed murre	Fish, squid, crustaceans	Not likely	Somewhat likely