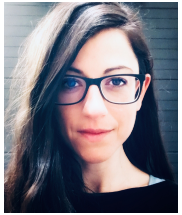
Arctic Sea-Ice Decline Impacts On Primary Production

Perspective Review In preparation for Nature Reviews Earth & Environment

Ed. Graham Simpkins



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Scope of the Review

-->**Summarize** current knowledge on the changing Arctic Icescape, pulses of marine primary production, ecological cascades and links to terrestrial productivity.

-->**deliver** a set of predictions for key productivity indicators such as timing and magnitude of algal blooming.

-->**propose** a semi-quantitative model of the expected future changes in primary and secondary production in the ice-covered Arctic Ocean and terrestrial linkages.

Highlight # 1

Changing Arctic Icescape

- During the satellite era, Arctic sea-ice areal coverage has decreased in every month. Changes are largest in summer --> Multiyear Ice (MYI) replacing First-Year Ice (FYI) --> loss in sea-ice volume exceeding that of sea-ice area in all months (Stroeve and Notz 2018).

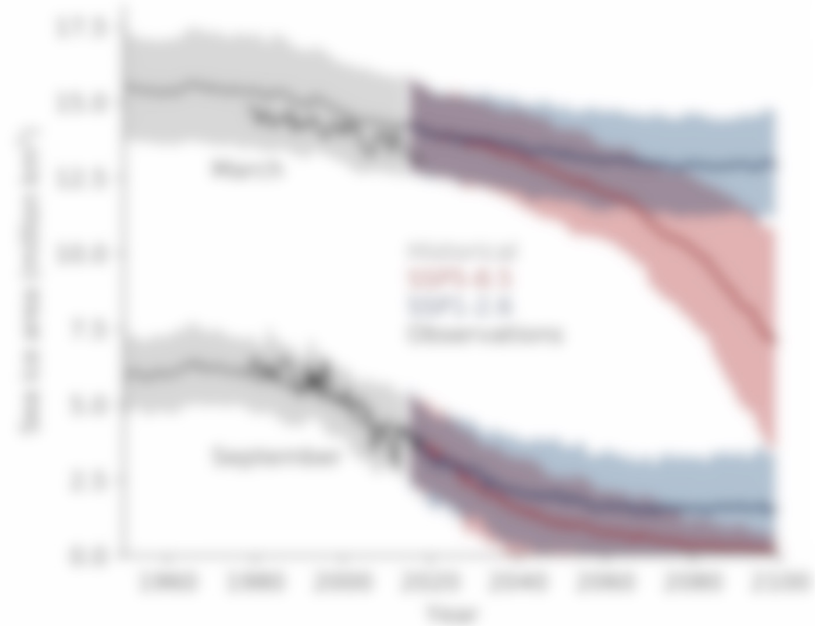
- Suggested that most of the Arctic sea-ice loss attributed to Anthropogenic Greenhouse Gas emissions (Notz and Stroeve 2016).

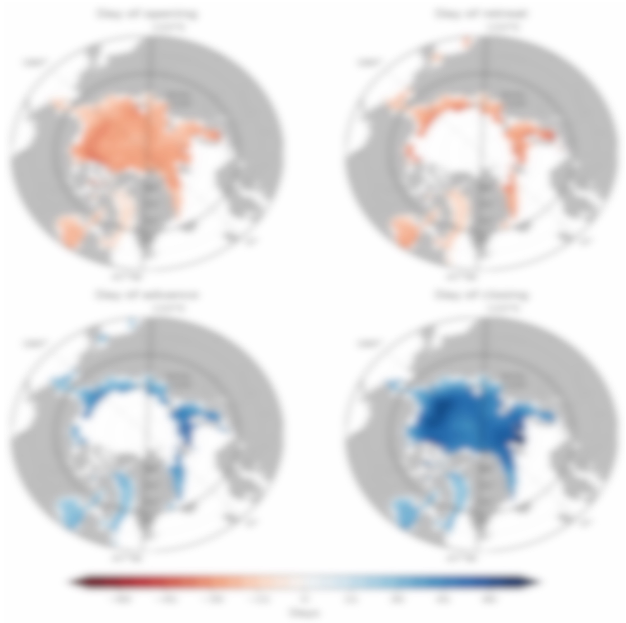
- Rainfall rather than snowfall predicted to become the dominant form of precipitation in th Arctic (Bintanja and Andry 2017).

Highlight # 1

Changing Arctic Icescape

--> We present a range of projections from an ensemble of CMIP6 (SSP5-8.5) daily Arctic sea-ice and snow data: it is confirmed a clear dependence of sea-ice evolution on future emission scenarios also within CMIP6.





Tedesco et al., NREE, In Preparation.

Highlight #2

Drivers of marine biological changes

LIGHT

- controls both timing and magnitude of primary producers' growth (Gradinger 2009, Tedesco and Vichi 2014; Leu et al 2015).
- Sea-ice decline expected to continue as well as snow thinning (CMIP5, e.g., Tedesco et al 2019).

NUTRIENTS

- impact on bloom magnitude and termination, and taxonomic composition (Gradinger 2009, Tedesco and Vichi 2014, Leu et al 2015, Assmy et al 2017, Campbell et al 2018).
- Increasing freshwater runoff and sea-ice melt --> stronger thermo-haline stratification (Carmack and McLaughlin 2011) and freshening (e.g., McPhee et al 2009) --> hindering vertical mixing.
- More ice-free waters exposed to wind/storms --> mixing enhanced (Rainville and Woodgate 2009), particularly across shelf breaks (Linciln et al 2016).

Highlight #2

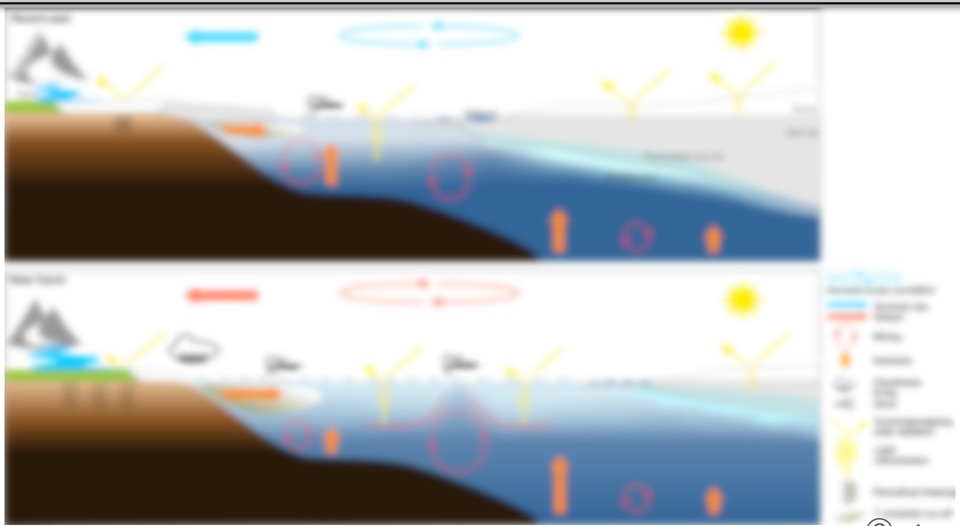
Drivers of marine biological changes

LIGHT

--> We predict sea ice and snow further declining also with CMIP6 (This work) --> More light available.

NUTRIENTS

--> We expect prevailing conditions offset between stratification and mixing, regionally distinct.



Tedesco et al., NREE, In Preparation

Highlight #3

Pulses of marine primary production

- **Traditional Paradigm**: a first pulse of energy due to ice algal blooming, a second brief and intense open water (summer) phytoplankton bloom, and a third pulse of degrading organic matter (e.g., Wassmann and Reigstad 2011, Ji et al 2013).

- On a pan-Arctic scale, earlier blooms and overall increase in FYI algal gross primary production (GPP) over the 21st century under a RCP8.5 scenario (and unchanged nutrient concentrations) predicted, based on an ensemble of 18 CMIP5 with a sea-ice biogeochemical model (Tedesco et al 2019).

- Increasing occurrence of under-ice phytoplankton blooms with a thinning and more dynamic ice cover is expected (Mundy et al 2009, Arrigo et al. 2012, Assmy et al 2017).

- Observed (e.g., Arrigo and van Dijken 2015) and expected (Vancoppenolle et al 2013) increase in phytoplankton production. However, increase in cloudiness (Belanger et al 2013), caution with interpretation of images of Chl-a, and high uncertainties in the sea-ice zone.

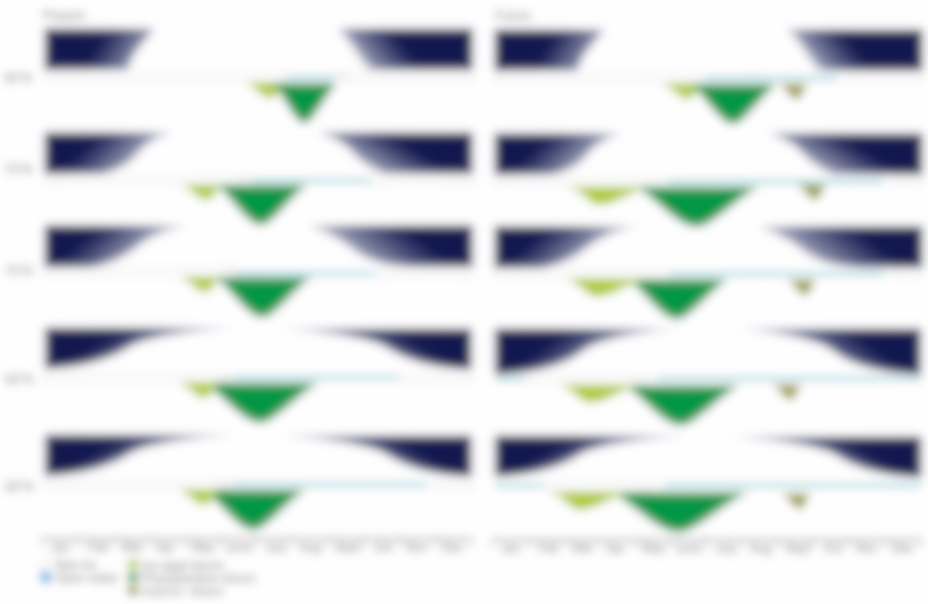
- Due to later freeze-up, fall blooms are becoming more frequent (Ardyna et al 2014).

Highlight #3

Pulses of marine primary production

-->We revise and extend previous conceptual models (Wassmann and Reigstad 2011, Barber et al 2015) and present a semi-quantitative model of the expected changes in Arctic algal bloom timing and magnitude based on recent observational and modelling findings, by:

- Extending the model from the Marginal Ice Zone (MIZ) to the entire ice-covered Artic Ocean
- using the physical sea-ice changes predicted by a new ensemble of 10 climate models (CMIP6, SSP5-8.5 mitigation scenario) as a background to predict changes in algal dynamics
- Discerning the Western Arctic by the Eastern Arctic
- Presenting algal dynamics in bands of 10-degree latitude for both arctic sectors



Highlight #4

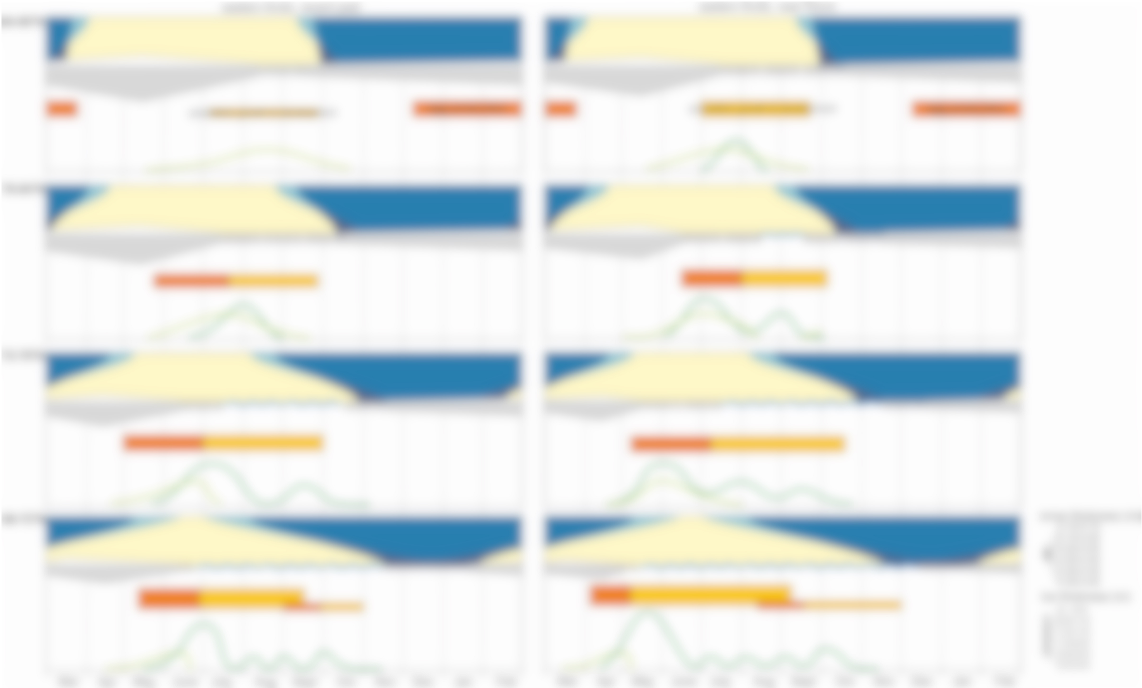
Matching pulses and ecological cascades

- Changes in timing, magnitude and duration of primary production can have consequences for higher trophic levels (søreide et al 2010, renaud et al 2018).
- On longer timescales, community compositional shifts, trophic mismatches, and differential success or demise of species with stronger or weaker adaptability and resilience traits can be expected (Post, 2017).
- Calanoid copepods of the genus Calanus comprise up to 80% of the zooplankton biomass in the Arctic Ocean (Tremblay et al 2006, Søreide et al 2008).
- Algal changing dynamics can lead to faster growth and higher turnover rates, shorter life cycles and reduced Calanus body sizes (Ejsmond et al 2018) as well as shifts in Calanus community composition (Möller and Nielsen 2019).
- The reduced body sizes can impact predators preferring a certain prey size, e.g., planktivorous fish (Renkawitz et al 2015), and consequently the entire Arctic food web (Falk-Petersen et al 2007).

Highlight #4

Matching pulses and ecological cascades

--> We propose a semi-quantitative model of the expected changes in copepods' population growth and development timing based on the same setup as for the algal model.



Highlight #5

Linking sea-ice decline to terrestrial productivity

- Traditionally, the influence of Arctic sea ice on terrestrial biota limited to effects of the proximity of sea ice on local abiotic conditions and near-shore tundra vegetation community composition (e.g., Walker et al 2012).

- Recent studies: associations of Arctic sea-ice dynamics with plant phenology (Kerby & Post 2013) and tundra shrub productivity and greening (Bhatt et al 2010, Macias-Fauria et al 2012, Post et al 2013, Forchhammer 2017)

- Consequences for higher-order dynamics, e.g. demographic variation and population declines of reindeer and caribou (e.g., Kerby & Post 2013, Forbes et al 2016) and decreased access from cliff habitat to seabird prey with changing sea-ice conditions (e.g. Renner et al 2016, Hunt et al 2018) --> consequences for the nutrient cycling of these environments.

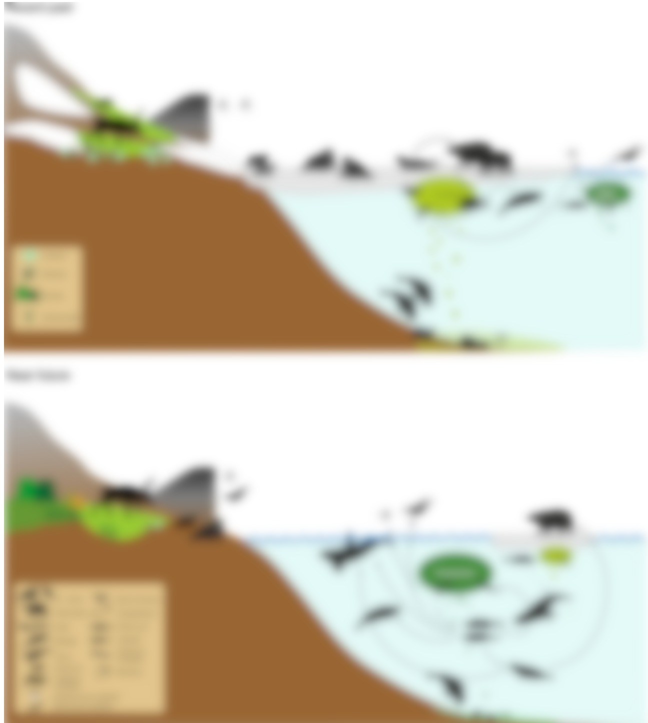
- Closer statistical associations of terrestrial ecological dynamics with Arctic-wide sea-ice decline or dynamics than with local weather conditions (e.g., Kerby and Post 2013, Post et al. 2016).

- Geographic variation in the direction and magnitude of associations between terrestrial shrub abundance or productivity and Arctic-wide sea-ice decline (e.g., Macias-Fauria et al 2012, Forchhammer 2017, Macias-Fauria et al 2017)

Highlight #5

Linking sea-ice decline to terrestrial productivity

--> We revise the conceptual model of the ecological interactions influenced by sea ice of post et al (2013) by adding a quantitative representation of the changes in key species abundance, besides distribution and interactions between marine and terrestrial species.



Tedesco et al., NREE, In Preparation

- For the non-presented parts of the review, stay tuned with Nature Review Earth & Environment for upcoming issues: https://www.nature.com/natrevearthenviron

- For projections of future phenological and trophic Arctic Ice algal changes --> see also Display 20328 "**Tedesco et al., Sea-Ice Algal Phenology in a Warmer Arctic**" https://doi.org/10.1126/sciadv.aav4830

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