Can we detect changes in Arctic ecosystems? (ARISE)

Contact: Dr Claire Mahaffey, Department of Earth, Ocean and Ecological Sciences, University of Liverpool (+44 (0)151 794 5421, mahaffey@liverpool.ac.uk)

1. Rationale and scientific issues to be addressed: Due to unprecedented rates of environmental change, the Arctic is now a crucible of multiple concurrent stressors. Understanding how food webs are being reshaped over different spatial and temporal scales in response to these stressors is crucial in addressing the impacts of future change on biodiversity and ecosystem services. Rather than evaluate an entire ecosystem, the ARISE project will take a specific focus on the base of the food web and two species of pelagic-feeding ice-dependent predators, the harp seal (*Pagophilus groenlandicus*) and the ringed seal (*Phoca hispida*), which are excellent 'indicator species' of food web functioning. Due to their wide Arctic distributions, long-range migrations and thus substantial time spent at sea, as well as flexible foraging patterns, these seals are exposed to multiple stressors across the Arctic region and so are excellent candidates for this study.

Stable isotopes of nitrogen (^{14}N, ^{15}N) and carbon (^{12}C, ^{13}C) have the potential to be important food web tracers due to the isotopic discrimination in ^{15}N by ~ 2-5 per mil (‰) and ^{13}C by <1‰ with each trophic transfer. This approach provides quantitative information on seal trophic position and food chain length. However, the isotopic signal recorded by seals is sensitive to the ^{15}N and ^{13}C at the base of the food web, termed the 'isoscape'. Particulate organic material (POM) makes up the bulk of the isoscape and is itself underpinned by primary producers, whose ^{15}N and ^{13}C value is controlled by bottom-up factors, specifically (a) the ^{15}N and ^{13}C of the dissolved nutrient and carbon sources, (b) the magnitude of N and C sources and (c) isotope fractionation during N and C phytoplankton assimilation. All are likely to vary in response to environmental change in the Arctic.

2. The Problem: Determining the inferred trophic position of an Arctic seal and food chain length from ^{15}N and ^{13}C tracers could be problematic for two reasons. Firstly, the strong spatio-temporal gradients in the isoscape across the Arctic must be constrained to accurately quantify seal trophic position. Secondly, as seals migrate and forage widely, they are exposed to a variety of isoscapes. For example, the ^{15}N value of nitrate varies by up to 2 to 3‰ between the Atlantic and Pacific inflows, which is equivalent to one trophic position from a food web perspective. Equally, the ^{13}C baseline will lighten due to ongoing uptake of ^{13}C-deplete anthropogenic CO_2 and its transport into the Arctic from the Atlantic and Pacific, directly affecting the ^{13}C signal in seals. Indeed, there are many examples of the sensitivity of the ^{15}N and ^{13}C of predators to a changing isoscape (Lorrain et al 2015, Newsome et al 2007, 2010, Iken et al 2010, Hansen et al 2012, Yurkowski et al 2015).

Our goal is to develop a framework to detect and attribute changes to Arctic food webs during periods of decadal change. This will be achieved by benchmarking novel food web tracer techniques to the underlying changes in the isoscape and seal foraging behaviour using observational and modelling techniques.

3. Overview of Objectives: We have three main objectives encompassing observational and modelling studies. A fourth objective provides the means to link our findings to conservation and management of seals in the Arctic.

Objective 1 will constrain the spatial and temporal variability of the isoscape and determine the local and external drivers of its variability at pan-Arctic scales. We have designed a pan-Arctic, seasonal resolved and well-integrated fieldwork campaign to achieve this objective. We will measure or access data on ^{15}N and ^{13}C composition of nutrients, carbon and the isoscape (POM) during NERC and project partner cruises (Hop and Dodd (NPI), von Appen (AWI), Geotraces via Francois (UBC) and Granger (UConn), Sorenson and King (NIVA)) and from riverine end members (ArcGRO, Spencer, FSU). Alongside water mass characteristics, remote sensing datasets on sea ice, surface phytoplankton biomass, and productivity (Arrigo, SU) and targeted model experiments using PISCES (Bopp, LSCE), a state of the art three-dimensional coupled physical–biogeochemical model, we will isolate the mechanisms driving variability in the isoscape. Uncertainty in representation of local physics will be assessed using a regional ocean modelling system model (ROMS, Duarte NPI).

Objective 2 will determine the sensitivity of the food web tracers in seals to the ^{15}N and ^{13}C composition of the isoscape and the impact on inferred trophic position. We will directly study two harp seal stocks, the Greenland Sea or 'west ice' stock and the White Sea-Barents Sea or 'east ice' stock. We will use telemetry to study the migratory and foraging behaviour of harp seals (Haug and Biuw (IMR)) which, when linked to remote sensing datasets and hydrography from tags, will reveal the drivers behind their migration and foraging patterns.

In parallel, we will have access to seal tissues (blood, muscle, liver, whiskers) from commercial hunting programmes in the Greenland-Iceland-Norwegian Seas and Siberian sector (Haug and Biuw (IMR)) and from Inuit subsistence hunting programmes of harp (Stenson, DFO) and ringed seals (Ferguson, DFO) in the Canadian Arctic throughout the year for biomarker analysis. To study the connectivity between seals and the base of the food web, we will use ^{15}N of amino acids (hereafter ^{15}N-AA) and the H-print (Brown, UoP). Use of ^{15}N-AA overcomes the problem of constraining a varying isoscape baseline because ^{15}N-AA e.g. phenylalanine, indirectly fingerprints the base of the food web as it conservatively traces the ^{15}N of primary producers, while 'trophic' amino acids, e.g. glutamic acid, are enriched during trophic transfer and so isolate a predator's trophic position. Using this approach for seals, we can simultaneously compare the isoscape and determine both trophic position and food chain length. To determine changes in the C source at the base of the food chain, we will measure the ^{13}C alongside the H-print biomarker. We will also have access to zooplankton and fish samples. We will compare biomarker signatures from seals with our understanding of isoscape variability from Objective 1.

Objective 3 will quantify how decadal variability affects the attribution of variations in the food web tracer signals recorded by seals to changes in the isoscape in the context of Arctic and global change. We will have access to samples from the best available archives of ringed and harp seal teeth. Seal teeth grow throughout life and dentine layers are deposited annually, thus providing a "tape recorder" of trophic history. We will have access to teeth from (a) harp seal teeth collected from 1970's from Newfoundland and Labrador Shelves (Stenson, DFO), (b) harp seal teeth collected from 1950's from the west and east ice stocks in the Barents Sea (Haug, UT) and (c) ringed seal teeth collected from the 1980's from the Canadian Arctic (Ferguson, DFO). Using the ^{15}N-AA approach, we will simultaneously compare the isoscape, trophic position and food chain length over decadal time scales from seal teeth. We will use long-term model simulations in collaboration with NOC alongside remote sensing data sets to attribute drivers of past decadal change. Future simulations will provide the 'signal to noise' ratio necessary for detecting future change in the Arctic food web from tracers against the climate change signal. Finally, we will compare the foraging behaviour of seals gathered via historical telemetry data with remote sensing data sets and model output on relevant environmental variables to better understand which environmental factors have driven any observed changes in migratory patterns.

Objective 4 will quantify the effects of environmental change on seal populations. To link Arctic environmental change, predator life history and population trends, we combine information from the laboratory, field and model studies obtained during objectives 1 to 3 to assess the impacts on harp and ringed seal body condition and vital rates, and consequences for population dynamics. We will use both statistical and structured mechanistic population models (Buren, Hammill, DFO). This will allow the practical and applied outputs of the project to be discussed in the context of management and policy for Arctic marine mammals, with potential to inform future decision making for these important populations. Interaction with working groups at NAMMCO and ICES will be facilitated by already existing experience at SMRU, SAHFOS and by project partners.

Our work will be complimented by two PhD studentships: **(1) Liverpool-SAHFOS PhD project:** Using archive samples from the CPR collected from the Barents Sea since 2008, the PhD student will investigate if the food source for zooplankton has altered in response to environmental change in the Arctic using stable isotope and molecular techniques. **(2). Manchester-Liverpool PhD project:** Using geochemical and stable isotope biomarkers, the PhD student will quantify the contribution of terrestrially derived organic matter to the Arctic isoscape.

Complimentary topics may include: impact of environmental change on intermediate trophic levels (e.g. fish) and other predators (e.g. polar bears, birds) in the Arctic, and on foraging and migratory behavior of predators (e.g. via telemetry), upstream and downstream impact of changes in the Arctic on the North Atlantic Ocean (e.g. changes in water column stability, nutrients, carbon), impact of changing physical environment (e.g. water column stability, storminess) on the isoscape.