Supplementary File: Table on Available Environmental Covariate Data

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Covariate/dataset	Relevance to harp and hooded seal populations	Future projections available?	Data sources for different areas	Notes about the data sets	Literature	Links
1. Global climate indices						
North Atlantic Oscillation	Links to seal vital rates not demonstrated in studies to date.	No	NOAA	Difference in surface pressure between the subtropics (latitudes 20°N to 40°N ('the Azores High')), and further North (latitudes 50°N to 70°N (the 'Icelandic Low')). Associated with changes in temperature, winds, and rainfall in Europe.	1, 2, 3	1, 2
Atlantic Multidecadal Oscillation	This covariate might be more relevant to the seal populations than NAO	No	NOAA	Periodicity in North Atlantic SST, from remote sensing.		1, 3
Subpolar Gyre Index	This might be a more precise predictor than NAO and AMO, for effects on NE Atlantic and even even West Greenland seal populations. There is finer spatial resolution for this index than for NAO.	These may become available.	NOAA	Associated with North Atlantic circulation and upwelling. Based on satellite observations of sea surface height.		1, 4
2. Environmental covariates						
Sea Surface Temperature (mean and standard deviation)	Mechanism would be through effects of ocean temperature on the marine foodweb, and might operate at a range of temporal scales.	Y - extract from CMIP6.	NOAA	The SST and ice metrics come from the NOAA's Optimal Interpolation SST v2.1.		1, 5
Sea Surface Temperature anomaly relative to the 30 year climatological mean from 1971-2000 (mean and standard deviation)		Y - extract from CMIP6.	NOAA	The SST and ice metrics come from the NOAA's Optimal Interpolation SST v2.2.	4	1
Sea ice (maximum annual extent, day of maximum extent, minimum annual extent, day of minimum extent)	Effects would be through foodweb interactions, or if ice is unavailable in traditional whelping areas.	Y - extract from CMIP6.	NOAA	The SST and ice metrics come from the NOAA's Optimal Interpolation SST v2.3.	4, 5	1, 6, 7

Thin ice - coverage low, especially with high winds	Short term effect: ice related pupping mortality observed directly in NW Atlantic populations and likely in NE Atlantic populations.			Satellite or ice charts, sealer records.	1, 3	
KOLA time series temperatures			PINRO (Polar Branch of VINRO, named after N.M. Knipovich)			8
Station 27			Fisheries and Oceans Canada	An oceanographic sampling station off St. John's with a long time series. It is used as an indicator of the grand banks and Newfoundland Shelf environmental condition.	6	9
Inflow Atlantic water in the Barents Sea	Changes in fish community may impact the foraging success of seals			Indicator of borealisation in Arctic waters.	2	
Composite environmental index (NW Atlantic)	Linked to harp and hooded NW Atlantic populations.			Surface temperature; bottom temperature; and others combined together to provide one index.	7	
3. Predator abundance						
Polar bear (*Ursus maritimus*)	Predation of hooded and harp seals. Svalbard harp seals are impacted by polar bear predation.			Diverse surveys, see IUCN assessment for references.	8	10
Killer whales (*Orcinus orca*)	Probably predation on harp and hooded seals, but predation mortality is not well quantified.			Diverse surveys, see IUCN assessment for references.	9	10
4. Prey abundance						
General	Information about the size, age and (seasonal) caloric content of prey might be lacking; data on commercial species is more complete than for forage fish and invertebrates.	Forward projections are not easily available, though ecosytem models may provide some scenario-based predictions.	CSAS, NAFO	**NW Atlantic:** CSAS (includes stock assessments) and NAFO (stakfin, outside of the 200 mile limit and transboundary species).		11
			ICES	**Greenland Sea**: limited data, DATRAS and reports of ICES working groups.		12

General cont.	*As above*	*As above*	IMR/PINRO	**White/Barents Sea**: here there are relatively good data, and new data sets will soon be available (WGIBAR, among others).		12, 13
Capelin (*Mallotus villosus*)	Important in harp seal diets. Relationship with late term abortion/ condition (NW Atlantic) and with condition (White Sea/Barents Sea).			Commercial species with substantial survey and stock assessment information.	1, 10, 11	14, 15
Arctic/polar cod (*Boreogadus saida*)	Important in harp and hooded seal diets. Relationship with harp seal condition in the White Sea/Barents Sea.			Some survey data are available; coverage is very patchy in time and space.	10, 11, 12	14
Cod (*Gadhus morhua*)	Important in harp seal diets. Relationship with harp seal condition in the White Sea/Barents Sea. Cod may act as prey, and also as competitors with seals for forage species.			Commercial species with substantial survey and stock assessment information.	10, 12	14, 15
Amphipod sp.	Important component of harp seal diet			Some survey data are available; coverage is patchy in time and space.	12, 13	13, 16, 17
Krill sp.	Important in harp and hooded seal diets. Relationship with harp seal condition in the White Sea/Barents Sea.			Some survey data are available; coverage is patchy in time and space.	10, 11, 13, 14,	13
Calanus sp.	Foodweb impacts on seals especailly through capelin. Calanus abudance is related to ice cover and timing.			Some survey data are available; coverage is patchy in time and space.	15	13, 16
Squid (especially Gonatus sp.)	Important component of hooded seal diet.			Diverse surveys.	16, 17	11, 12
5. Base of the foodweb						
Primary productivity	Potential impacts on the wider marine community and seal foraging success.		NASA	Remote sensing data. PP has been increasing in the White Sea/Barents Sea. Historical time series begins in late 20th century. Model hindcasts may be available.	18	18
Chlorophyll A	Potential impacts on the wider marine community and seal foraging success.		NASA	Remote sensing data. Increased production due to ice retreat and nutrient input.	18	18

Literature

1 Stenson, G. B., Buren, A. D. & Koen-Alonso, M. (2016). The impact of changing climate and abundance on reproduction in an ice-dependent species, the Northwest Atlantic harp seal, Pagophilus groenlandicus. *ICES Journal of Marine Science, 73* (2), 250–262. https://doi.org/10.1093/icesjms/fsv202

2 Øigård, T. A., Lindstrøm, U., Haug, T., Nilssen, K. T. & Smout, S. (2013). Functional relationship between harp seal body condition and available prey in the Barents Sea. *Marine Ecology Progress Series, 484* , 287–301. https://doi.org/10.3354/meps10272

3 Johnston, David W., Matthew T. Bowers, Ari S. Friedlaender, & David M. Lavigne (2012). The effects of climate change on harp seals (Pagophilus groenlandicus). *PLoS One 7* (1): e29158. https://doi.org/10.1371/journal.pone.0029158

4 Banzon, V., Smith, T. M., Steele, M., Huang, B. & Zhang, H. M. (2020). Improved estimation of proxy sea surface temperature in the Arctic. *Journal of Atmospheric and Oceanic Technology, 37* (2), 341-349. https://doi.org/10.1175/JTECH-D-19-0177.1

5 Laidre, K. L., Stern, H., Kovacs, K. M., Lowry, L., Moore, S. E., Regehr, E. V., ... & Ugarte, F. (2015). Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. *Conservation Biology, 29* (3), 724–737. https://doi.org/10.1111/cobi.12474

6 Petrie, B., Loder, J. W., Akenhead, S., & Lazier, J. (1991). Temperature and salinity variability on the eastern Newfoundland shelf: the annual harmonic. *Atmosphere-Ocean, 29* (1), 14-36. https://doi.org/10.1080/07055900.1992.9649433

7 Cyr, F., Snook, S., Bishop, C., Galbraith, P.S., Pye, B., Chen, N., and Han, G. (2021). Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2019. (DFO Canadian Science Advisory Secretariat Research Document 2021/017). Retrieved from https://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2021/2021_017-eng.pdf

8 Hamilton, S. G., & Derocher, A. E. (2019). Assessment of global polar bear abundance and vulnerability. *Animal Conservation, 22* (1), 83-95. https://doi.org/10.1111/acv.12439

9 Forney, K. A., & Wade, P. R. (2006). Worldwide distribution and abundance of killer whales. In J. Estes, D. P. Demaster, D. F. Doak, T. M. Williams, & R. L. Browell Jr. (Eds.), *Whales, whaling and ocean ecosystems* (pp. 145-162). Berkeley: University of California Press. https://doi.org/10.1525/california/9780520248847.003.0012

10 Haug, T., Biuw, M., Gjøsæter, H., Knutsen, T., Lindstrøm, U., MacKenzie, K. M., ... & Nilssen, K. T. (2021). Harp seal body condition and trophic interactions with prey in Norwegian high Arctic waters in early autumn. *Progress in Oceanography, 191,* 102498. https://doi.org/10.1016/j.pocean.2020.102498

11 Enoksen, S., Haug, T., Lindstrøm, U., & Nilssen, K. T. (2017). Recent summer diet of hooded Cystophora cristata and harp Pagophilus groenlandicus seals in the drift ice of the Greenland Sea. *Polar Biology, 40* (4), 931-937. https://doi.org/ 10.1007/s00300-016-2002-2

12 Malde, A. (2019). *Development of diving capacity and behaviour in harp seal (Pagophilus groenlandicus) weanlings from the Greenland Sea Stock* . UiT The Arctic University of Norway, Tromsø. https://munin.uit.no/handle/10037/15956

13 Nilssen, K. T., Haug, T., & Lindblom, C. (2001). Diet of weaned pups and seasonal variations in body condition of juvenile Barents Sea harp seals Phoca groenlandica. *Marine Mammal Science, 17* (4), 926-936. https://doi.org/10.1111/j.1748-7692.2001.tb01306.x

14 Eriksen, E., Skjoldal, H. R., Dolgov, A. V., Dalpadado, P., Orlova, E. L., & Prozorkevich, D. V. (2016). The Barents Sea euphausiids: methodological aspects of monitoring and estimation of abundance and biomass. *ICES Journal of Marine Science, 73* (6), 1533-1544. https://doi.org/10.1093/icesjms/fsw022.

15 Buren, A. D., Koen-Alonso, M., Pepin, P., Mowbray, F., Nakashima, B., Stenson, G., ... & Montevecchi, W. A. (2014). Bottom-up regulation of capelin, a keystone forage species. *PLoS One, 9* (2), e87589. https://doi.org/10.1371/journal.pone.0087589

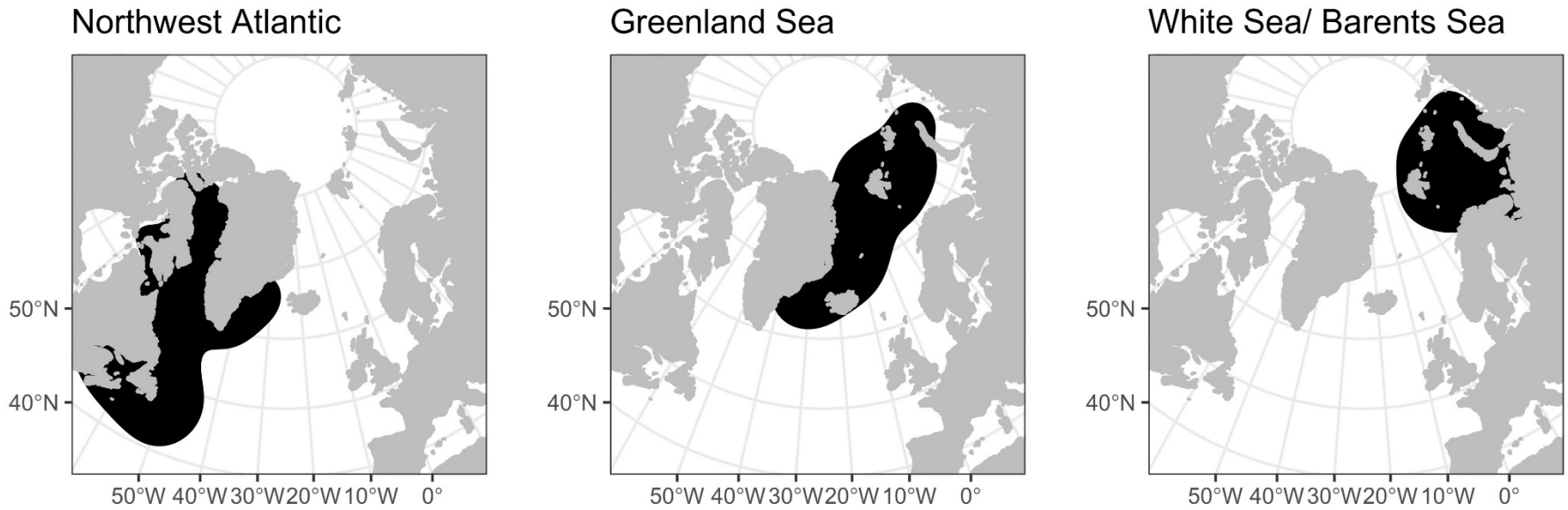
16 Xavier, J. C., Cherel, Y., Allcock, L., Rosa, R., Sabirov, R. M., Blicher, M. E., & Golikov, A. V. (2018). A review on the biodiversity, distribution and trophic role of cephalopods in the Arctic and Antarctic marine ecosystems under a changing ocean. *Marine biology, 165* (5), 1-26. https://doi.org/10.1007/s00227-018-3352-9

17 Gardiner, K., & Dick, T. A. (2010). Arctic cephalopod distributions and their associated predators. *Polar Research, 29* (2), 209-227. https://doi.org/10.1111/j.1751-8369.2010.00146.x.

18 Lewis, K. M., Van Dijken, G. L., & Arrigo, K. R. (2020). Changes in phytoplankton concentration now drive increased Arctic Ocean primary production. *Science, 369* (6500), 198-202. https://doi.org/10.1126/science.aay8380

Links			
1	GitHub repository	WGHARP	https://github.com/ices-eg/wk_WKSEALS-2020
2	NAO	NOAA	https://www.ncdc.noaa.gov/teleconnections/nao/
3	AMO	NOAA	https://psl.noaa.gov/data/timeseries/AMO/
4	SubPolarGyre	Marine Scotland Data	https://data.marine.gov.scot/dataset/sub-polar-gyre-index
5	Sea Surface Temperature	NOAA	https://www.ospo.noaa.gov/Products/ocean/sst/contour/
6	Various ice datasets	National Snow and Ice Data Centre, USA	http://www.nsidc.org
7	Sea Ice	ICDC (Generated from the second EOF of ssh produced by the ECMWF ORAS5 global reanalysis hindcast simulation)	https://icdc.cen.uni-hamburg.de/en/daten/reanalysis-ocean/easy-init-ocean/ecmwf-oras5.html
8	Kola Temperature	Polar Branch of VINRO ("PINRO" named after N.M. Knipovich)	http://www.pinro.vniro.ru/en/
9	Station 27 (Labrador Sea)	Fisheries and Oceans Canada	https://www.sciencedirect.com/science/article/pii/S1463500319300460#fig1
10	IUCN	Polar Bear and Orca abundance and distribution	https://www.iucnredlist.org/
11	NAFO	North Atlantic Fisheries Organisation	https://www.nafo.int
12	ICES ecosystem and survey data	Ecosystem assessments and prey surveys	https://www.ices.dk/Pages/default.aspx
13	Barents Sea environmental status updates	Barents Portal	https://www.barentsportal.com/barentsportal/index.php/en/more/current-monitoring-of-the-barents-sea
14	Barents Sea - pelagic fish	Barents Portal	https://www.barentsportal.com/barentsportal/index.php/en/status-2020/305-biotic-ecosystem-components-data-from-2019/pelagic-fish-2019/1018-pelagic-fish
15	ICES stock assessment graphs	ICES	https://standardgraphs.ices.dk/stockList.aspx
16	Coastal and Oceanic Plankton Ecology, Production and Observation Database	NOAA	https://www.st.nmfs.noaa.gov/copepod/
17	NOAA	NOAA Amphipod data	https://www.st.nmfs.noaa.gov/nauplius/media/copepedia/taxa/T4000015/
18	Primary Productivity	NASA	https://oceancolor.gsfc.nasa.gov/

Maps


Northwest Atlantic
Greenland Sea
White Sea/ Barents Sea
50°N
40°N
50°W 40°W 30°W 20°W 10°W 0°