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Habitat Modelling:

Influence of environmental parameters on movements and habitat utilization of humpback whales (*Megaptera novaeangliae*) in the Madagascar breeding ground

- investigating key habitat features of humpback whales is fundamental for conservation management of this species
- baleen whales are highly mobile and their distribution and abundance depends on the marine environment at different temporal and spatial scales
 - a migrating species such as humpbacks have a wide range of conditions they can exploit

Citation: Trudelle, L., Cerchio, S., Zerbini, A. N., Geyer, Y., Mayer, F. X., Jung, J. L., Hervé, M. R., Pous, S., Pous, S., Rosenbaum, H. C., et al. (2016). Influence of environmental parameters on movements and habitat utilization of humpback whales (*Megaptera novaeangliae*) in the madagascar breeding ground. *Royal Society Open Science*, 3 (12). [Online]. Available at: doi:10.1098/rsos.160616.

Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula

- used CART and GAM models
- supported an annua relationship between whale distribution and distance from ice edge and bathymetric slope
- oceanographic features like bathymetry help in prey aggregation, so that is why we might see a relationship with some of these
- Gams are exploratory data analysis tool for elucidating functional forms of relationships between observations and predictor variables
- GAMS are very useful for interpreting ecological interactions as they are able to fit non-parametric functions to estimate relationships between response and predictor variables without imposing limitations of any underlying relationship
 - they do not assume there is a set relationship between the variables
- CARTs are used as a variable selection method
- GAM package mgcv in R

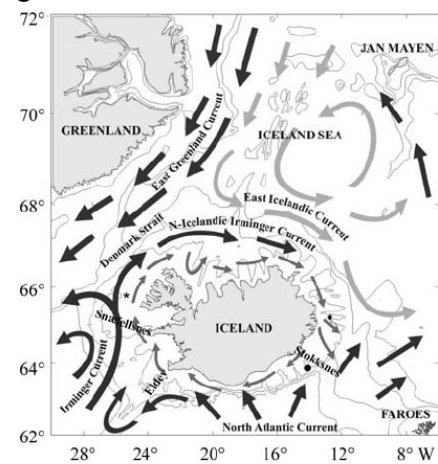
the shape of the outcome figures allows us to understand the relationship

- main env parameters identified by CARTS:
 - bathymetric slope
 - distance from the ice edge (in our case this could compare to distance from land in iceland (?))
 - distance to the inner shelf water boundary
 - surface chlorophyll a concentration
- NB: the flexibility of GAMs can lead to some overfitting that leads to misinterpretation

Citation: Friedlaender, A. S., Halpin, P. N., Qian, S. S., Lawson, G. L., Wiebe, P. H., Thiele, D. and Read, A. J. (2006). Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. *Marine Ecology Progress Series*, 317, pp.297–310. [Online]. Available at: doi:10.3354/meps317297.

Distribution, abundance, and feeding ecology of baleen whales in Icelandic waters: have recent environmental changes had an effect?

- the location of Iceland at the junction of the submarine ridges where warm and cold water masses meet just under the Arctic Circle, make it a highly productive area (picture of water circulation →)
- during last two decades a substantial increase in salinity and temperature have been reported
- reported increase in humpback whales in the last years in the Central north atlantic
- icelandic waters have 23 recorded cetaceans species, with 12-14 being considered regular residents and they play a fundamental role in the icelandic ecosystems
- only 12 species eat around four times all of icelandic fisheries landings
- divided transects into effort segments (each ended when there was a change in survey conditions)
- environmental parameters used:
 - depth
 - slope
 - aspect of the sea floor
 - distance to isobath (200m from the coast, which is approx the shelf edge)
 - Monthly sea surface temperatures SST
 - Current SST
- again they used GAMs for the relationship between these different parameters and (fin) whale distributions
- particularly steep rise in temperature from 1995 to 2000
- humpbacks showed an overall increase in recent years, especially around the turn of the century



- breeding humpback songs have also been recorded here, which doesn't necessarily mean anything, but it could be an indication that a breeding area is being established here, which might be why we see an increase in population

Citation: Víkingsson, G. A., Pike, D. G., Valdimarsson, H., Schleimer, A., Gunnlaugsson, T., Silva, T., Elvarsson, B. P., Mikkelsen, B., Øien, N., Desportes, G., et al. (2015). Distribution, abundance, and feeding ecology of baleen whales in Icelandic waters: Have recent environmental changes had an effect? *Frontiers in Ecology and Evolution*, 3 (FEB), pp.1-18. [Online]. Available at: doi:10.3389/fevo.2015.00006.

Distribution and relative abundance of humpback whales in relation to environmental variables in coastal British Columbia and adjacent waters

- once again using GIS and GAMS
- model selection using GCV scores
- humpback whales were found to be strongly correlated to latitude, bathymetric features, including depth, slope and distance from the 100m isoba
- distance to sst fronts and salinity were also included in the models
- Concerns about the effects of climate change on humpback whales cannot be properly addressed without a better understanding of species-habitat relationships
 - These types of studies are still rare in a lot of regions
 - Humpbacks seem to be associate with bathymetry in the bering sea (Moore et al., 2002)
 - Other important factors in north California:
 - Sea surface temperature
 - Depth and distance of upwelling fronts
 - Salinity and temperature as well as latitude (exactly how would we use latitude)
- **GOOD HYPOTHESIS: We hypothesize that the higher densities of humpback whales will be positively correlated with areas of enhanced biological productivity through physical forcing.**
- Methods:
 - The data was mostly transformed to have an even spread of values
 - Log transformation: depth, slope, NPP
 - Square root trans: distance to feature
 - Variables with lower resolution were dropped at later points
 - Gams were used (need to work on what GAMS actually are)
 - Spatial autocorrelation was also ran in the residuals through a variogram
- Results:
 - Humpbacks showed a strong correlation to bathymetry
 - Higher encounters between 50 and 200m
 - Dropped with increasing distance from the 100m isobar (NB: some people use the 100 some use the 200 isobar)
 - High encounter at 2.5 km from the isobar (?)

- Slight increase with increasing chl
- Higher encounter rates were also related to higher climatology values of salinity
- Seems that humpbacks here prefer mid-shelf waters
 - Especially between 50 and 200m depth, near the 100m countour from the shore
- *"The preference of humpback whales in BC for shelf waters is presumably related to the horizontal distribution of prey, but may also be influenced by the energetic cost of diving and foraging efficiency. "direct quote*
- *"Areas where we observed high concentrations of humpback whales are generally associated with topographically induced oceanographic processes that are known to influence the patchy distribution of euphausiids, an important prey of humpback whales*

Citation: Dalla Rosa, L., Ford, J. K. B. and Trites, A. W. (2012). Distribution and relative abundance of humpback whales in relation to environmental variables in coastal British Columbia and adjacent waters. *Continental Shelf Research*, 36, Elsevier., pp.89-104. [Online]. Available at: doi:10.1016/j.csr.2012.01.017.

Cetacean distribution in relation to environmental parameters between Drake Passage and northern Antarctic Peninsula

- Drake passage is a very dynamic oceanographic region but there is little info about it (noting that there is little info in iceland as well could be an important angle, especially in relation to the building of the port)
- Using of GAMs with:
 - Sst, bathymetry, topographic features (as a category)
- In this they mention goals of the whaling committee to better study the habitat preferences of whales in this area, maybe we can find something similar for iceland
- They used GIS to analyse spatial associations between location of cetaceans sightings and a suite of variables
- Variables:
 - Remotely sensed: sst
 - Physical variables: bathymetry, topographic features (treated as a categorical variable) and distance from land (more info in the paper on how distances were calculated in R)
- Methods for gams:
 - Divided the area in 30min squares, only the oes that had observations in it
 - Used pairwise comparison between the variables to check for correlation and multicollinearity
 - Only those that had not effects on collinearity were chosen
 - GAMs were used based on presence and absence of sightings
- There was model selection involved with restricted maximum likelihood
- Results for humpbacks:
 - Colder waters (read nicol et al., 2000 on this)

- Shelf areas
- In the past, the presence of whale watching boats, specifically in breeding areas has been studied especially as negative correlations were found between humpback whale songs and presence of boats
- In the context of this study, this is something important to consider with the new building of the port

Citation: Bassoi, M., Acevedo, J., Secchi, E. R., Aguayo-Lobo, A., Dalla Rosa, L., Torres, D., Santos, M. C. O. and Azevedo, A. F. (2020). Cetacean distribution in relation to environmental parameters between Drake Passage and northern Antarctic Peninsula. *Polar Biology*, 43 (1), Springer Berlin Heidelberg., pp.1-15. [Online]. Available at: doi:10.1007/s00300-019-02607-z.

NAMMCO Report 2017

- The goal of nammco is to generate north atlantic wide abundance estimates for major cetacean species
- The transect surveys have been used to provide the data necessary to manage anthropogenic takes of several cetacean species and they are both aerial and ship based
- **Gisili Vikingsson: changes in large whale distribution in the central north Atlantic**
 - The NASS survey have been used in this case to summarise the changes in distribution of large cetacean species
 - Humpback whale distribution increased from 1.800 in 1987 to 14.600 in 2015 (while the minke whale presented a decrease)
 - The warming in temperatures in recent years could also be linked to the changes, or at least some changes, in the nord Icelandic environment
- **Nadya Ramírez Martínez: Preliminary modelling NILS/NASS surveys pre-2015: Decadal-scale Changes in Cetacean Distribution in the North Atlantic**
 - The best model for mysticeti included depth and SST with a lagged relationship
- **Jessica Redfern: Cetacean-Habitat Relationships: From basic science to conservation and management**
 - Generalize additive models were used to relate species encounter rate and habitat variables → becker et al., 2016 (moving towards dynamic ocean management)
- **Igor M. Belkin: Fronts and whales**
 - Whales are known to congregate at oceanic fronts but this depends on the animal's activity
 - Many fronts are dependent on topography which means that can be determined using bathymetry
- **North Atlantic wide modelling of distribution**
 - The goal of NAMMCO is to develop a North Atlantic wide modelling of distribution and habitat used by the cetaceans

- These are useful especially as oceans continue to change
- Identify areas and times that are more susceptible to human impact (for example noise impact)
- Habitat variables that could be used for these modelling:
 - Depth
 - Bottom topography
 - Chlorophyll
 - Sea surface temperature (SST)
 - Salinity
 - Primary production
 - Ocean fronts
- NB: in this effort to create north Atlantic wide surveys, nammo wants to have an approach of generality on the large scale, and greater resolution on the smaller scale

Citation: NAMMCO. (2017). *REPORT OF THE WORKSHOP " CETACEAN ABUNDANCE AND DISTRIBUTION IN THE NORTH ATLANTIC "*. (October).

Baleen whale abundance and distribution in relation to environmental variables and prey density in the Eastern Bering Sea

- The population of baleen whales in the north Atlantic were severely depleted during the 19th and 20th century due to the wide-spread commercial whaling. However, since the end of this practices, baleen whales have been steadily returning to their original habitat.
- Species consume large amount of prey, thus modifying the ecosystem
- Better understanding the relationship between these whales and their environment is essential to improve understanding of ecosystem dynamics and to predict how these might respond to changes (eg: climate change but in our case this can be the building of a new port)
- In this study, humpback whales preferred shallower coasta waters in the Alaskan peninsula with sst, depth, chlorophyll-a concentration being the main drivers in the
- The increasing nubers of whales are likely to have an important impact on the ecosystem
 - Since they eat so much, there is a question of wheter the presence of aquaculture might reduce prey availability for them
- Main prey observed in the east bering sea for humpbacks:
 - Euphausiids (Thysanoessa sp.)
 - Mackerel (Pleurogrammus monopterygius)
- In the EBS the physical and biological processes that influence their preference of certain habitats
- The transects were prepared for analysis by splitting them into segments of 9km (matching the resolution of env. Variables)

- Environmental variables
 - 200m contour line and bathymetric slope were created using the ArcGIS spatial Analyst tool from the bathymetric layer
 - Chlorophyll-a was used as a proxy for primary productivity
 - Depth
 - SST
- For SST and CHL values from the two months (June and July) were merged into a single value to obtain June-July average for each year of the surveys
 - Then each cell was given a value
- Statistical modelling:
 - Models were constructed for the years together
 - Bivariate relationship between number of whales (for each species) and environmental parameters was initially examined with matrices of scatterplots that allowed them to visualize the relationship among the different sets of variables, prior to modelling
 - To formally characterize this relationship of each whale species and env conditions they then used GAMS
 - NB: the first tool is basically like what we did in our field report, it gives you an idea but it is not a statistical test
 - "Gams offer a flexible and robust approach for the exploration and characterization of complex, non-linear relationships among variables, and are widely used in cetacean modelling"
 - Response: estimated number of individuals per segment of effort
 - All the other factors were considered explanatory variables
 - The distribution of the estimated number of individuals was best characterized as an overdispersed Poisson distribution
 - An offset term was added to the GAMs to account for variability in effort
 - Natural logarithm (ln) of the effective area covered by each segment
 - Univariate GAMs were initially used with each variable to characterize the relationship between each variable and the species
 - The results from the univariate GAMs were then used as the terms for smoothness of the variable in the final multivariate GAM
 - NB: the variables with a Pearson's correlation higher than $r = 0.5$ were excluded from the GAMs -> avoid issues of collinearity
 - NB: variables with p values over 0.1 were also excluded to avoid putting in useless things
- Humpback results:
 - The highest explanatory models
 - Preference for mid-shelf waters
 - Positively correlated to prey presence
 - Preference for highly productive habitats during the feeding season

- This area is of high productivity because of a current, check Icelandic currents too!
- High productivity areas, look for diets of humpbacks in Iceland
- NB: slope was found to have collinearity with depth

Citation: Zerbini, A. N., Friday, N. A., Palacios, D. M., Waite, J. M., Ressler, P. H., Rone, B. K., Moore, S. E. and Clapham, P. J. (2016). Baleen whale abundance and distribution in relation to environmental variables and prey density in the Eastern Bering Sea. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 134, Elsevier., pp.312-330. [Online]. Available at: doi:10.1016/j.dsr2.2015.11.002.

Distribution, abundance and trends in abundance of fin and humpback whales in the North Atlantic

- NASS surveys are negatively biased because they can't account for the whales that are diving at the moment that the aircraft or ship encounters them
- Humpback whales are more abundant in shelf waters in the east and west of Iceland
- There has been a recorded 15% increase in humpback whales around Iceland, not in other areas covered by the surveys though
 - While an increase was expected after the end of whaling, the magnitude of this is greater than previously expected
- Among mammals, few species have undergone such dramatic changes in abundance over the past 200 years as the large cetaceans
- Large whales are long lived and slow growing, so having gaps between the years (over 15 years like in our case) provides a good chance of detecting changes
- There was post stratification done to estimate the presence of whales in area with no sightings
- Humpback whale results:
 - Worldwide, humpback whales seem to have the highest densities in shelf, relatively shallow, waters (<1000m)
 - However there were some instances in which humpbacks were recorded further away from the shelf, in much deeper areas, this seemed to be linked mostly to the increase in population size rather than a shift in habitat preferences
 - The population observed is beyond the biologically possible increase of these species, meaning that there might be emigration going on from other areas
 - There has been a substantial increase in the abundance of the Icelandic feeding stock
 - Icelandic feeding stock might have recovered above historical levels

Citation: Pike, D. G., Gunnlaugsson, T., Øien, N., Desportes, G., Víkingsson, G. A., Paxton, C. G. M. and Bloch, D. (2005). Distribution, abundance and trends in abundance of fin and humpback whales in the North Atlantic. *ICES CM 2005/ Session R/Marine Mammals: Monitoring Techniques*,

Abundance Estimation, and Interactions with Fisheries Distribution, abundance and trends in abundance of fin and humpback whales in the North Atlantic, (2001), pp.1-24.

Environmental predictors of habitat suitability and occurrence of cetaceans in the western North Atlantic Ocean

- Goal: estimate the main environmental covariates related to the abundance of 17 cetacean species in the western north Atlantic
- Main covariates included: latitude, sea surface temperature, bottom temperature, primary productivity, distance to the coast
 - GAM terms that explain most: SST, PP, CHL, LAT, D125
- Studies like this divide the study area in spatio-temporal cells
- Density/abundance information, habitat modelling, life history of species are all things that are required by ocean developers and, as the port is getting set up, it is something they will require as well.
 - (for my intro: this study could present the starting point to inform the port authority on the conditions of the humpback whale population in their area of interest and point out points of specific relevance that they need to be focused on)
- To limit overfitting, the number of degrees of freedom was restricted to 4
- The parameter estimates were optimized using restricted maximum likelihood
- USEFUL PAPER TO REREAD ONCE BETTER UNDERSTANDIN

Citation: Chavez-Rosales, S., Palka, D. L., Garrison, L. P. and Josephson, E. A. (2019). Environmental predictors of habitat suitability and occurrence of cetaceans in the western North Atlantic Ocean. *Scientific Reports*, 9 (1), pp.1-11. [Online]. Available at: doi:10.1038/s41598-019-42288-6.

Where the whales are: Using habitat modeling to support changes in shipping regulations within national marine sanctuaries in central California

NB: this could be a good resource on the whole port situation

- Understanding habitat preferences of species is very important for management strategies to insure minimum conflict between human uses and wildlife conservation
- This study focuses on identifying the most important oceanographic variables that predict (or relate in my case) to the occurrence of humpback whales in the Gulf of Farallones (San Francisco) order to asses potential conflict with shipping routes/vessel traffic
- They used a zero inflated binomial regression (NOT A GAM)
 - Methodology used a comparison of two models, one that only took into consideration surface oceanographic variables and one that took surface + mid-water oceanographic values → the surface + mid-water performed way better
 - NB: variables related to vessels were not uses

- Intro/useful background for me:
 - Whales are vulnerable to a multitude of anthropogenic threats that include acoustic disturbances, ship strikes, habitat degradation, tangling in fishing nets etc
 - Generally problems like ship-strike are on the rise (mostly due to larger and faster commercial vessels)
 - In the north Atlantic, ship strikes have already had a pronounced effect on the population on north Atlantic right whales (Knowlton & Kraus 2001 original study)
 - One of the leading causes of death in this species, due to the overlap of shipping lanes and their natural habitat
 - On the west coast of the US, ship strikes have also been found responsible for high mortality in whales like humpback and blue whales (Berman-Kowalewski, 2010)
- Since ship strikes are rarely documented (due to the unlikelyhood of being caught), this paper estimates that the actual number of shipstrikes with whales might be 10x what they have here
- NB: maybe find a layer with ship lanes, not for actual analysis but for context
- *"investigating where whale habitats are in relation to the current shipping lanes will help inform the effectiveness of vessel traffic adjustments" and it can "improve conservation efforts by focusing management on these critical areas"*
- While general whale habitats have been related to oceanographic processes like bathymetry (depth and shelf-break), climate (el nino) and prey availability, the factors driving habitat selection often remain poorly understood due to the dynamic nature of big marine species that are affected by oceanographic processes
 - Eg: Humpback whales usually show strong site fidelity in both their breeding and feeding grounds, especially female whales
 - NB: Humpback whales are also protected under the Convention on international Trade in Endangered Species and in Convention of Migratory Species
- They add subsurface properties
- Some studies have studied humpback whale relationship to thermocline topography (eg: mixed layer depth, especially due to prey presence)
 - Humpback whale generally forage between 20 and 120m so including some mid-depth properties is beneficial
- Data analysis:
 - Oceanographic data was interpolated using KRIGING in ArcGIS (look this up)
 - Whale counts were modelled using zero inflated negative binomial regression as a function of oceanographic, bathymetric and climate covariates
- Final model
 - Close relationship of humpbacks with ss salinity, sst, fluorescence and shallow depths with proximity to the 200m isobar

Citation: Dransfield, A., Hines, E., McGowan, J., Holzman, B., Nur, N., Elliott, M., Howar, J. and Jahncke, J. (2014). Where the whales are: Using habitat modeling to support changes in shipping regulations within national marine sanctuaries in central California. *Endangered Species Research*, 26 (1), pp.39–57. [Online]. Available at: doi:10.3354/esr00627.

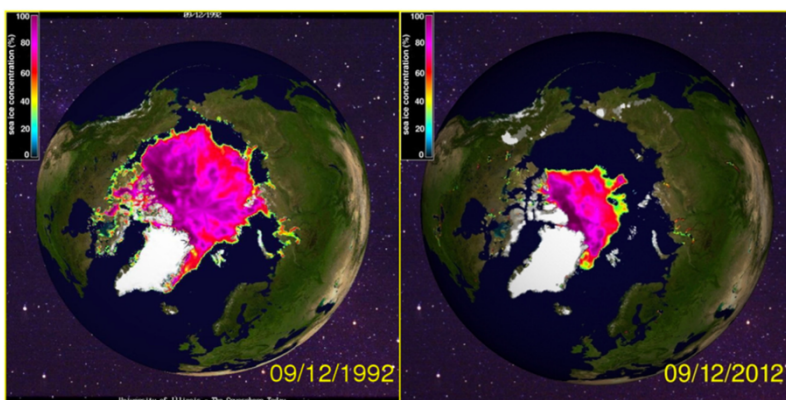
Trans-Arctic Shipping:

Economic Savings linked to future Arctic Shipping trade are at odds with climate change mitigation

- The arctic is generally an area of cold climate and elements like ice and darkness, that make it a rough and unwelcoming environment
- However, more recently, global warming has made a larger part of the Arctic ice-free, especially during the summer months, thus opening the area to new possibilities for Trans-arctic shipping routes
- 3 main sea arctic routes could be gained in the next few decades:
 - Northern sea route (likely to be ice free first)
 - Northwest passage (we could start using in 2020's)
 - Central Arctic route, across the bering strait to the Atlantic

Citation: Lindstad, H., Bright, R. M. and Strømman, A. H. (2016). Economic savings linked to future Arctic shipping trade are at odds with climate change mitigation. *Transport Policy*, 45, Elsevier., pp.24–30. [Online]. Available at: doi:10.1016/j.tranpol.2015.09.002.

Useful images:



Changes in the Arctic Ice sheet cover between September 1992 and September 2012 (Walsh et al., 2014) →

Citation: Walsh, J. E. (2014). Intensified warming of the Arctic: Causes and impacts on middle latitudes. *Global and Planetary Change*, 117, 52–63. <https://doi.org/10.1016/j.gloplacha.2014.03.003>

Implications of climate change for shipping: Opening the Arctic seas

- Shipping represents a fundamental human activity, with 80% of globally traded cargo being carried by ships → key component of global economies
- Arctic shipping is a field in which we can both observe the costs and benefits of climate change
- Reduced ice cover, in fact, may present big opportunities as marine routes that have historically been covered by sea ice become navigable for all or part of the year
 - Eg: allowing shorter routes that cut right through the pole
- In the last decades, the Arctic has been steadily warming, more so than lower latitudes, due to a process called Polar amplification
 - Increasingly warming temperature in the past decades have triggered a myriad of changes in the Arctic, including the major loss of sea ice
- Why is ice declining:
 - Average temperatures in the arctic are increasing, affecting sea-ice formation, growth, persistence and movement through the years
 - Warmer temperatures also drives a series of feedback loops that cause further accelerated and non-linear ice loss
- Current projections for future ice-loss contain considerable uncertainties
- Recent research into the NSR shows that the NSR will reduce travel distance by approximately 40%, with a 3-5% fuel reduction

Citation: Ng, A. K. Y., Andrews, J., Babb, D., Lin, Y. and Becker, A. (2018). Implications of climate change for shipping: Opening the Arctic seas. *Wiley Interdisciplinary Reviews: Climate Change*, 9 (2), pp.1–18. [Online]. Available at: doi:10.1002/wcc.507.

New Trans-Arctic shipping routes navigable by midcentury

- From the second half of the 20th century, satellite mapping has revealed an overall trend of decreasing sea ice over the arctic, especially in the late-summer months. Climate models projection expect this trend to continue, leading areas previously inaccessible year round, at least partially ice-free. This has started an important discussion about what these changes mean specifically for the shipping and the possible opening of new, shorter routes to connect the Atlantic to the Pacific, cutting straight through the pole (northern sea route, north west passage)
- Studies like this, on optimal navigation routes, have found that, by mid-century, the region's navigational potential will increase substantially due to climate forcing. While the extent of ice-free areas is not the only factor to take into consideration when it comes to trans-arctic shipping, it definitely opens the possibilities for future discussions

Citation: Smith, L. C. and Stephenson, S. R. (2013). New Trans-Arctic shipping routes navigable by midcentury. *Proceedings of the National Academy of Sciences of the United States of America*, 110 (13), pp.6–10. [Online]. Available at: doi:10.1073/pnas.1214212110.

Sea ice decline and 21st century trans-Arctic shipping routes

- Using the route through the Arctic as a short cut between the Pacific and Atlantic ocean
 - Reducing the distance that is otherwise travelled through the Suez or Panama canal
- The main routes are the northern sea route (NSR), which has a high variability on when it going to be ice free and the Northwest passage (NWP)
- Voyages through these routes have been increasing in the recent years
- The Arctic is in transition to a seasonally ice free state, increasing economic opportunities to niche commercial shipping markets, with the opportunity for new and faster routes through the trans-Arctic
- Even if we stick under the 2°C increase, there is still a possibility for the doubling of frequency of open water vessels passing through the pole by the mid 21st century

Citation: Melia, N., Haines, K. and Hawkins, E. (2016). Sea ice decline and 21st century trans-Arctic shipping routes. *Geophysical Research Letters*, 43 (18), pp.9720–9728. [Online]. Available at: doi:10.1002/2016GL069315.

Towards seasonal Arctic shipping routes

- The continuing decline in Arctic sea-ice will lead to increased human activity and opportunities for shipping in the region → route openings will become more important in this region
- Satellite observations have shown that Arctic sea-ice is in a state of rapid decline and all the global climate prediction now foresee this trend continuing well into the 21st century
- The main obstacle to Arctic shipping, thus far, has been the inclement weather and the presence of extensive sea ice for much of the year, however, with climate change, many routes are likely to open more frequently and for longer periods thus becoming faster to travel
- As of now, historical models show a slow expansion of the season (both in terms of start and closing date), however a lot of this change is still dependent on year-to-year variability

Citation: Melia, N., Haines, K., Hawkins, E. and Day, J. J. (2017). Towards seasonal Arctic shipping route predictions. *Environmental Research Letters*, 12 (8). [Online]. Available at: doi:10.1088/1748-9326/aa7a60.

Arctic shipping emissions inventories and future scenarios

- The Arctic is a sensitive region in terms of climate change but also a rich resource for global economic activity
- Dramatic arctic sea ice decline has been observed over the past few decades culminating in a record minimum sea ice extent of 4.28 million km² in 2007 (10 million in 1970)
- The decline of arctic sea ice has reignited interests in establishing new trade passages through the pole, raising the possibility of economically viable trans-arctic shipping as well as increasing access to natural resources

Citation: Corbett, J. J., Lack, D. A., Winebrake, J. J., Harder, S., Silberman, J. A. and Gold, M. (2010). Arctic shipping emissions inventories and future scenarios. *Atmospheric Chemistry and Physics*, 10 (19), pp.9689–9704. [Online]. Available at: doi:10.5194/acp-10-9689-2010.

Climate change in the Arctic and North Atlantic:

Arctic climate change and its impacts on the ecology of the North Atlantic

Citation: Greene, C. H., Pershing, A. J., Cronin, T. M. and Ceci, N. (2008). Arctic climate change and its impacts on the ecology of the North Atlantic. *Ecology*, 89 (11 SUPPL.), pp.24–38. [Online]. Available at: doi:10.1890/07-0550.1.

- For centuries, arctic explorers have searched in vain for the northwest passage, linking the north Atlantic and north Pacific oceans. However, due to the thick sea ice cover, the movement of flora and fauna between the two basins has been virtually impossible since the mid-Pleistocene
- It has been proposed that the Arctic ocean may become ice free entirely during the summer before the beginning of the next century
- Rapid climatic and oceanographic changes in the Arctic may already have had an impact on the shelf ecosystems downstream in the North Atlantic
 - This is mostly due to the observed drop in salinity in the Arctic with this water coming from the Canadian archipelago and the Fram Strait into the North Atlantic
 - The freshening of water most definitely impacts stratification (ocean circulation is thermohaline, meaning that is driven by temperature and salinity)
- The arctic ice-cover has played a very important role in the earth system's climate and its variability during the Quaternary period, especially via the glacial/interglacial climate cycles over the last thousands of years
- In the Holocene (10ka) the North Atlantic Oscillation, is the main driver of climate variability
- The North Atlantic Deep Water (NADW)

Ongoing climate change in the Arctic

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