FutureArcticLives

Scalable framework to assess population trends for Greenland's data-scarce wildlife

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1. **Introduction:**

In the context of accelerating global change, understanding how wildlife populations respond to climate change is essential for conservation, population management and the well-being of human communities that depend on these resources. Yet many populations around the world lack the systematic, long-term data needed to identify trends and assess impacts (1). This lack is often due to limited funding, logistical constraints or the inherent difficulty of surveying certain species (1). These challenges are particularly acute in remote and environmentally extreme regions such as Greenland.

As one of the most remote and inhospitable regions on Earth, Greenland presents unique challenges for wildlife monitoring. Harsh environmental conditions, limited accessibility and logistical constraints physically and financially prohibit repeated, systematic surveys (2). In addition, many species are difficult to detect using traditional survey methods such as aerial or ship-based observations (3). Mammals, a typically well-studied group, illustrate the resulting extent of data gaps (4,5). For example, population trends are unknown for 60% of polar bear (*Ursus maritimus*) subpopulations and 20% of narwhal (*Monodon monoceros*) stocks, particularly in East Greenland[5]. Similarly, there is no trend data for one of two beluga whale (*Delphinapterus leucas*) populations and one of three bowhead whale (*Balaena mysticetus*) populations have documented trends. Other species, such as ringed seals (*Pusa hispida*), grey seals (*Halichoerus grypus*), white-sided dolphins (*Lagenorhynchus acutus*), bottlenose whales (*Hyperoodon ampullatus*), sperm whales (*Physeter macrocephalus*), pilot whales (*Globicephala* spp.), white-beaked dolphins (*Lagenorhynchus albirostris*) and harbour porpoises (*Phocoena phocoena*) (5). These deficiencies extend beyond mammals to many bird and fish species, highlighting a widespread lack of information that is critical for understanding population dynamics and managing use as well as climate change impacts.

To address these gaps, we propose a novel framework for inferring wildlife population trends in data-poor contexts rooted in evidence-based conservation (6). Using a hybrid approach, we integrate expert knowledge through a questionnaire, a method commonly used by the IPCC (7) and IUCN (8) and IPBES (9) in data-poor settings, combined with a systematic literature review. First, experts provide synthesised insights based on the species' biology, ecology and climate associations to assess potential population trends. Second, experts use a scoring system similar to a weighted literature review. This allows us to systematically incorporate and prioritise different levels of evidence, ensuring a structured synthesis. Our approach uses multiple streams of evidence, including direct trend data, indirect indicators such as reproductive success, and general evidence from related populations, such as correlations between sea ice dynamics and reproduction. An analogy can be drawn to simplified population-level distribution or habitat models, where trend data from other locations, ecological traits or associations with habitat variables are used to infer trends in poorly studied areas (10). However, this approach allows assessing a wider range of species, incorporates expert knowledge, and can include weaker evidence, such as potential ecological traps or disruptions to migratory routes for which empirical data are not yet available.

Our aim is twofold. First, we seek to develop a robust framework that integrates expert knowledge with published studies to assess trends in data-poor environments. Using Greenland as a case study, we aim to create a user-friendly approach accessible to researchers and practitioners with limited resources for complex modelling or extensive literature reviews to provide practical tools for conservation decision-making. Second, we aim to determine the most likely population trends for mammals, birds and fish in Greenland up to 2030 and 2050, highlighting critical knowledge gaps and revealing large-scale patterns that shape population changes across species, regions and functional groups. By analysing data availability, exploring heterogeneity and identifying evidence gaps, we aim to assess the impacts of climate change on wildlife population dynamics. Combining expert synthesis and systematic literature reviews, this interdisciplinary approach provides a scalable solution to inform conservation strategies in data-limited regions worldwide. It identifies population trends and highlights areas of uncertainty, guiding future research and monitoring efforts.

2. **Method:**

2.1. Expert questionnaire:

To comprehensively assess wildlife trends in Greenland, we identified 66 species based on catch statistics from Statistics Greenland. These species are all considered important to local communities and/or Greenland's economy. Experts on the ecology of the 66 Arctic species in question were identified based on their scientific publication records. Additionally, we reached out to practitioners working with conservation and wildlife management organizations in the Atlantic Arctic. Experts were first invited to complete a questionnaire, including sections on personal background information. This information was used to create a profile to evaluate the quality of input. For example, experts with extensive experience working on a specific species or those specializing in certain taxa were rated higher than generalists or those with less experience in Arctic conditions. Experts were then asked to provide projected trends for 2020–2030 and 2030–2050 based on their synthesized species knowledge and species climate sensitivity. To enhance the quality of the assessment, we employed a three-point interval elicitation method, which allowed experts to express current and expected trends considering uncertainty (11). Experts provided three values for the trend: the highest plausible proportional change, the lowest plausible change, and their best estimate (12). This stepwise approach encourages consideration of diverse evidence and reduces bias. Experts provided interval estimates first, thus avoiding fixation on the best estimate, which often narrows intervals or inflates values (13). In addition, assigning their own confidence levels to their estimates improves accuracy by preventing overconfidence in estimates at 95% intervals (12,14). To increase reliability, we aimed to consult three experts per species or species group (e.g. seals, Arctic birds). Aggregating their judgments gives more robust results, using means for normal distributions and medians for skewed data (12). If the data from two experts diverged significantly, we employed the Delphi Method, where results were iteratively shared between the experts, and they were asked to refine their predictions until a consensus or reliable forecast was achieved (15). See example questionnaire here.

2.2. Literature review:

2.2.1. Type of evidence collected

A comprehensive literature search was performed using Google Scholar™ with keywords including species names (common and scientific), "Greenland," "climate change," "global warming," “threats”, "hunting" and "trend" and “status”. Additional sources included institutional websites (e.g., Greenland Institute of Natural Resources, NAFO, ICES, IWC, NAMMCO, JCNB) and reports from meta-analyses and literature reviews. The gathered evidence types include direct evidence, indirect evidence and generic evidence (Table 1):

Table 1 Categories and definitions of evidence considered in the literature review.

Category	**Definition**
Direct evidence	Information on Greenlandic populations on trends, including reported or estimated trends in wildlife populations and scenarios.
Indirect evidence	Data on Greenlandic populations related to climate impacts, including reproductive trends, catch data, behavioural changes, physiological changes, dietary shifts, reported climate change effects, potential behavioural traps, habitat suitability scenarios, and pollutants or noise stressors.
Generic evidence	Observations from populations outside Greenland, primarily in the European and Canadian Arctic, focusing on large-scale and long-term population or habitat trends, general climate effects on species (e.g., associations between sea ice loss and reproduction), physiological and behavioural adaptations, and impacts of climate-related pollutants and noise.

Although several aspects were tested, a publication was accessed as one piece of evidence. We assumed that scientists would combine different analyses to test an overall hypothesis and thus follow their expertise. This choice was made to avoid over-representing papers with multiple analyses, which is often the case in publications on birds, where a wide range of breeding success predictions. However, publications covering more than one species or region were categorised separately, as results vary between species and regions.

2.2.2. Criteria for inclusion and exclusion

Evidence was included from studies published from 2000 onward considering research conducted in the Scandinavian and Canadian Arctic, as well as wintering areas for migratory species. Data from all relevant habitats were included for populations with extensive ranges, migration routes, or breeding grounds outside Greenland. Studies from the Pacific Arctic were excluded due to significant ecological, evolutionary, and historical differences from the Atlantic Arctic. The Pacific supports a more diverse and older biota, with key species and functional groups absent in the Atlantic, resulting in fundamentally different ecosystem dynamics and limiting the reliability of direct comparisons. Additionally, we aimed to minimize time commitments for respondents and focus exclusively on experts in Atlantic Arctic systems.

Only empirical studies or literature reviews that provided additional analyses were included. For trend analyses involving multiple publications, only the most recent data were used to maintain data independence. Unlike other systematic reviews, our research question was broad, so studies were not excluded based on quality. This approach allowed for the inclusion of less detailed studies, such as anecdotal evidence of adaptation or species sightings. Experts in Arctic species were consulted to assess the relevance and quality of studies after the literature collection phase. A precautionary approach was adopted, including all potentially relevant studies for later expert evaluation. Experts were also asked to identify and incorporate any missing literature to ensure completeness.

2.3. Expert-assessment of the literature review:

2.3.1. Evidence quality and relevance:

Experts were asked to evaluate the identified literature in terms of quality and relevance to the research question about population trends. We developed a modified version of the Balance Evidence Assessment Method (BEAM) (6), in consultation with scientists from the Conservation Evidence Project at the University of Cambridge (https://www.conservationevidence.com/content/page/82) . The

BEAM provides an intuitive and systematic way of weighing and assessing evidence. The total weight of evidence for each publication was calculated based on the relevance and quality (i.e., information and source reliability) of the evidence (see Sutherland, 2022) (Table 2).

Table 2 Rating criteria based on Sutherland 2022

Category	**Definition**
Information reliability (I)	"How much can the information contained within a piece of evidence be trusted - e.g., how rigorous is the experimental design?"
Source reliability (S)	"How much trust can be placed in the source of the evidence - e.g., what is the quality of the journal/report, is there a conflict of interest, or bias?"
Relevance (R)	"How closely does the context in which the evidence was derived apply to the assumption being considered - e.g., does it relate to a similar problem, action or situation?"

2.3.2. *Scoring system:*

The standardized weight of a piece of evidence is determined as follows:

$$\text{Weight} = \frac{R \times I \times S}{\text{Maximum Score}}$$

For example, on a **0–3 scale**, the maximum possible score would be **27** (calculated as 3 (R)×3 (I)×3 (S)), and an overall score could be calculated as:

$$\text{Weight} = \frac{2 \times 2 \times 3}{27} = \frac{12}{27} = 0.44$$

2.3.3. Ecological content:

We further assessed the ecological information provided in the publications by asking experts: Does the publication suggest a population trend for the Greenlandic population for the period 2020-2030 and/or 2030-2050) (response category: decreasing, stable or increasing)? Can the magnitude of the trend be estimated (e.g., small, moderate, large or in percentage terms)? Does the publication indicate a range shift, and if so, can its magnitude be quantified (e.g., 1 km/decade)?

For all trend and range assumptions, experts were asked to assess the strength of support for these trends, focusing on how well each publication supports the assumptions made (e.g., long-term data provide a stronger basis for reliable conclusions about trend development than short-term studies).

2.3.4. Cumulative Weights:

Cumulative weights were calculated for each unit, e.g., (sub) population, species or region, and population trend indicator by first assigning a trend direction to each piece of evidence, classified as declining, stable, or increasing. The weights for all pieces of evidence supporting each trend direction were then summed to determine the overall evidence strength for that trend. This process was repeated to calculate cumulative weights for evidence related to the magnitude of change, proportional change and range change. See Figure 1 for a graphical representation of the weighting process.

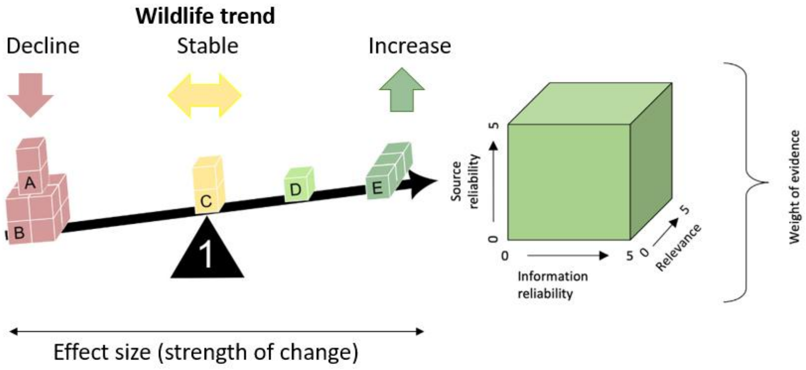


Figure 1. The weight of evidence is determined by the formula: (Source reliability × Information reliability × Relevance) / Total possible score**.** The effect size, representing the strength of change, determines the position of the weight on the scale (from left to right). populations.

The example illustrates a balance with five distinct pieces of evidence (A–E), each varying in weight (depicted by size) and corresponding to the strength of change on an ordinal scale, reflecting proportional increases or declines in wildlife

3. Statistical approach:

3.1. Development of a novel methodological approach

3.1.1. Planned analyses:

a) Effectiveness of the method:

This analysis examines how effectively the method determines wildlife trends in the absence of direct data. The usefulness of indirect or generic evidence will be assessed by comparing trends derived by the method with those reported in existing literature.

b) Reliability of ratings:

To assess reliability, the analysis will evaluate expert assessments and their consistency in assessing trends, using interrater reliability analyses to measure the consistency of expert assessments across experts and species. Cross-validation analyses will compare expert-assessed trends (categorical or ordinal) with observed population data using linear models. The reliability of generic evidence is also examined by comparing trends inferred from indirect data with trends based on direct evidence. A sensitivity analysis will examine how splitting the evidence into generic and direct categories affects trend assessments.

c) Developing a practitioner-friendly approach:

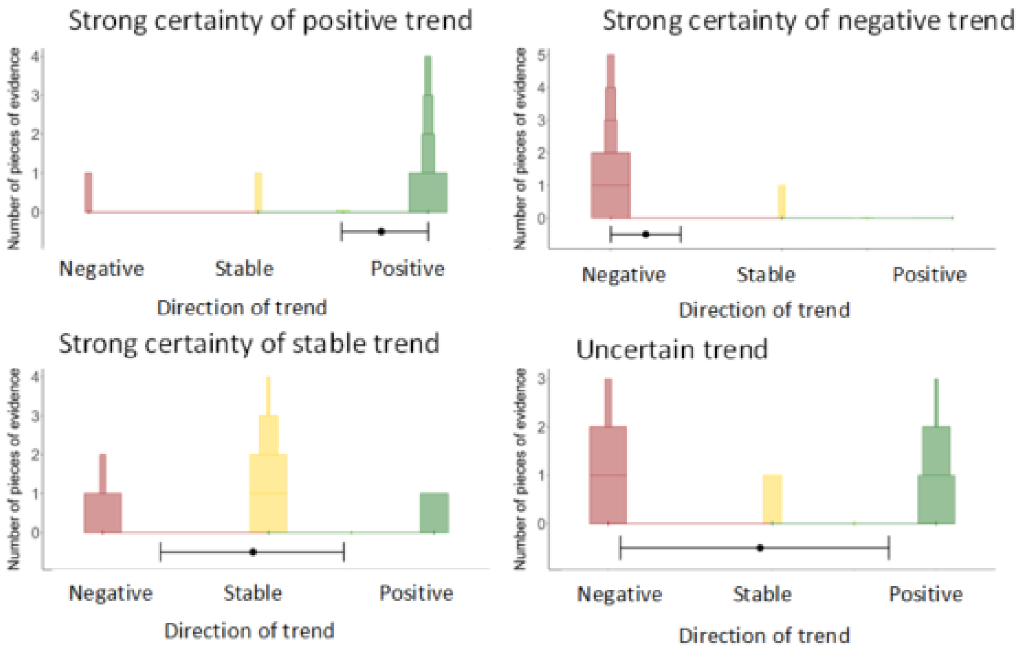
Using Greenland as a case study, the project aims to develop a robust and user-friendly methodology that can be easily applied by practitioners, such as scientists and conservation staff, in data-poor environments. The approach prioritizes accessibility and practicality and leverages the advantages of this method over traditional literature reviews or meta-analyses. The project will explore the minimum evidence required for reliable trend estimation to simplify the process. A saturation analysis will identify the threshold of evidence required for accurate results. In addition, expert recommendations will be sought to identify the key publications that are most informative for assessing current and future trends. These recommendations will then be assessed.

All analyses will be conducted in the R package (R version 4.4.2 (2024-10-31)

3.2. Assessments of trends

3.2.1. Weighted scoring and evidence strength

The cumulative weighted averages that identify where the balance of evidence lies were used to identify patterns and gaps in the evidence for wildlife trends. Bootstrapped 95% confidence intervals are used to quantify uncertainty, which narrows as evidence quantity increases. These cumulative scores were calculated not only for populations and species but also for regions and functional groups, helping to pinpoint gaps and highlight data deficient as well as well-researched populations, regions, and taxa. To intuitively visualise the collective weight and strength of evidence supporting a hypothesis, we will use a 'ziggurat' plot. In this plot, blocks are stacked along the y-axis according to their weight and along the x-axis based on their strength of support (Figure 2). Weighted averages will indicate the overall balance of evidence, while bootstrapped 95% confidence intervals will reflect uncertainty, narrowing as the quantity and consistency of evidence increase. This approach provides an intuitive representation of both the strength and variability of the evidence. Ziggurat plots are used to show the available evidence for each species, highlighting heterogeneity in the results by plotting evidence across species, regions, and functional groups. For an interactive overview, a Shiny application is available here: https://alecchristie888.shinyapps.io/ziggurat-plot-app/. Figure 2 illustrates an example of four Ziggurat plots, demonstrating how the Balance Evidence Assessment Method (BEAM) can visualize the weight of evidence supporting specific trend directions.


Strong certainty of positive trend

Strong certainty of negative trend

Strong certainty of stable trend

Uncertain trend

Figure 2. Ziggurat plots generated using the Balance Evidence Assessment Method (BEAM) illustrating the distribution of evidence supporting various trend directions. The top-left panel depicts a scenario where the balance of evidence strongly favors increasing trends, while the top-right panel represents a situation where the evidence primarily supports declining trends. The bottom-left panel indicates evidence suggesting a stable trend, whereas the bottom-right panel highlights conflicting and mixed evidence, resulting in an inconclusive overall conclusion. The weighted average strength of support (indicated by the black point) reflects the central balance of evidence for the assumption, with bootstrapped 95% confidence intervals providing a measure of precision

3.2.2. *Sensitivity analysis*

The robustness of responses will be tested by sub-setting data based on evidence quality (e.g., high vs. low reliability) or type (e.g., direct vs. indirect evidence). Linear models will assess the consistency in trends across subsets.

3.2.3. *Trend and threat assessment*

The status of each population and species will be assessed to identify priority conservation areas and populations with the most significant declines, focusing on those affected by notable population decreases or ecological pressures. Additionally, species or populations exhibiting growth trends that could provide opportunities for sustainable hunting and fishing, benefiting local communities, will be identified.

To address questions of trend development, all populations of each species will be identified as increasing, declining, stable, or unknown. For populations classified as declining, categorisation will be refined by assessing their threat levels based on the IUCN Guidelines for Threat Categories Based on Decline Rates (1970–2100) (8,16**)** where data is available (Table 3). These guidelines outline the following categories for population trends:

Table 3 Threat categories as defined by the IUCN

Threat category	**Definition**
Highest Threat	>7.5% loss per decade (~>50% loss from 1970–2100).
Second Highest Threat	4–7.5% loss per decade (~16–50% loss from 1970–2100).
Moderate Threat	1–4% loss per decade (~10–16% loss from 1970–2100).
Lowest Threat	<1% decline per decade (species may be stable or increasing).

This approach ensures a systematic assessment of population trends, identifies populations most at risk, and highlights opportunities for community benefits through sustainable resource use.

3.3. Evidence and gabs

To summarise and analyse the available evidence and gaps, we present a systematic map (17) detailing the evidence and its strength for each population and species, as derived from our analyses above to investigate potential biases in the evidence, such as those related to specific species, regions, or time periods. By doing so, we aim to support prioritising future research efforts.

4. State of the project:

4.1. Summary of evidence collected

Overall, we extracted 1,389 pieces of evidence, where each piece of evidence typically corresponds to a single publication. However, when a publication investigated multiple species or populations in Greenland, we separated and categorized the evidence by region or species. The breakdown of the collected evidence is as follows: Birds**:** 259 pieces of evidence, Terrestrial mammals: 190**,** Seals**:** 155 pieces of evidence, Fish**:** 520 pieces of evidence, Whales: 265 pieces of evidence, Total**:** 1,389 pieces of evidence (Figure 3).

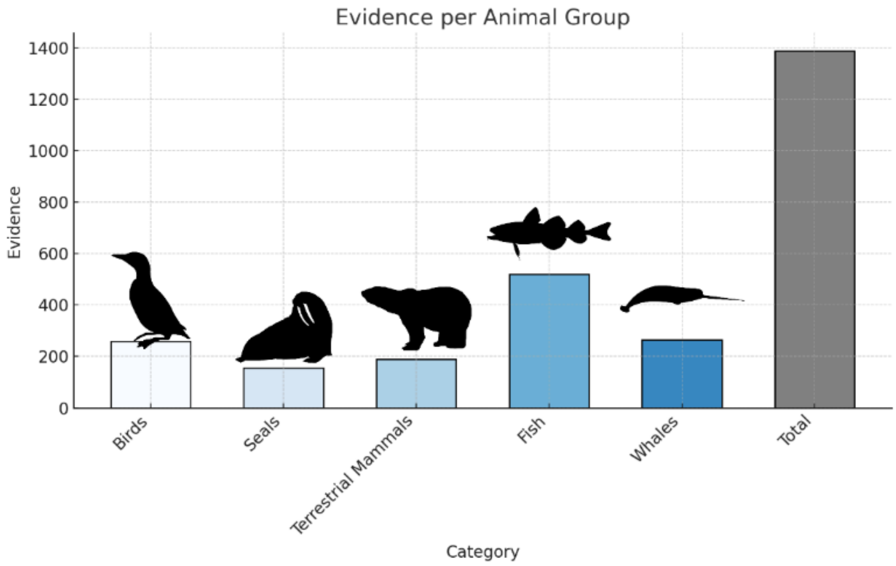


Figure 3. Number of pieces of evidence per species group

4.2. **Expert consultation**

578 experts specializing in Arctic wildlife were contacted (overview available here). Experts were identified based on their publications, with more relevant publications and their affiliations with organizations focused on mammals, birds, or fish in Greenland considered evidence of expert status. Organisations included the Northwest Atlantic Fisheries Organization (NAFO), the International Council for the Exploration of the Sea (ICES), the International Whaling Commission (IWC), the North Atlantic Marine Mammal Commission (NAMMCO), and the Canada/Greenland Joint Commission for the Conservation of Narwhal and Beluga (JCNB). Despite positive feedback, participation has been limited due to significant time commitments, including extended field trips and competing responsibilities, such as providing governmental advice. This is particularly true for experts specializing in high-profile Arctic species in Greenland. To date, only 18 experts have participated; however, we are actively continuing efforts to engage additional contributors.

4.3. **Engagement process**

To support participation, the project:

1. Conducted a Zoom call with interested participants to explain our goals and methods (presentation available here).
2. Provided each participant with a personalized link where they can directly enter their assessments using a dropdown menu.
    - The spreadsheet includes an overview of publications with the most relevant data for evaluation.
    - Example input sheet here
    - Example filled sheet for Barnacle Goose here

Data collection is planned to be concluded by the end of February. However, this date may need to be adjusted to accommodate field stays and other commitments.

4.4. Next steps

To further advance data collection and mobilise participation, field trips are planned to:

1. The Greenland Institute for Natural Resources (Greenland)
2. The Marine and Freshwater Research Institute in Hafnarfjörður, Iceland

This aims to leverage synergistic effects through on-site engagement and collaboration to increase participation.

5. Results:

So far, 20 questionnaires have been received covering trends for 39 species and 119 populations, subpopulations, or regions. Here, results are presented from the filled questionnaires received so far. The analysis representing expert-derived expected population trends for 119 Arctic, Arctic-boreal, and Boreal species reveals clear quantitative contrasts between climate-resilient generalists and ice-dependent specialists. Overall, approximately 83 per cent of Arctic species are projected to decline or remain stable by 2030, and this pattern continues into 2050. This is evident for Arctic mammals such as polar bears (e.g., the population in Baffin Bay is expected to decline by 15 per cent by 2050), as well as ringed seals and seabirds including Thick-billed murres (*Uria lomvia*) and Glaucous gulls (*Larus hyperboreus*), all of which show significant negative trends. In contrast, about 17 per cent of Boreal species, including Atlantic cod (Gadus morhua) and Canada goose (Branta canadensis), are expected to increase by up to 50 per cent by 2030, persisting through 2050, a trend driven by the expansion of warming-enhanced habitats.

Temporal variability is also pronounced. Near-term estimates for many Arctic taxa appear relatively stable; however, the period from 2030 to 2050 is marked by sharper changes. For example, one Atlantic cod population in the Norwegian Sea, Barents Sea, and North Sea is projected to decline from a best estimate of negative 50 in 2020–2030 to negative 100 in 2030–2050, while another group in West Greenland shows an increase from 10 to 75 over the same periods. Among Atlantic salmon (*Salmo salar*), the Southwest Greenland population shifts from an estimated positive 10 to negative 10, whereas the West Greenland population improves from positive 25 to positive 60. Similarly, polar bear populations differ regionally, with those in Kane Basin declining from positive 10 to neutral and those in Baffin Bay falling from near neutral to negative 15. These results underscore that Arctic population trends are highly species- and region-specific, reflecting the complex interplay between environmental drivers and local conditions.

5.1. Arctic vs. Boreal Species

Arctic species, particularly ice-dependent mammals and seabirds are expected to decline by 2050. For Arctic mammals, beluga whales in Baffin Bay is expected to increase by 5% until 2050, showing localized stability. Narwhals remain stable in most monitored regions in West Greenland, with no significant declines projected. Polar bears exhibit positive trends in select areas (Kane Basin), though other populations remain under pressure. Atlantic walrus also shows some regional stability despite ongoing habitat loss. Arctic-boreal and boreal mammals, such as Harp seals (*Pagophilus groenlandicus*) and Hooded seals (*Cystophora cristata*), are expected to experience regional increases, though trends vary across populations. Harp seals (*Pagophilus groenlandicus*) in the Northwest Atlantic will decline by 15% as changing ice conditions impact pup survival. Some boreal and Arctic-boreal mammals benefit from changing conditions, but overall trends remain mixed. No Arctic fish species show positive population trends by 2050. Arctic charr (*Salvelinus alpinus*) declines, likely due to habitat loss, competition with other fish species, and changing thermal conditions. Arctic-boreal fish, such as Atlantic cod, exhibit mixed trends, with some populations increasing while others face severe regional losses, with Northeast Greenland populations declining by 95% and Norwegian Sea stocks disappearing entirely (-100%). Thorny skate (*Amblyraja radiata*) faces negative trends, reflecting sensitivity to shifting ocean conditions and fisheries pressures. This summary highlights the lack of positive trends among Arctic fish and the mixed responses of Arctic-Boreal species, with some populations benefiting while others decline. Several Arctic-boreal bird species exhibit positive trends, including Barnacle goose (*Branta leucopsis*), Canada goose, Pink-footed goose (*Anser brachyrhynchus*), common eider (*Somateria mollissima*), and mallard (*Anas platyrhynchos*), will likely benefit from expanding breeding grounds and milder temperatures. Some seabirds and scavengers, such as the Common guillemot (*Uria aalge*), Iceland gull (*Larus glaucoides*), Great black-backed gull (*Larus marinus*), and Great cormorant (*Phalacrocorax carbo*), will likely also show increasing trends. Conversely, several Arctic-boreal seabirds and waterfowl decline, including King eider (*Somateria spectabilis*), Long-tailed duck (*Clangula hyemalis*), Thick-billed murre, Little auk (*Alle alle*), and Glaucous gull. Declining trends are also observed for Black-legged kittiwake (*Rissa tridactyla*), Common loon (*Gavia immer*), Northern fulmar (*Fulmarus glacialis*), Common raven (*Corvus corax*), and Black guillemot (*Cepphus grylle*), likely due to changing prey availability, habitat shifts, and human-induced pressures. Overall, while certain Arctic-boreal species show regional stability, overall patterns highlight increasing pressures on ice-reliant taxa and shifts favouring species adapted to warming conditions.

5.2. **Species group:**

For mammals, the evidence is dominated by stable and declining trends, particularly for Arctic species, where only belugas showed one slightly positive trend (Figure 5). For polar bears the evidence is characterised by regional differences with stable trends in the Kane Basin (+10% by 2030) but declining (-15% by 2050) in Baffin Bay. Narwhal populations exhibit stability across monitored regions, with no significant increases or declines projected by 2050. While Jones Sound and Somerset Island populations remain stable if vessel traffic is regulated, Admiralty Inlet narwhals' plateau as escalating noise pollution counterbalances potential habitat shifts. Ringed seals in West Greenland are expected to decline 15% by 2050, suffering ice loss and novel pathogens. Conversely, beluga whales in Baffin Bay will likely stabilise (+5%) due to harvest quotas, highlighting management efficacy.

Birds exhibit divergent fates. Canada geese in Greenland will surge 50% by 2050 due to climate-driven range expansion, while Thick-billed murres in West Greenland will plummet 50% by 2030 due to illegal hunting and shifting ice regimes. Common eiders in East Greenland will increase by 20% as reduced ice enhances foraging conditions, but barnacle geese might decline slightly (-5% by 2050) due to avian flu.

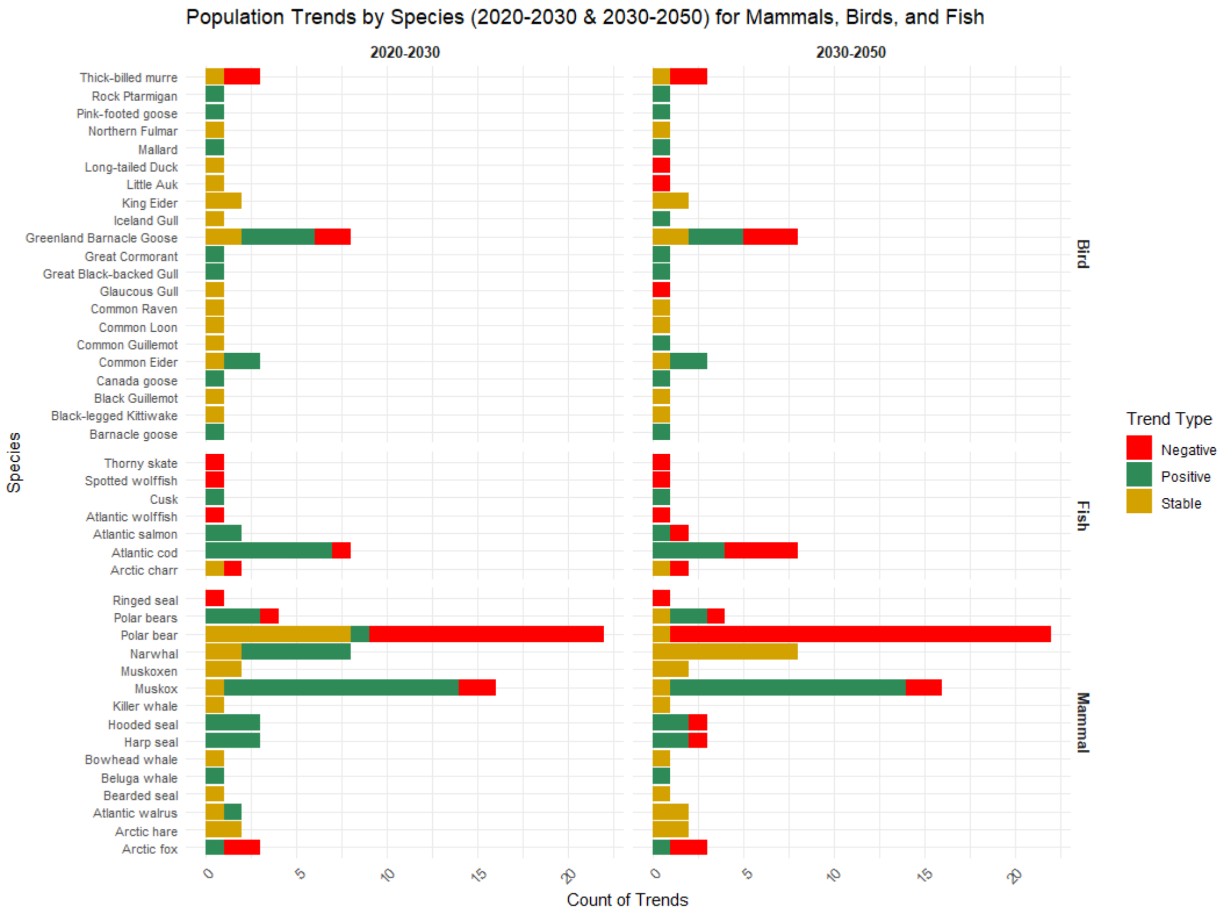


Figure 4. Population trends by species group (fish, mammal birds) for the two timeframes (2020-2030 left, and 2030-2050 right)

Fish trends will split along thermal niches. Norwegian Sea populations will decline progressively until complete disappearance (-100% by 2050), and those in Northeast Greenland will undergo a severe reduction (-95%), indicating near-total collapse. Arctic specialists like Arctic char in Southwest Greenland will collapse (-30% by 2050) from salmon competition and habitat loss. Wolffish (*Anarhichas lupus*), constrained by benthic specialization, may decline by 20% towards 2050.

5.3.**Regional variability**

Expected species developments vary across geographic regions, with trends diverging between 2030 and 2050. In Kane Basin, polar bear populations are expected to remain stable through 2050, while declines are evident in other Arctic areas. Atlantic cod populations in Northeast Greenland may decline by 95% toward 2050, with an even steeper decline of 100% in the Barents Sea by the same time. Harp seal pup production declines by 15% by 2050 in the Northwest Atlantic due to reduced ice cover. By 2030, East Greenland's common eider populations show potential increases as ice-free coastal areas expand. In contrast, Arctic salmon populations will experience regional declines by 2050, attributed to overfishing and habitat pressures.

5.4.**Temporal variability**

Based on the analysis comparing the best-estimated changes for the periods 2020–2030 and 2030–2050, it appears that many species are expected to experience more negative population trends in the later period. For Arctic species, the near-term estimates tend to be relatively stable or only slightly negative, but a steeper decline is often projected for 2030–2050 (Figure 5). In contrast, Arctic-boreal species display considerable variability, with some populations already showing significant declines in the later period while others appear to be less affected in the near term. This variability suggests that local and regional factors might be playing a significant role in shaping these trends. Boreal species, on the other hand, sometimes show more positive or modest declines in the first period, but the long-term outlook appears more negative, although the magnitude of change can vary considerably among different populations.

Overall, these findings imply that environmental pressures on these groups are likely to intensify over time, which means that conservation and management strategies will need to be specifically tailored to the unique challenges faced by Arctic, Arctic-boreal, and Boreal species. For instance, the Atlantic cod population in the Norwegian Sea/Barents Sea/North Sea is estimated to decline by a best estimate of –50 in the 2020–2030 period to –100 in the 2030–2050 period, indicating a dramatic decline. In contrast, an Atlantic cod stock in West Greenland shows an increase by 10 to 75% over the same periods. Similarly, among Atlantic salmon, the Southwest Greenland population shifts from an estimate of +10 in 2030 to –10% in 2050, while the West Greenland population increases by 25 to 60%. Among Arctic species, Polar bear populations are also highly variable. One population in Baffin Bay has a near-neutral estimate of 0 in 2030, which declines to a -15% trend by 2050, whereas the Kane Basin group falls from 10% to 0. These specific numerical changes demonstrate that while the overall trend is toward more negative outcomes in the longer term, the direction and magnitude of change vary significantly between populations. Narwhal populations in Jones Sound, Admiralty Inlet, Somerset Island, Smith Sound, and Eclipse Sound all increase until 2030 and are expected to remain stable after that. Harp seal pup production in the Northwest Atlantic will remain relatively stable until 2030 but will decline by 15% towards 2050 as ice-dependent breeding grounds shrink. Similarly, seabird populations exhibit contrasting patterns, with Common Eiders in East Greenland benefiting from reduced sea ice by 2030, while Thick-billed murres in West Greenland face ongoing pressures from hunting and ecosystem shifts. These findings illustrate that while some species remain stable over short time frames, cumulative environmental stressors may drive long-term shifts in Arctic and boreal ecosystems.

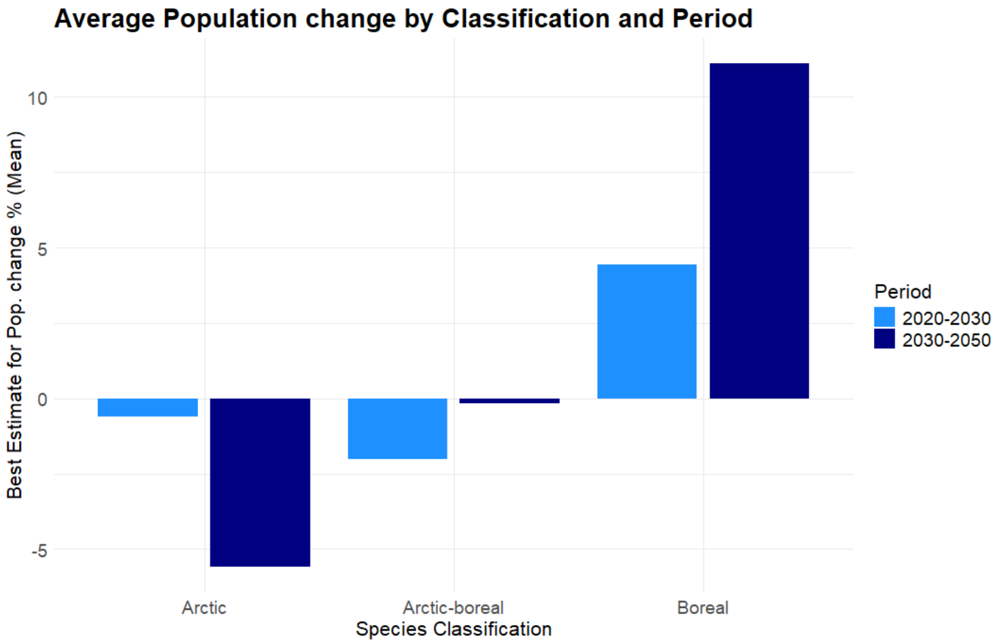


Figure 5 Mean best estimate for Arctic, Arctic-boreal and Boreal species across 2020-2030 and 2030-2050

5.5. **Drivers of population change**

Population trends across Arctic, Arctic-boreal, and Boreal species are shaped by environmental, ecological, and human-driven factors (Figure 6). Climate change (18.9%) is the overarching driver of change, influencing multiple underlying factors such as sea ice loss, temperature rise, and environmental shifts. Sea ice loss (21.6%) is the most frequent direct cause of population changes, particularly affecting Arctic species such as polar bears and ringed seals that depend on stable ice habitats. Vessel traffic (10.8%) plays a complex role, contributing to both stability and decline depending on species' ability to adapt to increasing human presence in marine environments.

For declining populations, climate change (18.9%) and its consequences, such as sea ice loss (21.6%) and broader environmental changes (5.4%), are the leading causes. These factors impact food availability, habitat quality, and migration patterns. Increasing populations are less common but are linked to temperature rise (5.4%), which benefits some boreal fish and waterfowl expanding into newly available habitats.

Stable populations are often associated with vessel traffic (10.8%), which has mixed effects depending on species resilience, and climate change (18.9%), and can either pose risks or create new ecological opportunities. These nested influences highlight that while climate change is the primary driver, its effects manifest through specific mechanisms such as habitat transformation, shifting prey distributions, and increased human activity, reinforcing the contrast between Arctic species facing greater risks and Boreal and Arctic-boreal species showing higher adaptability.

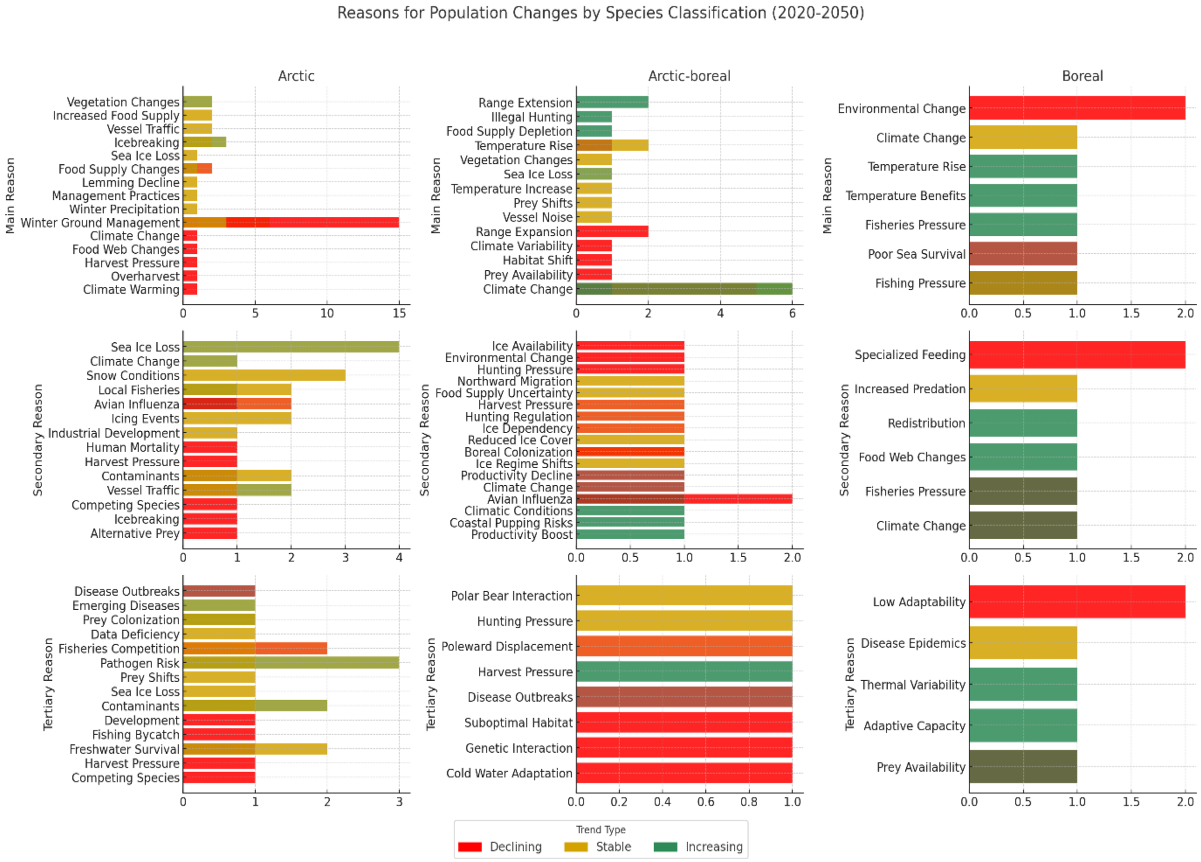


Figure 6. Reasons for trend development divided by Arctic, Arctic-boreal and Boreal species and main, secondary and tertiary reason for population developments.

5.6. **Confidence and Uncertainty**

The projected population trends are based on expert interviews, with confidence levels reflecting varying degrees of certainty across species and regions. Most species fall within the medium (3) to high (4) confidence range, though some show very high (5) confidence, particularly where data availability is strong (Figure 7). Conversely, species with limited monitoring data or high ecological variability exhibit low (2) to very low (1) confidence levels, highlighting the challenges of long-term projections. The mean confidence level is 2.51 (low/medium) for 2030 and 2.37 for 2050, with a slight decline in certainty over time. Confidence levels vary across species. Bearded seals (*Erignathus barbatus*), hooded seals, and narwhals in Eclipse Sound and Inglefield Bredning have low confidence scores (≤2, very low, low) due to data limitations. In contrast, polar bears in the Arctic Basin and Atlantic cod in East Greenland have high confidence scores (≥4, high, very high). Muskoxen (*Ovibos moschatus*) in Zackenberg show high certainty in declines (-25% by 2050), while populations in North Greenland have lower confidence due to limited data availability. Expert assessments reveal substantial variation in the range between the lowest and highest estimates, with the degree of divergence differing markedly by species and region. For instance, Atlantic cod assessments are highly variable. In West Greenland, the 2050 estimates range by as much as 220 percentage points, while in East Greenland the divergence is lower yet still notable (approximately 50 percentage points in 2030 and 100 percentage points in 2050). Similarly, Atlantic salmon in West Greenland show a divergence of around 60 points in 2030 and up to 180 points in 2050. In contrast, species such as beluga whales, narwhals, and bowhead whales

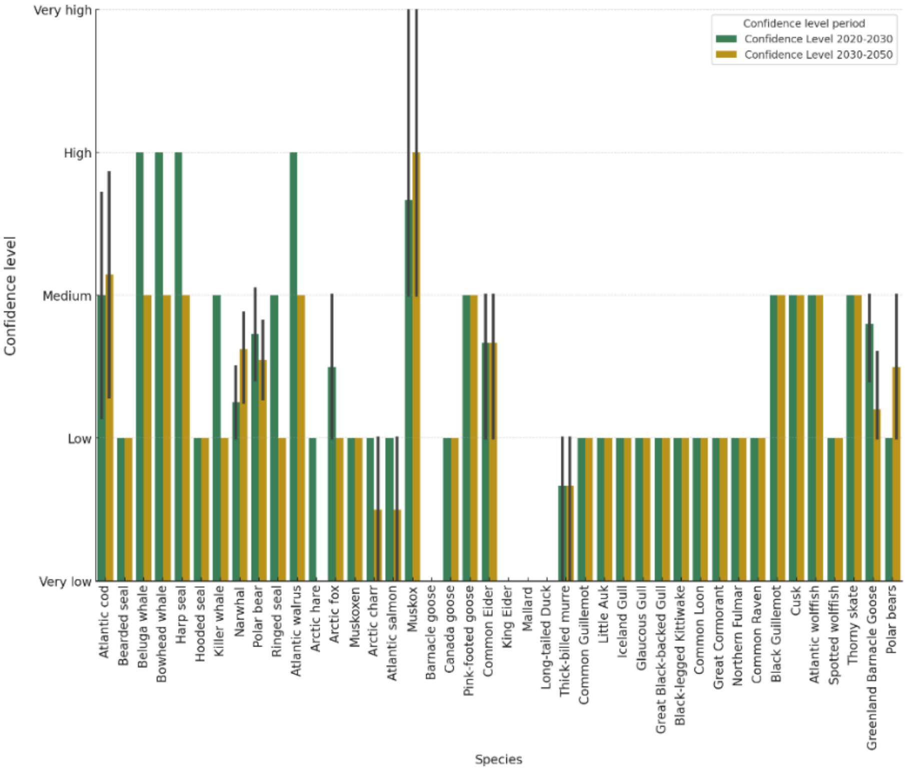


Figure 7. Confidence level across species. Medians in black are shown for multiple ratings per species.

tend to have more moderate differences between the lowest and highest estimates, typically in the range of 15 to 30 percentage points. Many polar bear populations exhibit narrow ranges, with differences as low as 2 to 6 points, indicating a higher level of consensus among experts for these groups. These patterns underscore that divergence in expert assessments is both species- and region-specific, with some taxa, particularly certain fish populations, showing high variability and others, such as polar bears, displaying more consistent projections.

5.7. Species-specific trajectories:

Mammals:

1) Polar bear (*Ursus maritimus*)

Polar bear populations are expected to decline across most regions, driven by ongoing sea ice loss, which reduces hunting opportunities and habitat stability (Figure 8). While Baffin Bay and the Southern Beaufort Sea show moderate declines of around -15%, some regions such as Kane Basin exhibit less pronounced changes. The highest confidence levels are in well-monitored areas like Baffin Bay, while confidence is lower in regions where monitoring is limited (e.g., East Greenland and the Kara Sea).

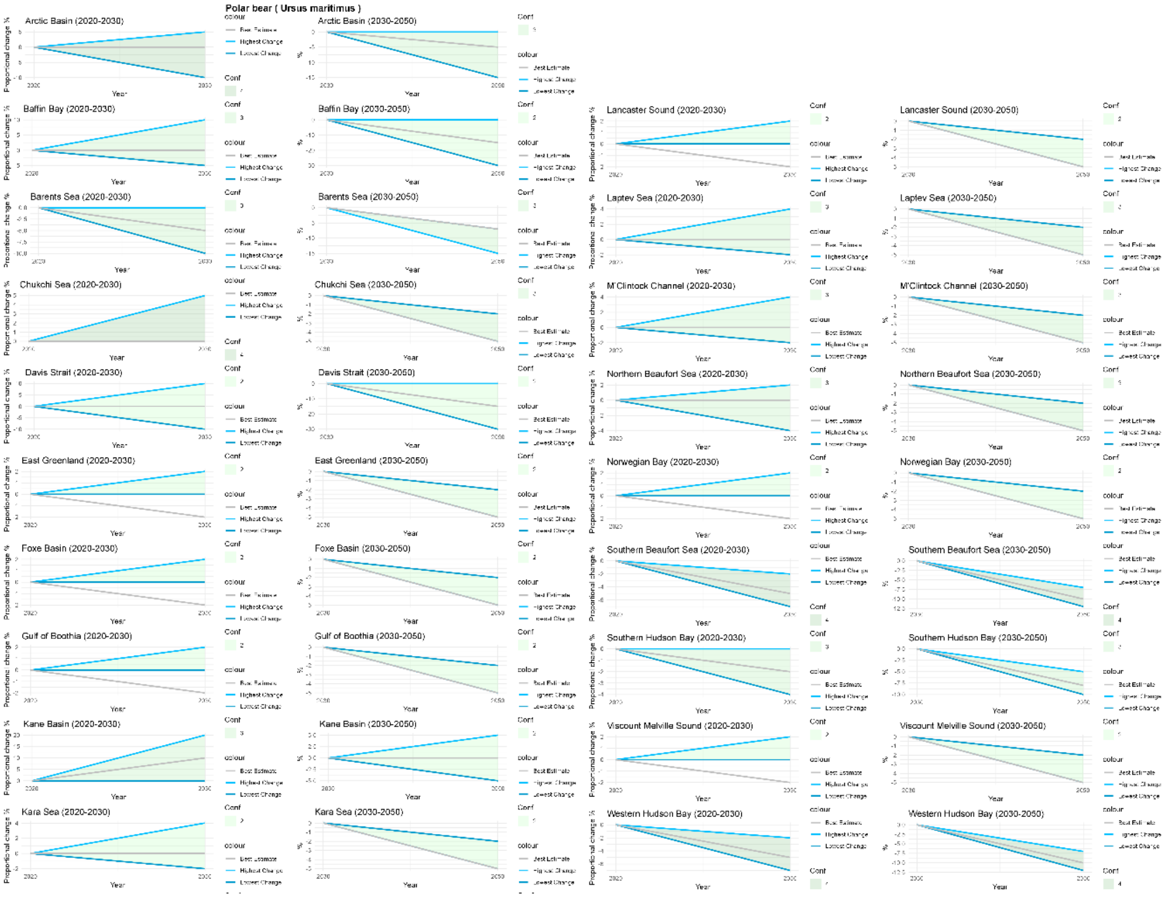


Figure 8. Expert-estimated proportional change in polar bear populations between 2020-2030 and 2030-2050 for all sub-populations

2) Muskox (*Ovibos moschatus*)

Muskoxen populations overall is expected to slightly in Greenland (2% until 2030 and 10% between 2030 and 2050) due to increased winter precipitation (snow), icing events and emerging diseases (Figure 9). Confidence levels reach up to declines from 50%. For East Greenland, both assessments expect stable trends, although confidence level diverge between low and very high. Moreover, there are declines in the Zackenberg Valley by 20% and additional decline by 50% towards 2050. Reasons are a northward shift of species distribution range due to increased temperature and wet conditions in the south leading to local population decline. For Zackenberg Valley altered climatic conditions (increased temperature and moisture) are expected to lead to suboptimal living conditions (e.g., changes in vegetation) with animals either migrating north or dying. Confidence levels range between moderate for all Greenland, high, and very high for the Northeast areas.

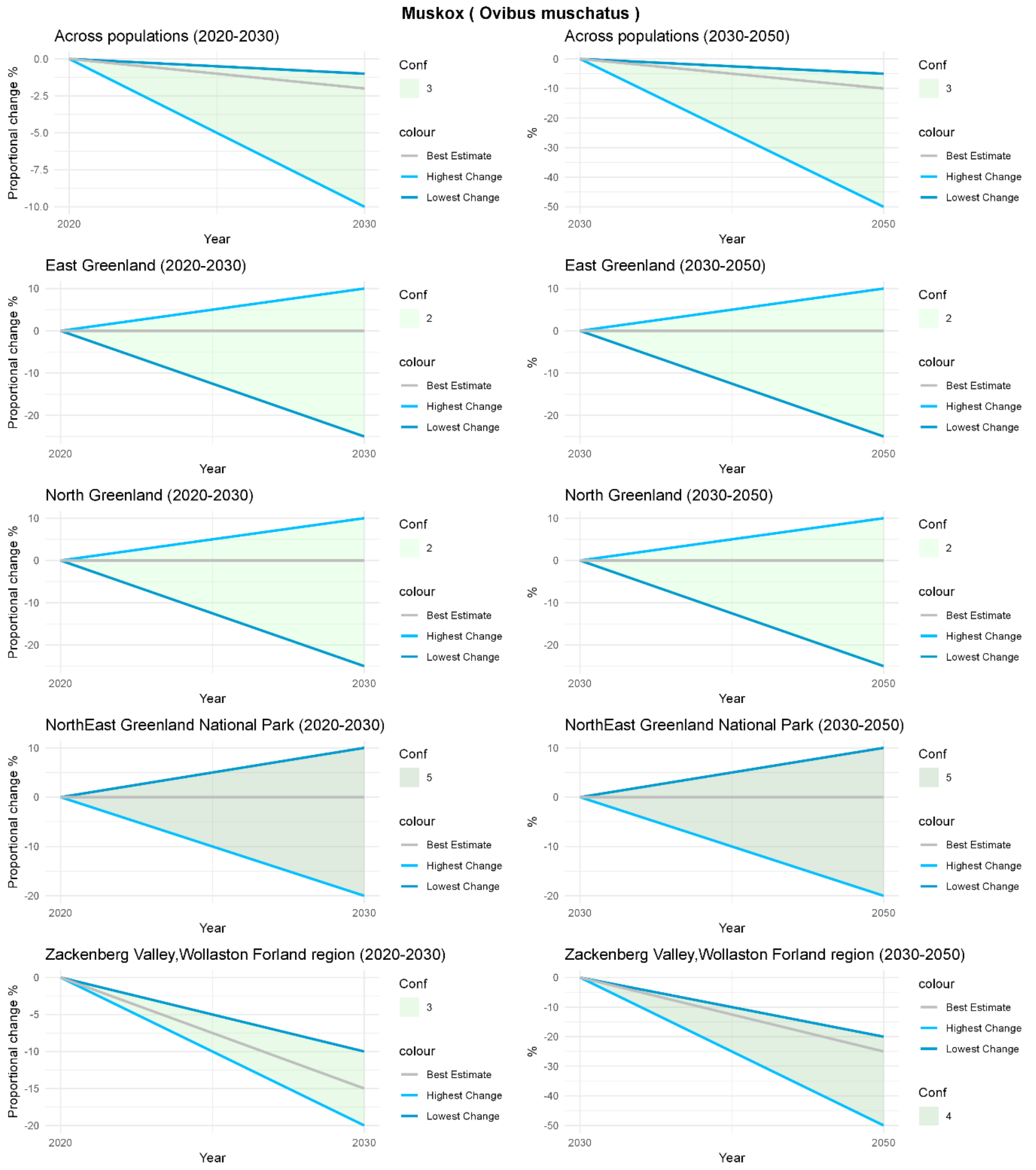


Figure 9. Expert-estimated proportional change in muskox populations between 2020-2030 and 2030-2050 by population.

3) Narwhal (*Monodon monoceros*)

Narwhal stocks show mixed trends, with stable or slightly increasing populations in Eastern Baffin Island and Melville Bay, whereas declines (-15%) are expected in regions such as Jones Sound and Eclipse Sound (Fig ure10). Climate change impacts prey availability, and increasing vessel traffic, ice breaking and industrial development adds stress to this species. Confidence is low to moderate for most stocks.

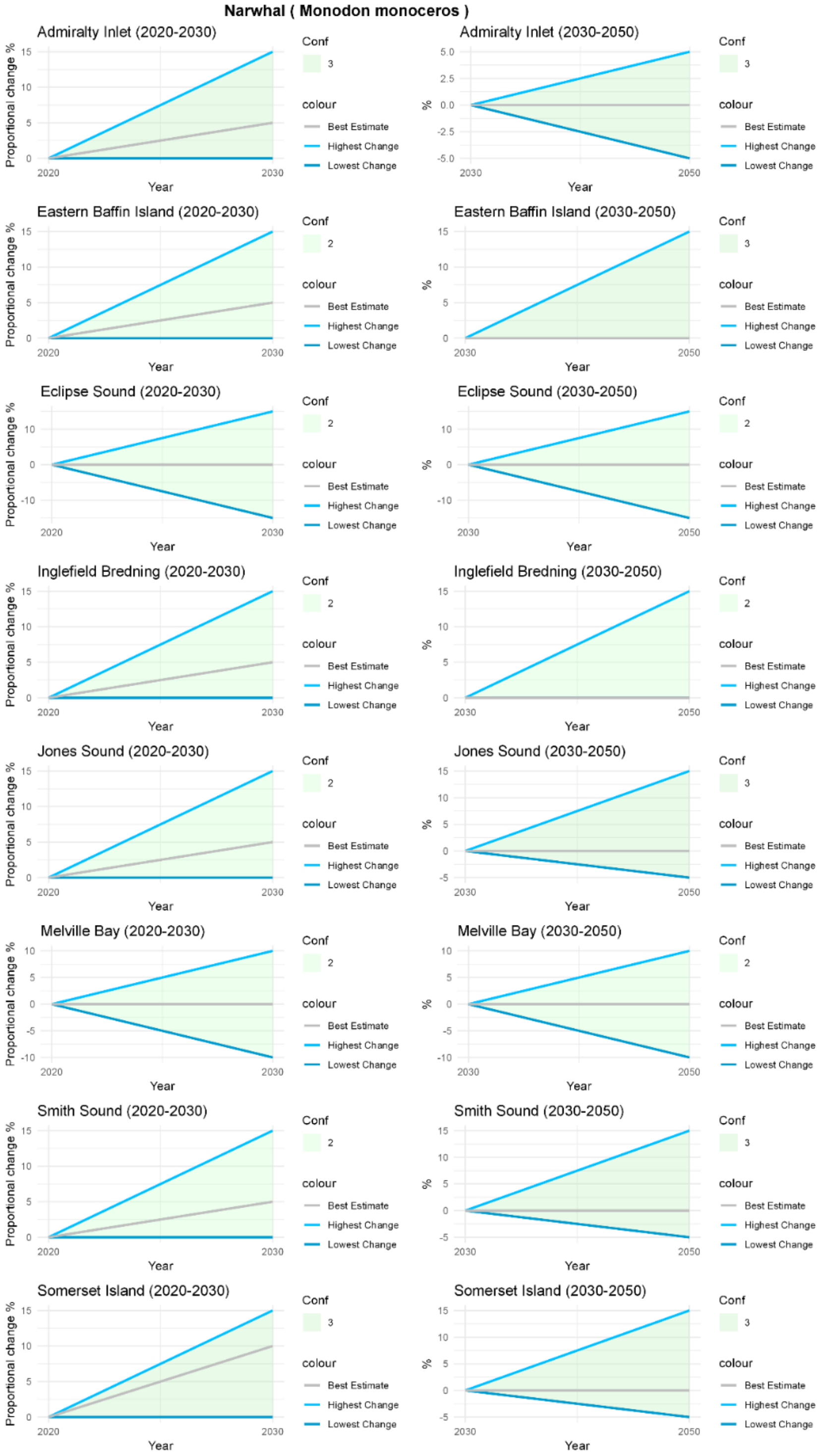


Figure 10. Expert-estimated proportional change in narwhal stocks between 2020-2030 and 2030-2050 for all stocks

4) Beluga whale (*Delphinapterus leucas*)

Beluga populations are expected to slightly increases by +5%, benefiting from conservation measures (Figure 11). Vessel traffic and noise including icebreaking and climate change, particularly the loss of sea ice and harvest will impact beluga stocks. Future trends in the beluga population will be highly dependent on harvest levels. Introduction of quotas in West Greenland halted population decline, but increases in harvests in Canada or Greenland could result in future declines. Confidence levels are high and moderate for long-term trends.

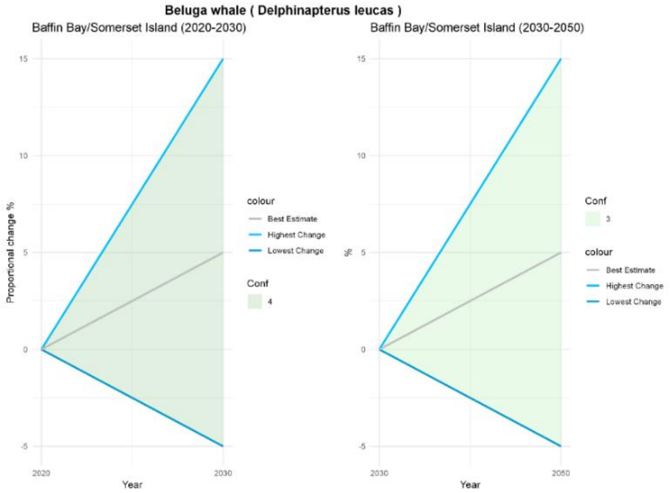


Figure 11. Expert-estimated population trends of beluga whales in Baffin Bay between 2020-2030 and 2030-2050.

5) Hooded seal (*Cystophora cristata*)

Hooded seals exhibit an expected declining trend of up to -30% in the Northwest Atlantic until 2050, due to climate change and associated sea ice declines and harvest (Figure 12). One of the explanations for the high threats for the North Atlantic hooded seals may be uncertainty on population abundance and trends. This species is data deficient (at least for the stock found in Baffin Bay, Davis Strait, and the NW Atlantic). Confidence is low, as surveys are not available.

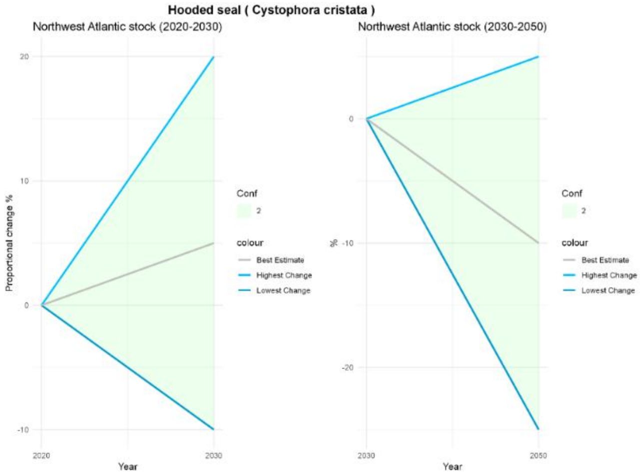
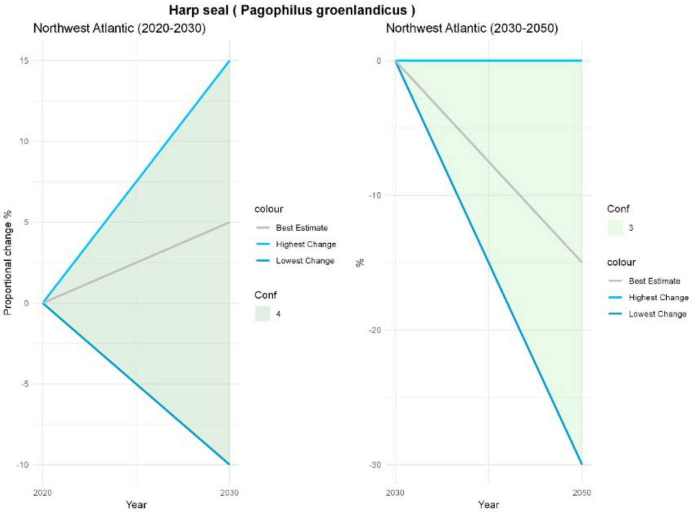


Figure 12. Expert-estimated change in hooded seal populations between 2020-2030 and 2030-2050.

6) Harp seal (*Pagophilus groenlandicus*)

Harp seal populations are expected to decline by -15% in the Northwest Atlantic, primarily due to reduced sea ice affecting breeding and foraging, harvest and novel diseases (Figure 13). Continued declines in spring ice quality will continue to affect recruitment and disease outbreaks could have significant impacts. Highest reductions are observed post-2030. Confidence is moderate to high.


Harp seal (Pagophilus groenlandicus)

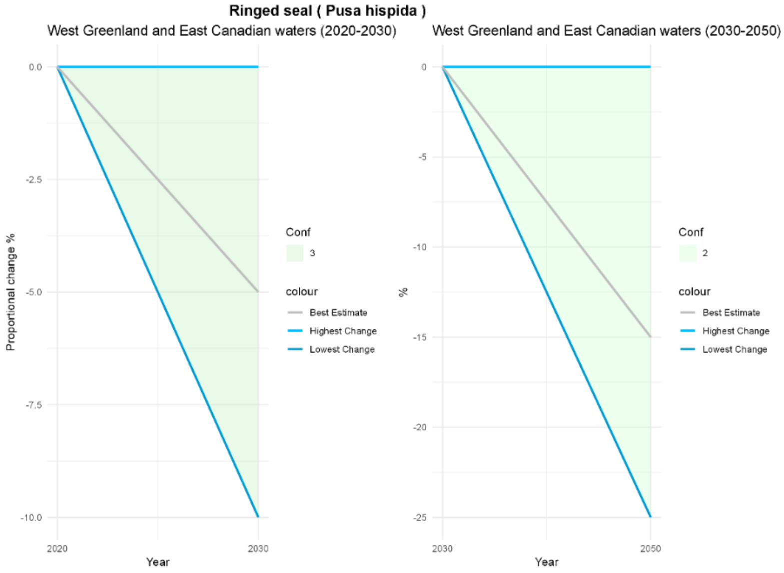
Northwest Atlantic (2020-2030)

Northwest Atlantic (2030-2050)

Figure 13. Experts assessed proportional change in harp seal populations between 2020-2030 and 2030-2050.

7) Ringed seal (*Pusa hispida*)

Ringed seal populations are declining, particularly in West Greenland and East Canadian waters, due to the loss of stable ice breeding platforms, and novel diseases (Figure 14). Reductions in snow cover and landfast ice quality will likely affect recruitment. Increased development and associated icebreaking activities will also affect habitat quality and cause disturbance. Confidence for this Arctic mammal is low to moderate, as surveys are not available for this species.


Ringed seal (Pusa hispida)

West Greenland and East Canadian waters (2020-2030)

West Greenland and East Canadian waters (2030-2050)

Figure 14. Experts estimated proportional change in ringed seal populations in Greenland between 2020-2030 and 2030-2050.

8) Bearded seal (*Erignathus barbatus*)

Bearded seal populations are expected to remain stable due to reasons such as climate change, vessel traffic and ending up as fishing bycatch (figure 15). Confidence levels are low due to lack of surveys for this species. Bearded seals are overall poorly studied and there is much uncertainty about assessment.

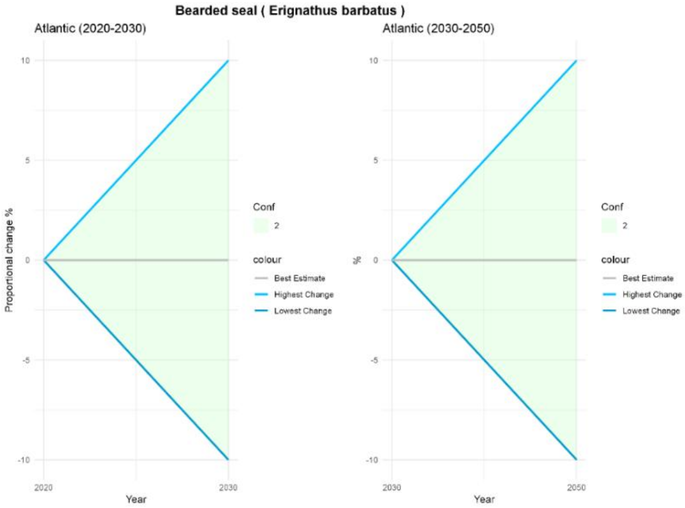


Figure 15. Experts estimated proportional change in bearded seal populations in Greenland between 2020-2030 and 2030-2050.

9) Atlantic walrus (*Odobenus rosmarus rosmarus*)

Stocks of the Atlantic walrus are assumed to remain stable in the Baffin Bay area and increase in Hudson Bay and Davis Strait until 2030, after which they are projected to plateau (Figure 16). The primary factors influencing this trend include changes in sea ice conditions, increased vessel traffic and harvest pressure. Harvest is considered low risk at present as it has declined but could become a threat in future. The confidence level in this estimate is moderate to high.

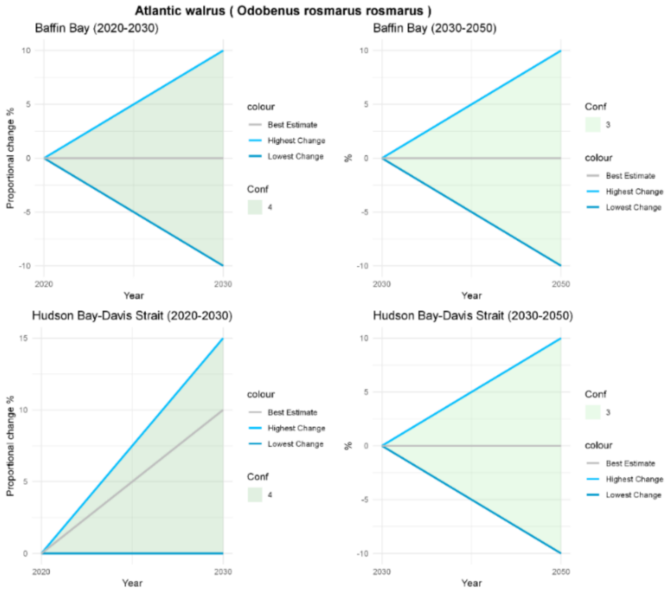


Figure 16. Experts estimated proportional change in Atlantic walrus populations in Greenland between 2020-2030 and 2030-2050.

10) Arctic fox (*Vulpes lagopus*)

The population of Arctic fox is projected to change by 2050, with a best estimate of -10 % in North Greenland and steep declines (-40%) in Northeast Greenland for 2050 (Figure 17). The projected range varies from the lowest potential change of 0 % to a highest potential change of 25 %. Confidence levels are low. The main factors influencing this trend include changes in food supply.

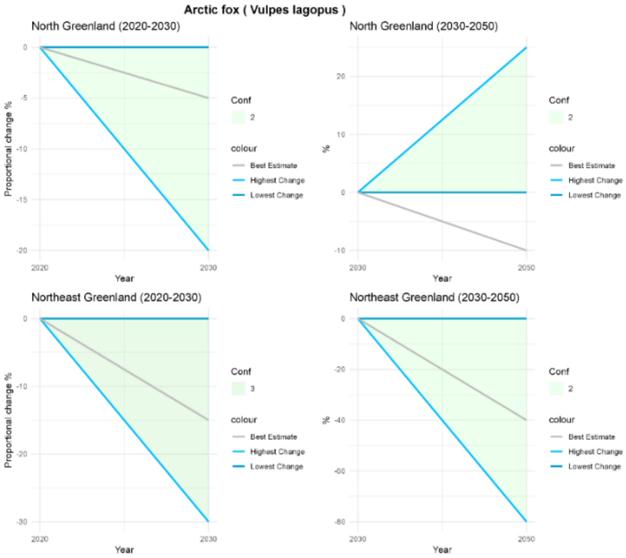


Figure 17. Experts estimated proportional change in Arctic fox populations in Greenland between 2020-2030 and 2030-2050.

11) Arctic hare (*Lepus arcticus*)

The expected trends for arctic hare is increasing populations for East Greenland and Northeast Greenland (National Park) (Figure 18). The projected range varies from the lowest potential change of 15 % to a highest potential change of 25 units. However, inconsistencies appear between the lowest and best estimate (expert is consulted). The main factors influencing this trend include increased food supply. Confidence level is here low to very low for the longer-term postulation.

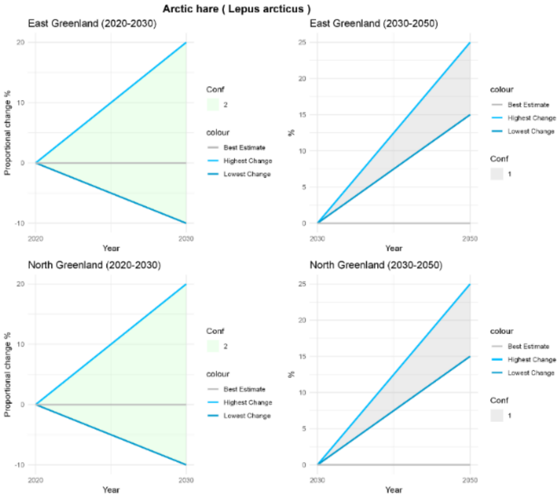


Figure 18, Experts estimated proportional change in Arctic hare populations in Greenland between 2020-2030 and 2030-2050.

12) Bowhead whale (*Balaena mysticetus*)

Bowhead whales populations are estimated to remain stable until 2030 and 2050 in West Greenland (Figure 19). The primary factor influencing this trend is vessel traffic and noise, climate change and prey shifts. Confidence level is high to moderate for the long-term projections.

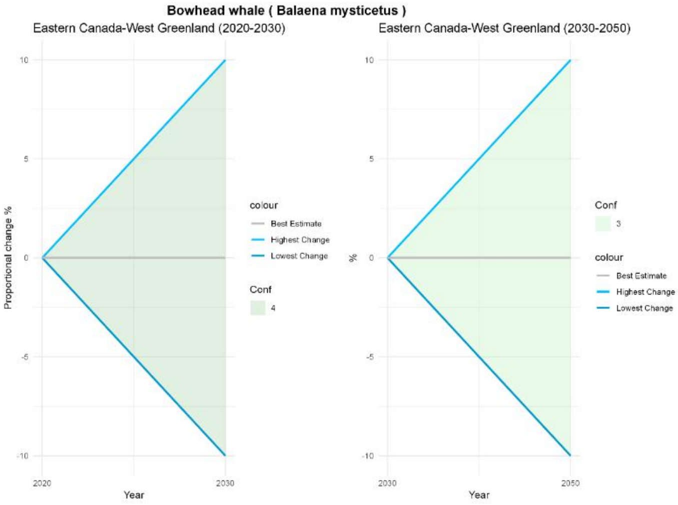


Figure 19. Experts estimated proportional change in Bowhead whale populations in Greenland between 2020-2030 and 2030-2050.

13) Killer whale (*Orcinus orca*)

The population of Killer Whales is projected to remain stable due to adaptability and broad prey availability (Figure 20). Threats are harvest, climate change and changing sea ice dynamics and contaminants. Killer whale population trends will be extremely dependent on human removal levels. Inuit in Canada have recently started harvesting killer whales, and they are regularly hunted in Greenland. Increases in human harvests would lead to declines in abundance. The confidence level is low to medium.

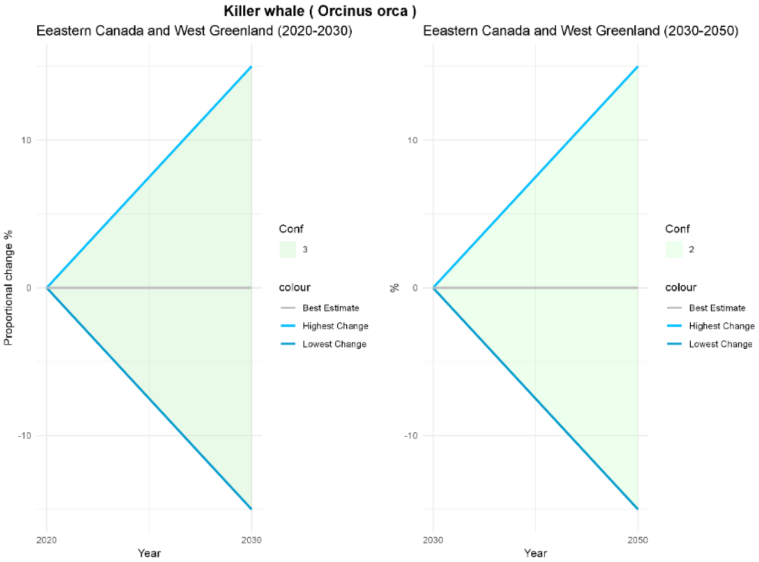


Figure 20. Experts estimated proportional change in Killer whale populations in Greenland between 2020-2030 and 2030-2050.

Birds:

14) Common Eider (*Somateria mollissima*)

Common eider populations are projected to increase in East Greenland for 2030 and 2050 (2%, 20%) due to climate change and disappearing ice cover and for West Greenland (5%, 10%) due to climate change (increase) and released hunting regulation (stable or decrease) (Figure 21). For the whole region spanning from Canada to Iceland, stable population trends are assumed. Confidence levels are low to moderate.

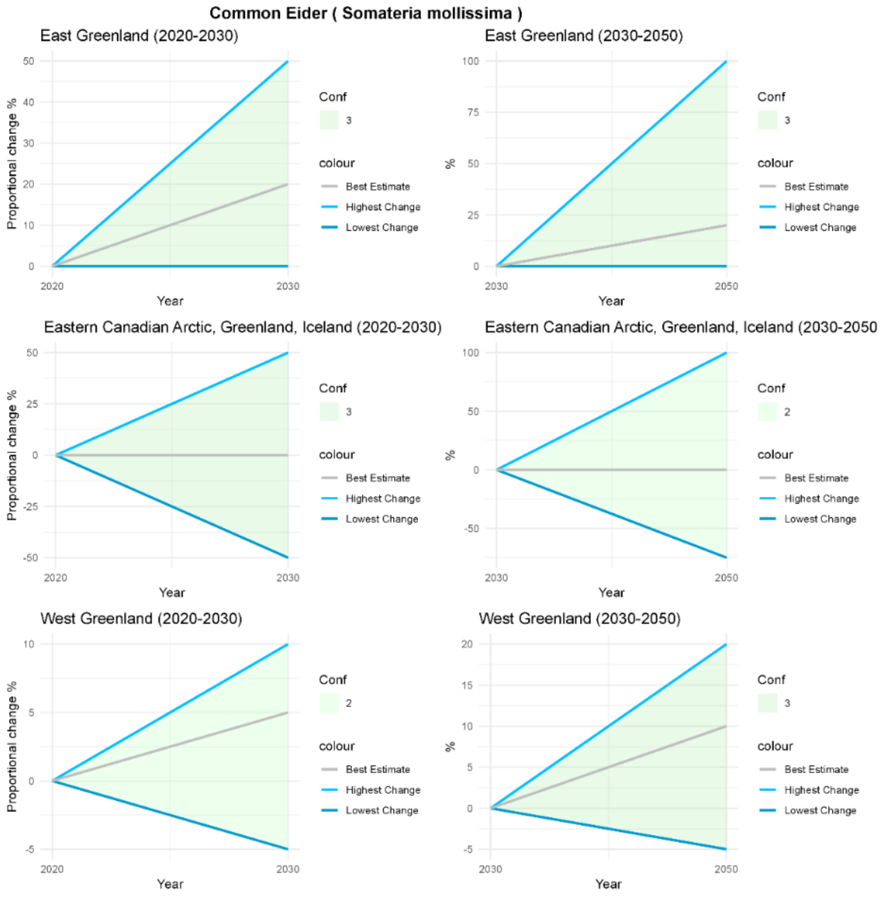


Figure 21. Experts estimated proportional change in common eider populations in Greenland between 2020-2030 and 2030-2050.

15) King eider (*Somateria spectabilis*)

The population of King Eider is assumed to remain stable due to climate change (Figure 22). The confidence level is very low.

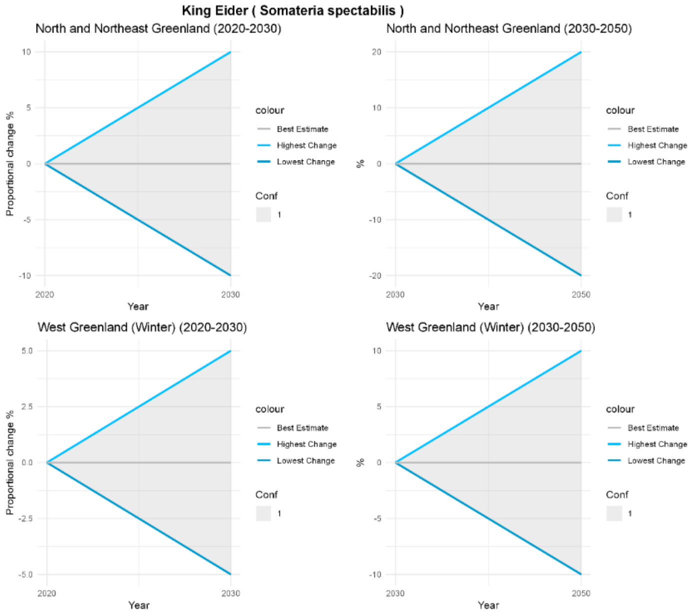


Figure 5.1 Experts estimated proportional change in king eider populations in Greenland between 2020-2030 and 2030-2050.

16) Common Guillemot (*Uria aalge*)

The population of common guillemot is assumed to be stable while increasing trends are expected after 20230 due to climate change (Figure 23). Confidence level is low.

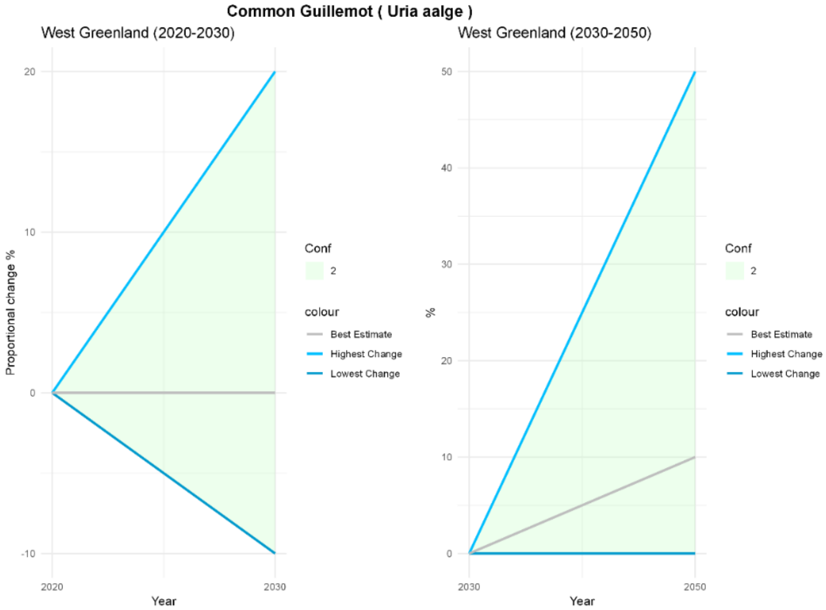


Figure 23. Experts estimated proportional change in common guillemot populations in Greenland between 2020-2030 and 2030-2050.

17) Common loon (*Gavia immer*)

For common loon, stable populations are assumed in Greenland despite climate change, confidence is low for this species (Figure 24).

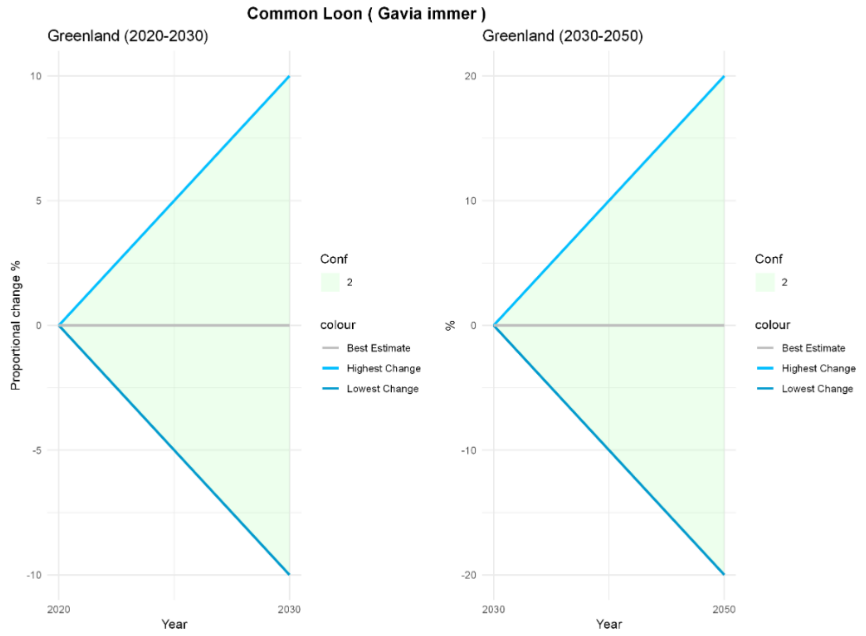


Figure 24. Experts estimated proportional change in common loon populations in Greenland between 2020-2030 and 2030-2050.

18) Mallard (*Anas platyrhynchos*)

The population of Mallard is expected to increase due to climate change (Figure 25). The confidence level is very low as surveys are not established.

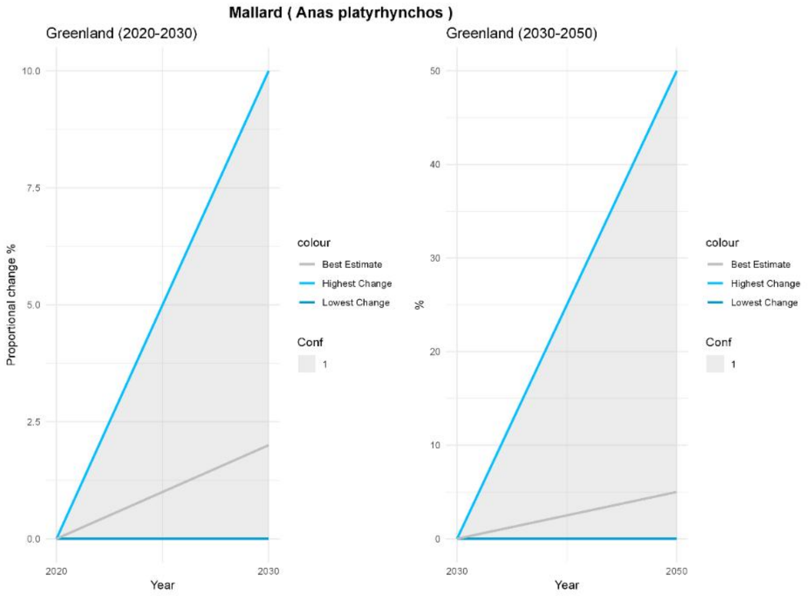


Figure 25. Experts estimated proportional change in mallard populations in Greenland between 2020-2030 and 2030-2050.

19) Common raven (*Corvus corax*)

Stable population trends are expected for ravens until 2050 despite climate change (figure 26). Confidence is low as there are no systematic surveys for ravens.

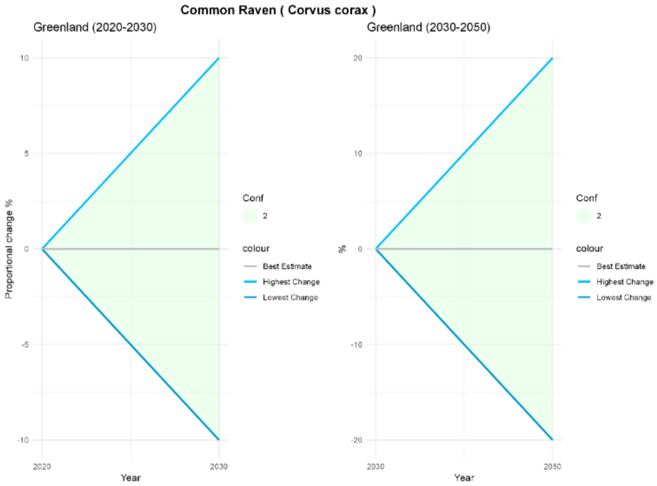


Figure 26. Experts estimated proportional change in Common raven populations in Greenland between 2020-2030 and 2030-2050.

20) Thick-billed murre (*Uria lomvia*)

Thick-billed murres show a strong declining trend, with steep population losses of up to -50% by 2030 in West Greenland (Figure 27). Inconsistencies within data appear with lowest and best estimate for East and West Greenland (expert is consulted). Climate-driven changes in prey availability and sea ice conditions significantly impact their survival. Confidence is low to very low for Thule population.

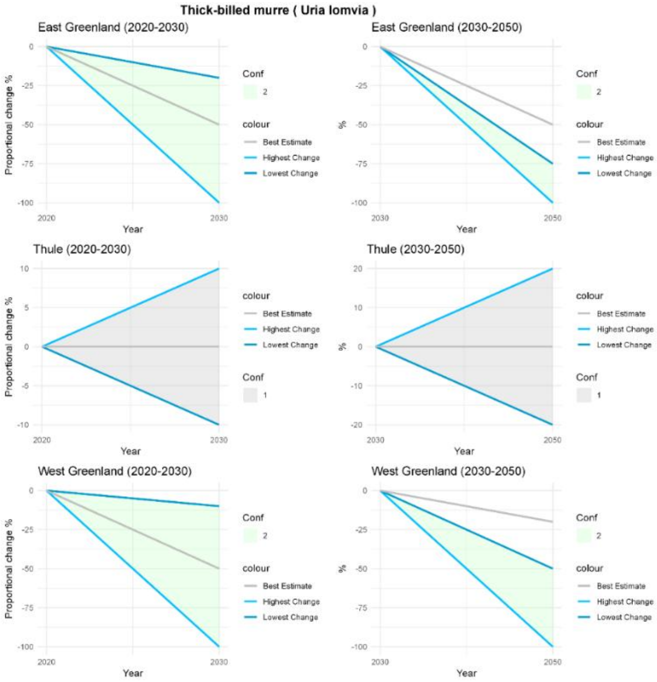


Figure 27. Experts assessed population change of thick-billed murres between 2020-2030 and 2030-2050.

21) Northern fulmar (*Fulmarus glacialis*)

The population of northern Fulmar is projected to remain stable, despite climate change (Figure 28). The confidence level is low.

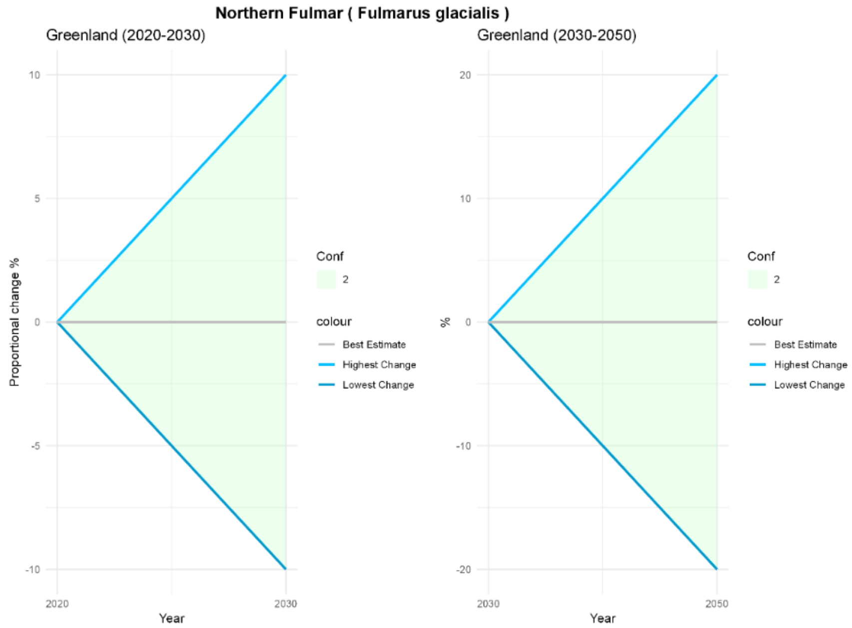


Figure 28. Experts estimated proportional change in Northern fulmar populations in Greenland between 2020-2030 and 2030-2050.

22) Black guillemot (*Cepphus grylle*)

The population of black guillemot is expected to remain stable throughout Greenland (Figure 29). The confidence level is moderate.

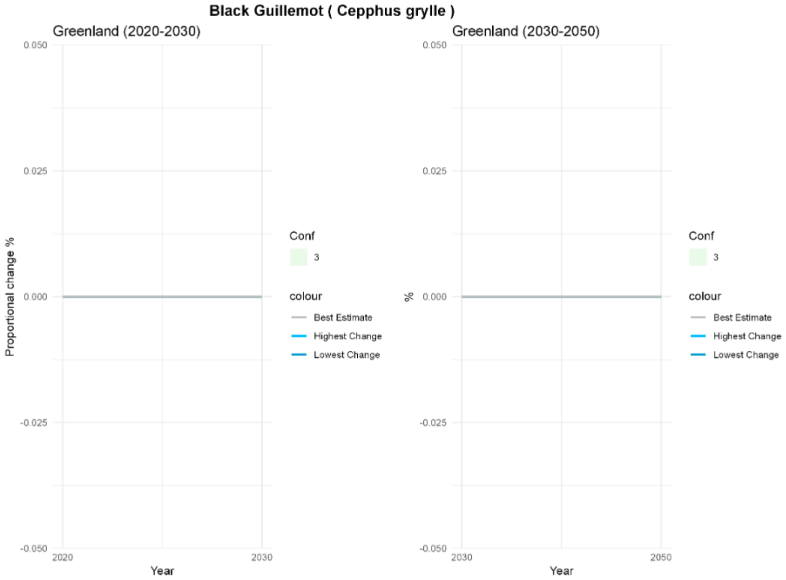


Figure 29. Experts estimated proportional change in black guillemot populations in Greenland between 2020-2030 and 2030-2050.

23) Black-legged kittiwake (*Rissa tridactyla*)

The population of black-legged kittiwake is expected to remain stable in Greenland and until 2050 even though climate change is affecting populations (Figure 30). The confidence level in this estimate is low.

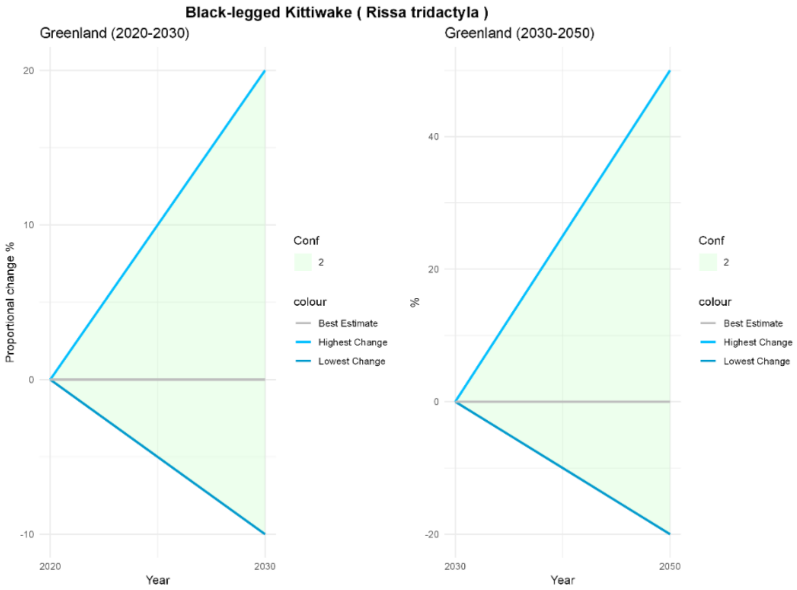


Figure 5.2 Experts estimated proportional change in Black-legged Kittiwake populations in Greenland between 2020-2030 and 2030-2050

24) Great cormorant (*Phalacrocorax carbo*)

The population of great cormorant is expected to increase sharply by 20% until 2030, and an additional 100% until 2050 (Figure 31). The main driving factor is climate change. Confidence level is low as surveys are lacking.

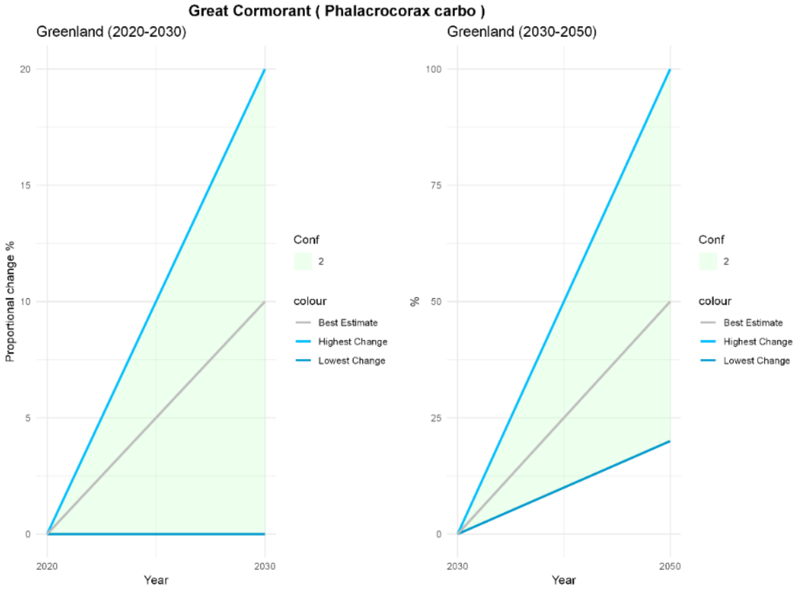


Figure 31. Experts estimated proportional change in great cormorant populations in Greenland between 2020-2030 and 2030-2050

25) Great black-backed gull (*Larus marinus*)

The population of great Black-backed gull is projected to increase by 2050, with a low confidence level (Figure 32). The main factors influencing this trend is climate change.

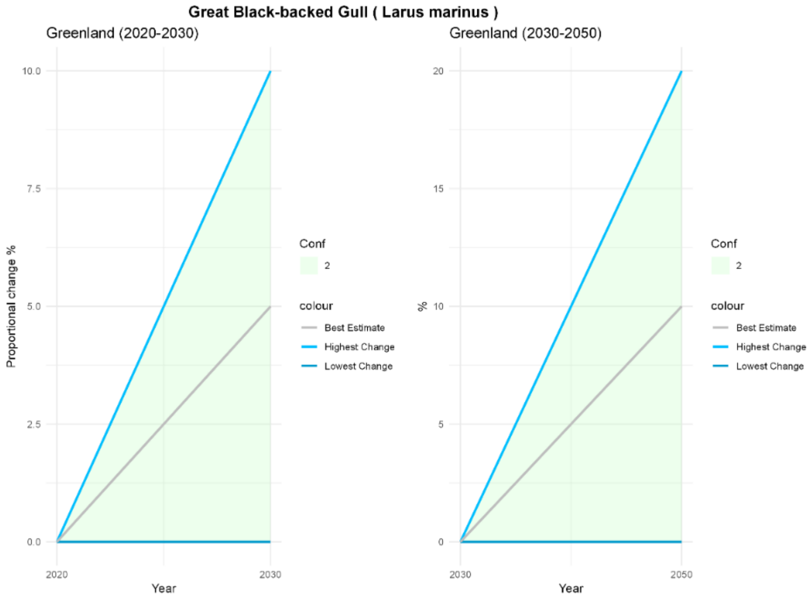


Figure 32 Experts estimated proportional change in Great Black-backed Gull populations in Greenland between 2020-2030 and 2030-2050

26) Glaucous gull (*Larus hyperboreus*)

Glaucous gull in Greenland are experiencing stable populations until 2030 and after that declines from -20% until 2050 due to climate change (Figure 33). Confidence level is low.

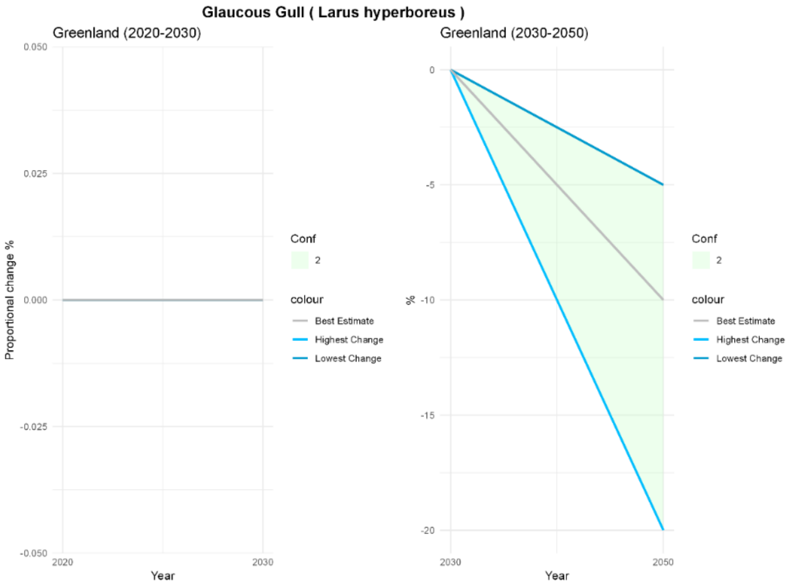


Figure 33. Expert-estimated population change of glaucous gulls between 2020-2030 and 2030-2050.

27) Iceland gull (*Larus glaucoides*)

The population of Iceland gull is expected to remain stable until 2030 and increase slightly towards 2050 by 10% due to climate change enabled range expansion (Figure 34). The confidence level is low.

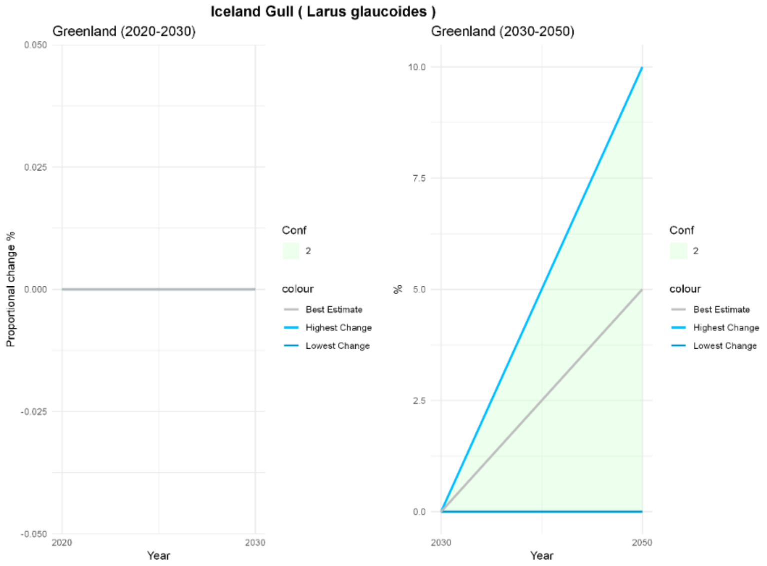


Figure 34. Experts estimated proportional change in Iceland gull populations in Greenland between 2020-2030 and 2030-2050

28) Canada goose (*Branta canadensis*)

Canada goose populations are expected to increase by up to +100% in Greenland until 2050, benefiting from milder winters and expanding food sources (Figure 35). Climate conditions favor their range expansion. Confidence levels are low as monitoring is not well established yet.

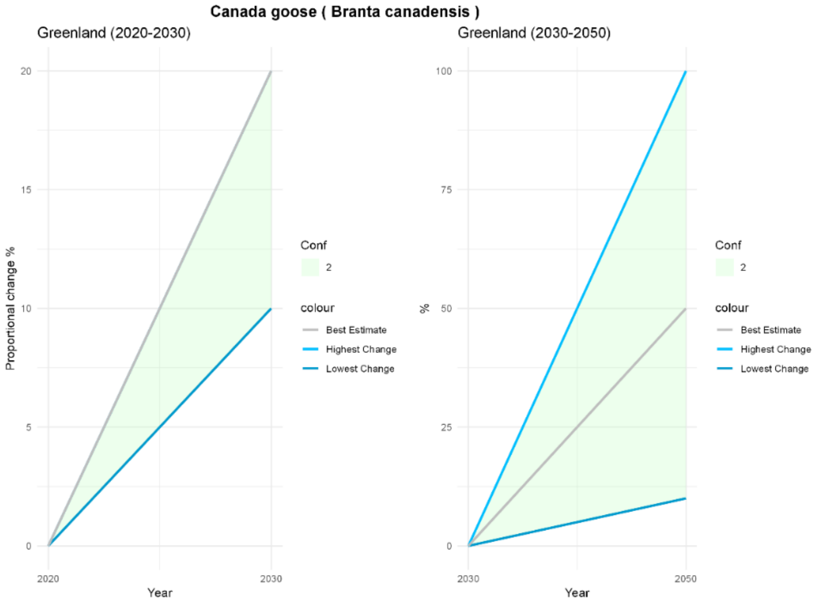


Figure 35. Experts estimated proportional change in Canada goose populations in Greenland between 2020-2030 and 2030-2050.

29) Greenland barnacle goose (*Branta leucopsis*)

Barnacle goose populations are increasing, particularly in Greenland, due to expanding breeding habitats and warming temperatures. Long-term impacts of harvest and avian flue could affect Northeast Greenland populations (Figure 36). However, expert opinions are diverging on Greenland trajectories between small declines and increasing populations. However, until 2050 declines for North Greenland are assumed to take place. Climate change has been a positive driver in their case, creating new nesting areas. Confidence is low since monitoring is not well established or hindered as new nesting sites are expanding into unsurveyed areas.

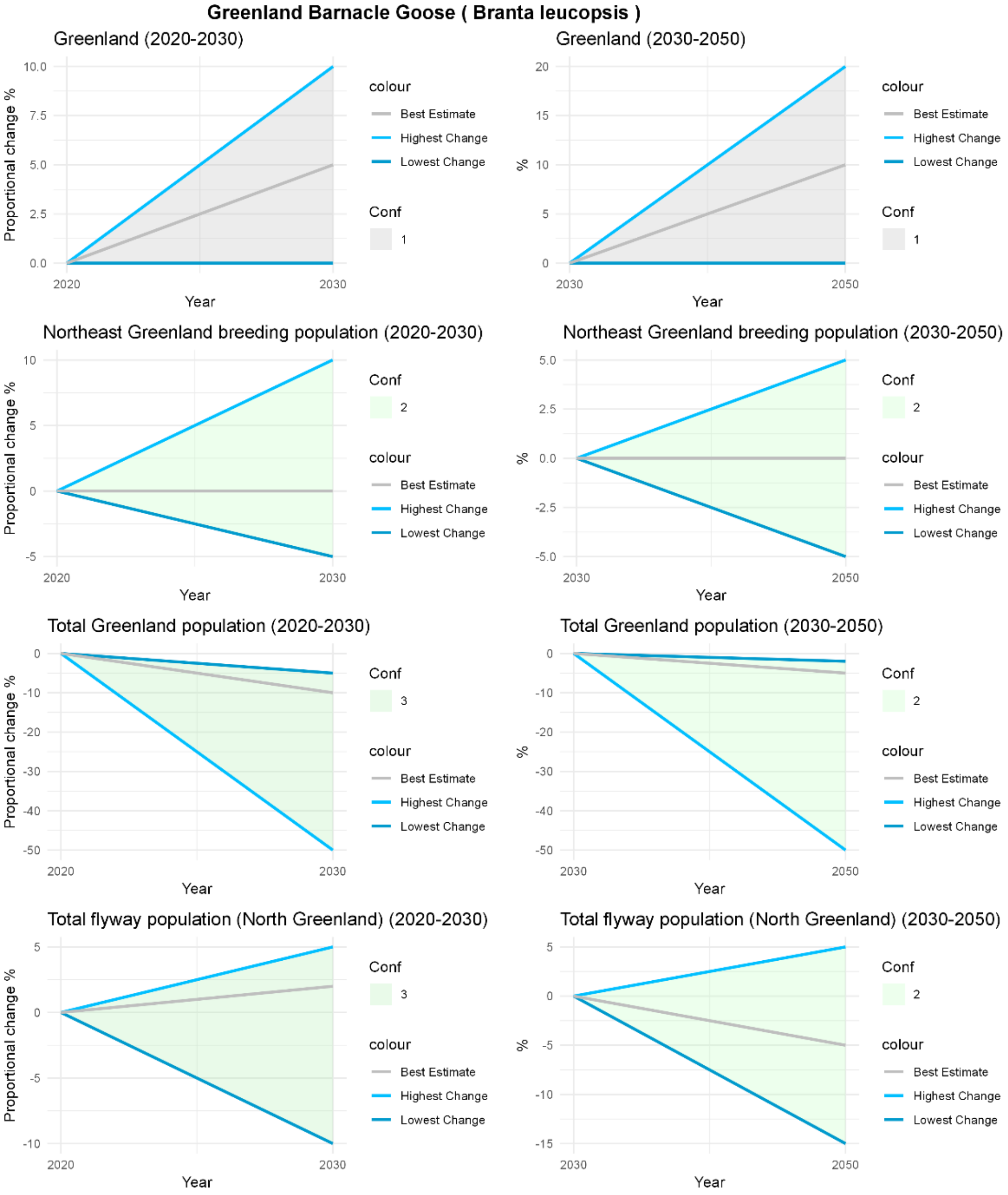


Figure 36. Experts estimated proportional change in Greenland Barnacle goose populations between 2020-2030 and 2030-2050.

30) Pink-footed goose (*Anser brachyrhynchus*)

The population of Pink-footed goose is expected to increase (+25% until 2030; +50% from 2030-2050) due to range expansion (Figure 37). The confidence level is moderate.

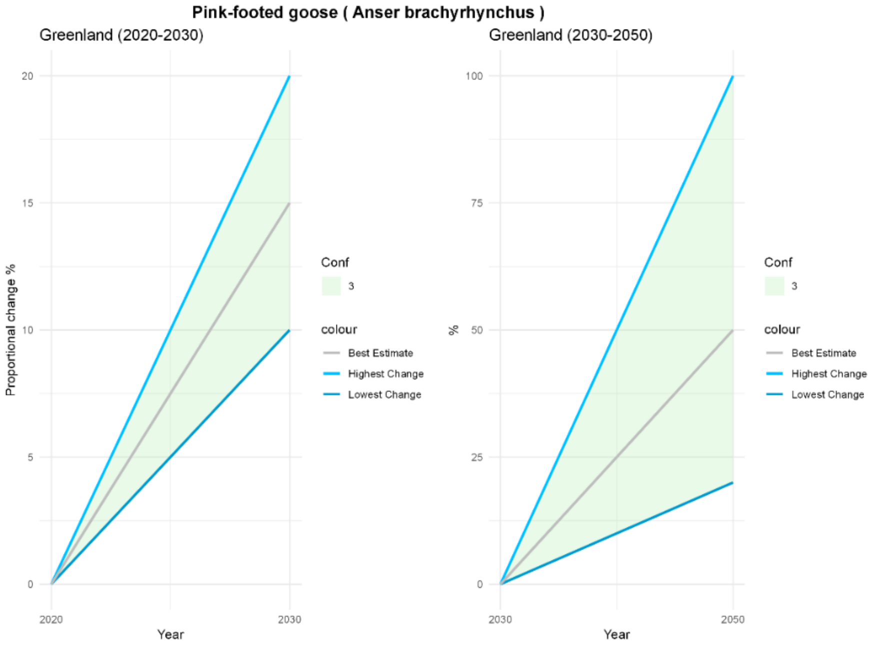


Figure 5.3 Experts estimated proportional change in pink-footed goose populations in Greenland between 2020-2030 and 2030-2050.

31) Little auk (*Alle alle*)

Little Auk populations show a stable and towards 2050 a slightly declining trend in Greenland due to climate change and changing ice conditions (Figure 38). Confidence is low.

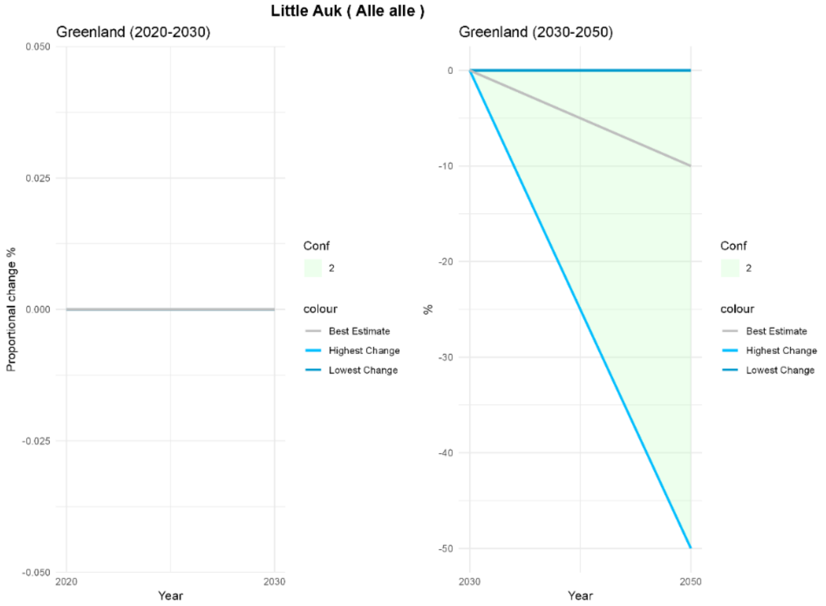


Figure 38. Experts estimated proportional change in Little Auk populations in Greenland between 2020-2030 and 2030-2050.

32) Long-tailed duck (*Clangula hyemalis*)

Long-tailed ducks are declining, with declines of -10% expected post-2030 in Greenland due to climate change (figure 39). Confidence is low.

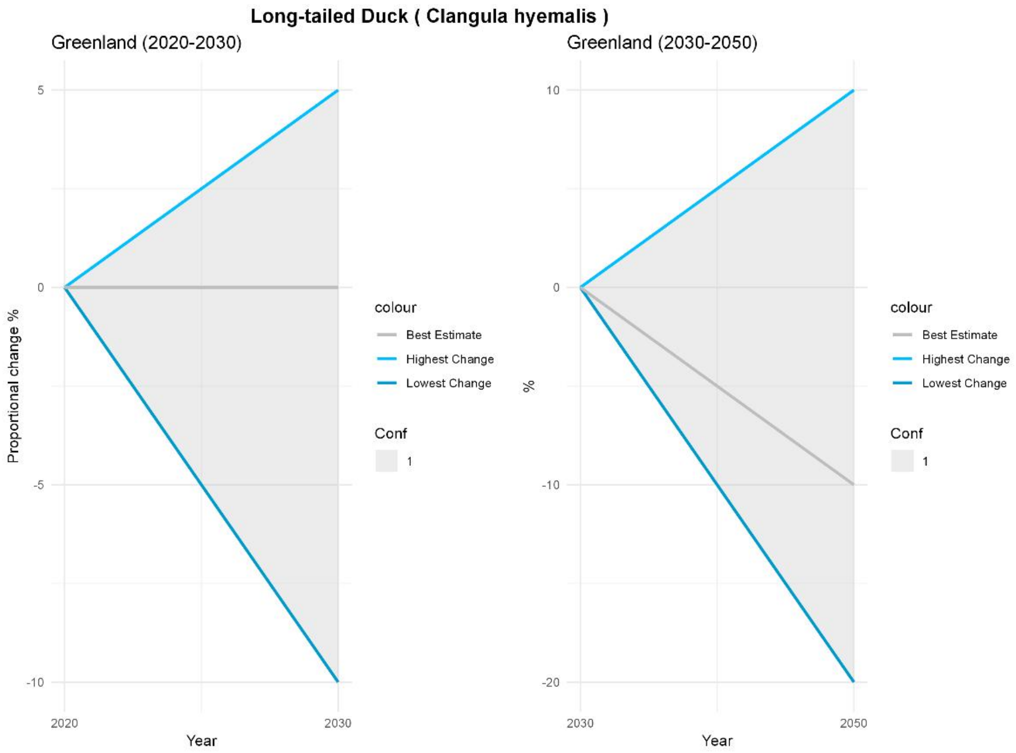


Figure 39. Experts estimated proportional change in long-tailed duck populations in Greenland between 2020-2030 and 2030-2050.

Fish species:

33) Atlantic cod (*Gadus morhua*)

Atlantic cod populations show a strongly increasing trend, particularly in West Greenland, where populations could surge by up to +200% due to warming waters expanding their range (Figure 40). However, variations in expert assessments are strong for West Greenland. Declines persist in more southern regions, where stocks in the Barents Sea are threatened with extinction due climate change (RCP 8.5 scenario), shifting prey distributions and genetic hybridization contribute to pressures. Confidence levels are high for East Greenland and Barents Sea, but lower in West Greenland.

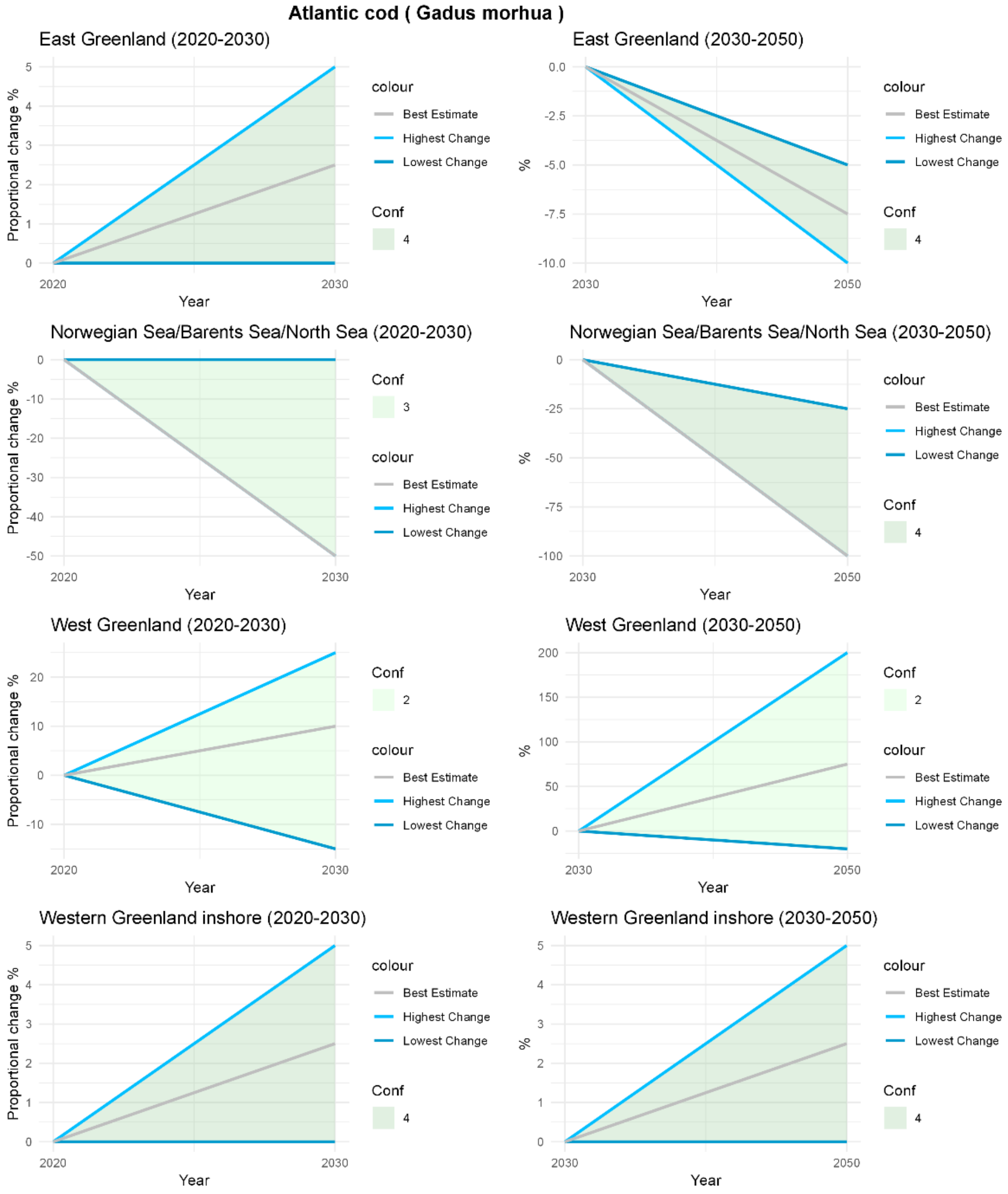


Figure 40. The plot illustrates the by experts assessed population change of Atlantic cod between 2020-2030 and 2030-2050.

34) Atlantic salmon (*Salmo salar*)

Atlantic salmon populations are estimated to increase by +60% in West Greenland, benefiting from warming conditions in freshwater habitats (Figure 41). However, not all populations are responding positively, with some regions showing slight declines (-10%) due to warming exceeding optimal thermal thresholds. The main factors influencing this trend include poor sea survival and potential Greenlandic harvest. Confidence levels are here low to very low.

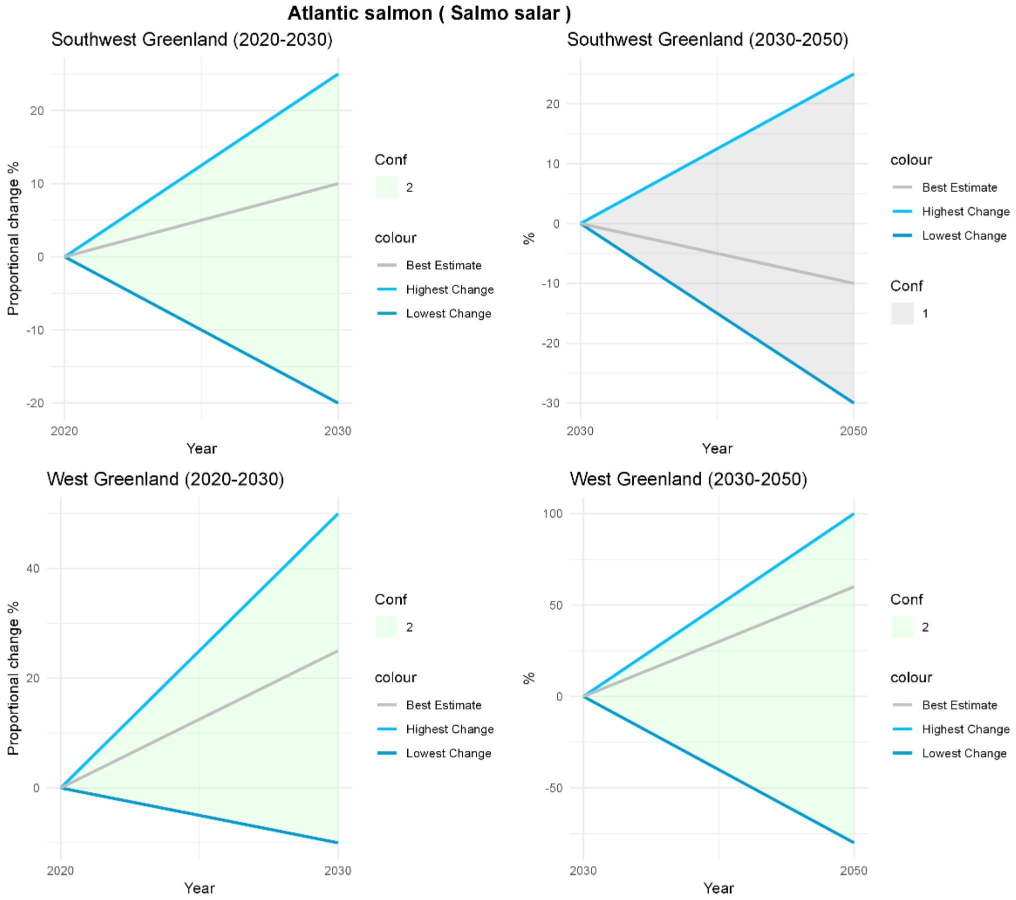


Figure 5.4 Experts assessed population change of Atlantic salmon between 2020-2030 and 2030-2050.

35) Arctic charr (*Salvelinus alpinus*)

The population of Arctic charr is projected to change by 2050, with a best estimate of -30 in Southwest Greenland (Figure 42). The projected range varies from the lowest potential change of 10 units to a highest potential change of -70 %. The confidence level is low to very low. The main factors influencing this trend include reductions in freshwater survival as climate warms, habitat loss and competition from expanding boreal fish species.

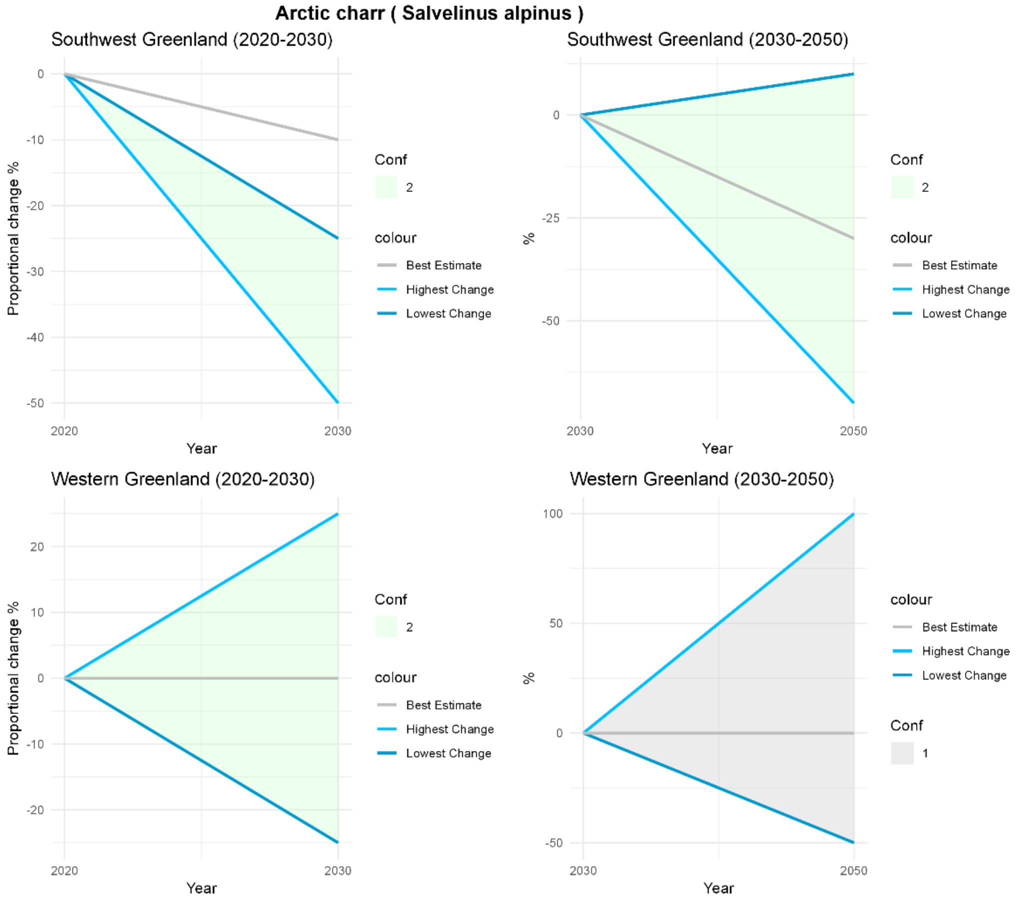


Figure 42. Expert-estimated changes in Arctic charr populations between 2020-2030 and 2030-2050

36) Spotted wolffish (*Anarhichas minor*)

Spotted wolffish populations show declining trends in Southeast Greenland due to environmental change, a benthivorous feeding behaviour and specialisation and a low adaptive capacity (Figure 43). Confidence levels are low.

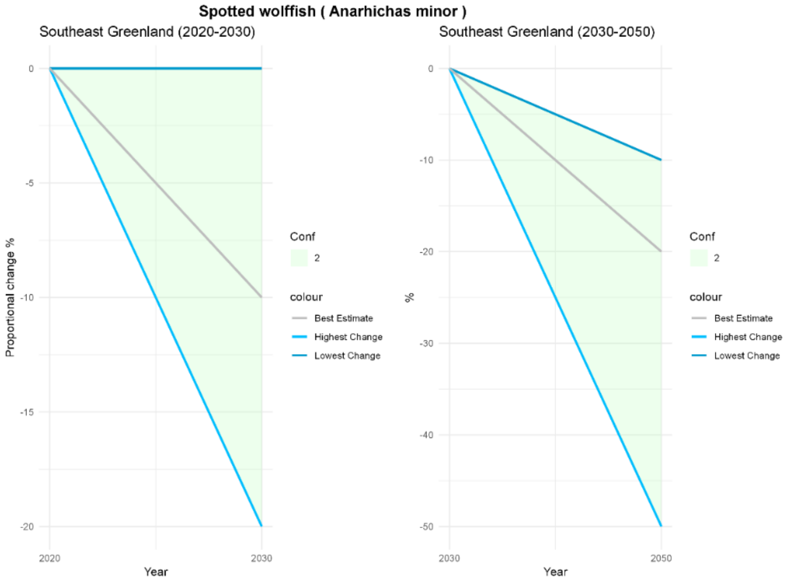


Figure 43. Experts estimated proportional change in spotted wolffish stocks in Southeast Greenland between 2020-2030 and 2030-2050.

37) Atlantic wolffish (*Anarhichas lupus*)

The population of Atlantic wolffish is expected to decline by 50% from 2030-2050, with a confidence level of moderate (Figure 44). The main factors contributing to this trend are environmental change, benthivorous feeding behaviour and specialisation and a low adaptive capacity.

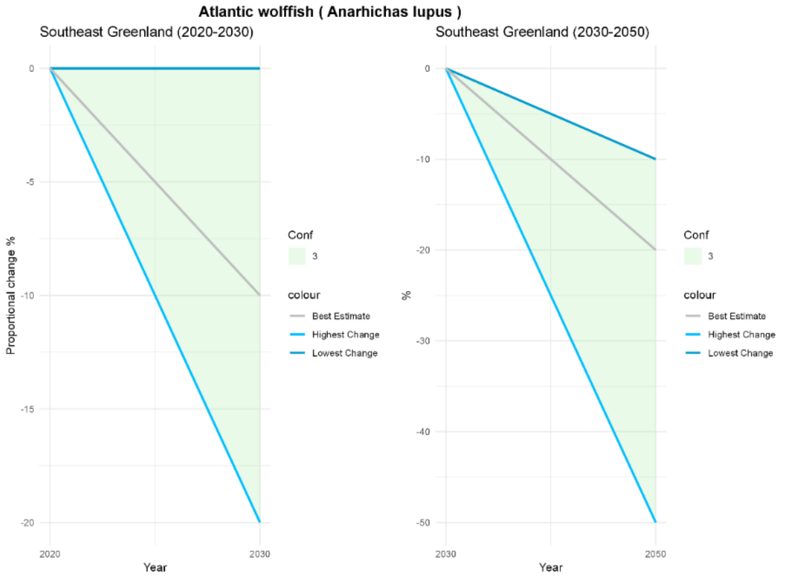


Figure 44. Experts estimated proportional change in Atlantic wolffish populations in Greenland between 2020-2030 and 2030-2050.

38) Thorny skate (*Amblyraja radiata*)

Thorny skate populations are expected to decline in Southeast Greenland (Figure 45). Habitat loss and temperature shifts negatively impact population stability. Confidence is moderate.

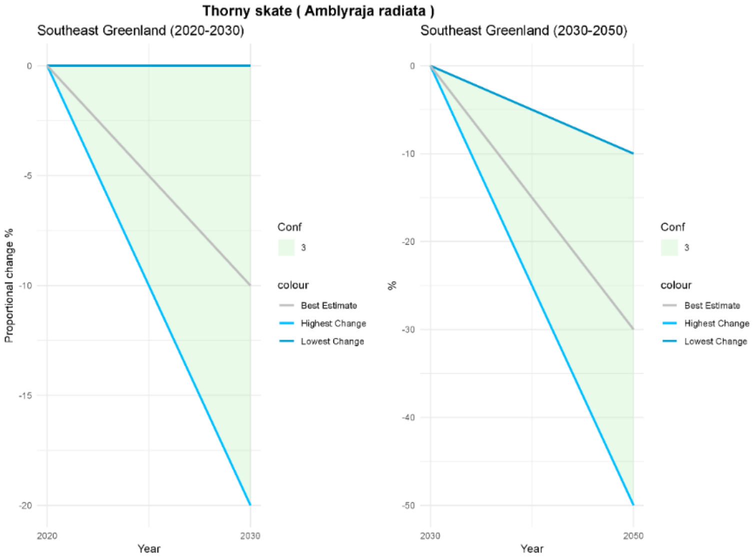


Figure 45. Experts estimated proportional change in Thorny skate stocks in Southeast Greenland between 2020-2030 and 2030-2050.

39) Cusk (*Brosme brosme*)

The population of Cusk is expected to increase by 2030 and 2050 due to temperature rise and environmental change, redistribution, and a generalist feeding behaviour and high adaptive capacity (Figure 46). The confidence level in this estimate is moderate.

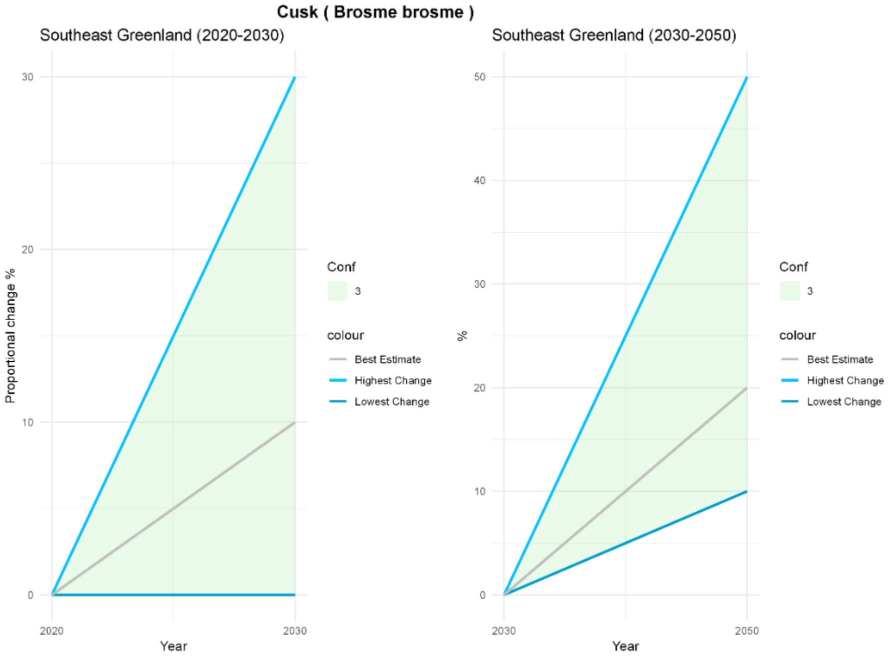


Figure 46. Experts estimated proportional change in Cusk stocks between 2020-2030 and 2030-2050.

6. Discussion

The available evidence reveals that the pressures on Arctic species are intensifying over time, particularly for ice-dependent taxa. The overall trend of accelerating declines in the 2030–2050 period compared to 2020–2030 emphasizes that even species that appear short-term stable, such as certain narwhal populations, face mounting long-term risks as sea ice loss and shifting ecological dynamics take hold. The stark numerical contrasts, for instance, the expected dramatic collapse of Atlantic cod stocks in the Norwegian Sea (–100% by 2050) versus significant gains in West Greenland (+75% by 2050), highlight that broad species-level trends can mask critical regional differences. Such variability is also evident within birds. While Canada geese in Greenland are projected to surge by up to +50% due to expanding breeding grounds and milder winters, other seabirds, like Thick-billed murres, suffer severe declines from combined pressures of illegal hunting and habitat loss.

This divergence points to a complex interplay of aspects driving these trends. Climate change, manifesting through sea ice loss, temperature increases, and altered prey dynamics, emerges as the primary stressor for many Arctic specialists. In contrast, boreal species appear to benefit initially from warming conditions, although this advantage may be countered by intensified human activities such as overfishing and habitat disturbance. Moreover, the differing trajectories within single species groups, for example, the mixed responses seen in Atlantic cod, Atlantic salmon, and various seal populations, suggest that regional environmental conditions, management practices, and local ecological interactions are critical determinants of future population viability. These findings highlight that, while the overall outlook is more negative for ice-dependent Arctic species, particularly as environmental pressures intensify over time, some Boreal and Arctic-boreal species benefit from warming conditions. Yet, the considerable variability, both regionally and among populations, emphasises that general trends mask critical local dynamics. This variability underscores the need for conservation and management strategies that are not only tailored to species’ ecological characteristics but also to the specific regional factors driving these population changes. Overall, these results emphasize the complex interplay between climate change and human activities in shaping species trajectories. Conservation strategies must account for these dynamics by addressing both direct human impacts, such as fisheries and industrial development, and broader environmental changes driven by climate shifts.

It is important to recognize that these findings are based on expert assessments rather than direct population measurements. Experts assigned threats based on their synthesized knowledge, including knowledge about existing projections, introducing a level of subjectivity. The findings with high confidence often reflect published studies. However, we also were able to derive estimates for some data-deficient populations, such as some seal populations or killer whales. Although this approach provides valuable insights into perceived drivers of change, assessments will benefit from integrating empirical data to validate and refine these assessments. By combining expert knowledge with the literature review and expert-rating, we aim to make more accurate predictions about species responses to future challenges, enabling policymakers and conservationists to implement more effective management strategies in the coming decades.

6.1. Temporal variability

Data show that short-term stability for many species masks more severe changes later. For example, one Atlantic cod population in the Norwegian Sea, Barents Sea, and North Sea is expected to shift from a best estimate of negative 50% expected change in 2020-2030 to negative 100% in 2030-2050. In contrast, another group in West Greenland rises from 10 to 75% change over the same periods. Similarly, trends among Atlantic salmon vary, with some populations moving from a positive 10 to negative 10% change and others improving from 25 to 60%. These differences indicate that population trajectories are not uniform over time. These findings extend beyond management to influence data collection and projection methods. Splitting assessments into multiple time frames captures species-specific trends more accurately than applying a simple linear assumption over extended periods. The consistent finding of steeper declines or more extreme changes in the 2030–2050 period across several groups underlines the urgency for targeted management actions that can address the anticipated intensification of environmental pressures.

6.2. Regional Differences

Species trends are highly specific to geographic regions. Polar bears in Kane Basin are projected to decline moderately, moving from an increase of 10% to neutral, while those in Baffin Bay are expected to decline from near neutral to a negative 15% change. Seabirds such as thick-billed murres and glaucous gulls also show significant declines in some regions but not others. The contrasting patterns observed also in the divergent trajectories of Atlantic cod and Atlantic salmon populations highlight that local environmental factors, regional climate or human pressures, or differences in management practices could be critical drivers behind these trends. This variability within and between species classifications calls for a more nuanced interpretation than a simple aggregated trend would suggest. Moreover, conservation efforts need to be designed with a focus on the individual population level, recognizing that species-level assessments might mask important underlying differences.

6.3. Drivers and Implications

Climate change is the primary driver, with sea ice loss and rising temperatures affecting ice-dependent species. Warming conditions benefit some Boreal taxa, allowing certain populations of Atlantic cod and Canada goose to increase by up to 50 per cent. However, human activities such as overfishing, vessel traffic, and habitat disturbance add further complexity. The combined effects of these drivers imply that environmental pressures will intensify over time, making it essential to develop conservation strategies that address both global climate trends and localized stressors.

6.4. Consistencies and Inconsistencies in Expert Assessments

Experts consistently identify climate change as the primary Arctic stressor with sea ice loss strongly affecting polar bears and seals. However, the average confidence levels were on average low to moderate, underscoring significant knowledge gaps across nearly all populations and species. Additionally, the confidence intervals for most species between highest and lowest estimate were high, highlighting a large uncertainty. Moreover, assessments diverge for species such as beluga whales and harp seals. Some experts note that harvest quotas help stabilize beluga populations while others predict declines driven by prey collapse. Among Boreal fish, warming is generally beneficial, yet regional discrepancies emerge. For example, Atlantic cod stocks in East Greenland are often viewed as resilient, with increases reaching up to 100 percent, whereas stocks in West Greenland and the Norwegian Sea may decline by up to 100 percent. Similar variability is evident in assessments of Atlantic salmon and the Greenland Barnacle Goose, the latter of which requires further refinement using consensus methods such as the Delphi approach. Moreover, these findings underscore the need to integrate multiple lines of evidence to achieve comprehensive and systematic trend assessments.

6.5. **Mechanisms of climate change for Arctic versu Boreal species**

Arctic specialists face compounding threats. Species such as polar bears and narwhals, which rely on stable ice ecosystems, have limited options as habitats fragment. Cold-adapted fish like Arctic char struggle against competition from invasive Boreal species, while seabirds experience declines as shifts in prey timing and availability undermine their survival. These mechanisms underscore the lower adaptive capacity of species that are closely tied to ice environments compared to more generalist species. Boreal species thrive where warming aligns with habitat flexibility. Cod and salmon expansions mirror historical shifts during past warm periods, but overfishing risks eroding gains. Waterfowl (geese, eiders) benefit from managed hunting and wetland expansion, though disease (avian flu) introduces volatility. These dynamics underscore human agency in moderating climate impacts through quotas and habitat protection.

6.6. **Regional management implications**

The pronounced regional disparities demand strategies that are tailored to local conditions. In Greenland, where a cod boom is evident, adaptive fisheries policies are needed to prevent overexploitation. In areas where narwhal habitats are impacted, implementing strict shipping regulations to reduce noise is critical. Although polar bear conservation ultimately depends on global carbon mitigation, local measures such as reducing mercury and other contaminants can provide immediate benefits.

6.7. **Limitations and Future Directions**

The findings are based on expert assessments, which inherently involve a level of subjectivity, particularly for species with limited data. Long-term monitoring and the integration of empirical data are essential to validate these projections. In the future, combining expert assessments with systematic literature reviews and Indigenous knowledge can enhance the accuracy of predictions and support the development of regionally sensitive conservation policies.

7. **Conclusion**

This synthesis of expert assessments highlights the Arctic’s ecological dichotomy where climate-resilient generalists are thriving while ice-dependent specialists face serious risk. Global warming and localized human activities interact to determine whether Arctic biodiversity stabilizes or moves toward irreversible loss. The findings emphasize the urgent need for conservation and management strategies that are tailored to local conditions rather than relying solely on aggregated species-level assessments. Regional management is essential to address these disparities. Moreover, the huge uncertainty on trend development across most species emphasises the need for more surveys. The evidence calls for targeted interventions such as adaptive fisheries management in Greenland’s cod fisheries, stricter shipping regulations in narwhal habitats, and focused habitat protection for ice-dependent species. Although expert assessments offer valuable insights into these complex dynamics, combining them with systematic literature reviews, long-term empirical data, and Indigenous knowledge will be crucial to refine projections and develop more effective, regionally sensitive conservation policies.

Literature:

1. Moussy, C. *et al.* A quantitative global review of species population monitoring. *Conservation Biology* **36**, e13721 (2022).
2. Taylor, J. J. *et al.* Arctic terrestrial biodiversity status and trends: A synopsis of science supporting the CBMP State of Arctic Terrestrial Biodiversity Report. *Ambio* **49**, 833–847 (2020).
3. Boertmann, D., Merkel, F. & Gilg, O. Seabird Breeding Colonies in East and North Greenland: A Baseline. *ARCTIC* **73**, 20–39 (2020).
4. Kovacs, K. M. *et al. State of the Arctic Marine Biodiversity Report (SAMBR) Update: 2021 State of the Arctic Marine Biodiversity Report (SAMBR) Update: Marine Mammals*. file:///C:/Users/dvj667/Downloads/210714%20CAFF-Marine%20Mammal%20LONG%202021%20vFINAL_compressed.pdf (2021).
5. Ugarte, F., Rosing-Asvid, A., Heide-Jørgensen, M. P. & Laidre, K. L. Marine Mammals of the Greenland Seas. in *Encyclopedia of the World's Biomes* 575–586 (Elsevier, 2020). doi:10.1016/B978-0-12-409548-9.12485-6.
6. Christie, A. P. *et al.* A practical conservation tool to combine diverse types of evidence for transparent evidence-based decision-making. *Conservat Sci and Prac* **4**, (2022).
7. IPCC. Summary for Policymakers. *In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. C* 1–41 (2021) doi:10.1260/095830507781076194.
8. IUCN. *IUCN Red List Categories and Criteria*. IUCN. iv + 32pp https://portals.iucn.org/library/sites/library/files/documents/RL-2001-001-2nd.pdf (2012).
9. IPBES. *The Methodological Assessment Report on SCENARIOS AND MODELS ECOSYSTEM SERVICES OF BIODIVERSITY AND ECOSYSTEM SERVICES SUMMARY FOR POLICYMAKERS*. (2016).
10. *Guidelines for Assessing Species' Vulnerability to Climate Change*. (IUCN International Union for Conservation of Nature, 2016). doi:10.2305/IUCN.CH.2016.SSC-OP.59.en.

11. Speirs-Bridge, A. *et al.* Reducing Overconfidence in the Interval Judgments of Experts. *Risk Analysis* **30**, 512–523 (2010).
12. Sutherland, W. J. *Transforming Conservation A Practical Guide to Evidence and Decision Making*. (UK: Open Book Publishers, Cambridge, 2022).
13. Soll, J. B. & Klayman, J. Overconfidence in Interval Estimates. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **30**, 299–314 (2004).
14. Teigen, K. H. & JØrgensen, M. When 90% confidence intervals are 50% certain: on the credibility of credible intervals. *Appl. Cognit. Psychol.* **19**, 455–475 (2005).
15. Linstone, H. A. & Turoff, M. The Delphi Method: Techniques and Applications. *Journal of Marketing Research* **13**, 317 (1976).
16. Thomas, C. D. *et al.* A framework for assessing threats and benefits to species responding to climate change. *Methods Ecol Evol* **2**, 125–142 (2011).
17. James, K. L., Randall, N. P. & Haddaway, N. R. A methodology for systematic mapping in environmental sciences. *Environ Evid* **5**, 7 (2016).