

Statistical Downscaling of CMIP6 Climate Projections in Areas of Interest - Part I: Marine Protected Areas of Canada's Three Oceans

Zeliang Wang, Erin McKee, Rick Danielson, Brendan DeTracey, Ellen Kenchington, Marc Skinner, Blair Greenan

Science Branch, Maritimes Region
Bedford Institute of Oceanography
Fisheries and Oceans Canada
1 Challenger Drive
Dartmouth, NS
B2Y 4A2

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1 Challenger Drive
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TABLE OF CONTENTS

Abstract	iv
Résumé.....	v
1. Introduction.....	1
2. Methodology and datasets	5
2.1 Datasets.....	5
2.2 Methodology.....	6
2.2.1 The Downscaling and Calibration Workflow.....	8
3. Evaluation of the Methodology	9
4. Results	13
4.1 The Gully MPA.....	13
4.2 Eastport MPA.....	16
4.3 Gilbert Bay MPA	19
4.4 Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA.....	22
4.5 Tang.ᑭwan – ᑲăċx ^w iqak – Tsigis MPA.....	26
4.6 SGáan Kínghlas-Bowie Seamount MPA.....	28
4.7 Anguniaqvia Niqiqyuam MPA.....	31
4.8 Tarium Niryutait MPA	34
4.9 Tuvaijuittuq MPA.....	37
5. Discussion	40
6. Conclusion	41
7. Acknowledgements	42
8. References	42
9. Appendix 1– Spatial Changes	47
10. Appendix 2– MPAs in the Maritimes	49

Abstract

Wang, Z., McKee, E., Danielson, R., DeTracey, B., Kenchington, E., Skinner, M., Greenan, B. 2026. Statistical Downscaling of CMIP6 Climate Projections in Areas of Interest – Part I: Marine Protected Areas of Canada’s Three Oceans. Can. Tech. Rep. Hydrogr. Ocean Sci. 423: v + 53p.
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To support marine conservation efforts, this study applied statistical downscaling and bias correction to a 22-member Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate model ensemble. Originally generated at ~ 100 km horizontal resolution, these models were refined to provide high-resolution ocean projections for Canada’s 14 Marine Protected Areas (MPAs) at the scale of ~ 8 km. By analyzing four emissions scenarios—SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5—we assessed potential changes in ocean temperature, salinity, mixed layer depth, and bottom currents over four time periods to 2099. These findings characterise the future oceanic conditions for the MPAs in Canada’s three oceans, offering precise insights into the climate-driven pressures facing their marine ecosystems. Both Sea Surface Temperature (SST) and Sea Bottom Temperature (BT) are projected to rise across all four climate scenarios for the 14 MPAs examined. The most significant increases are projected to occur under the SSP5-8.5 scenario during the final period (2080–2099). Surface salinity is projected to decline across all MPAs, while bottom salinity is projected to trend upward in Gully, Laurentian Channel, St. Anns Bank, and Musquash Estuary MPAs, indicating an increasing influence of subtropical waters for these areas. Under the SSP5-8.5 scenario by the end of the century, Banc-des-Américains, Basin Head and St. Anns Bank are projected to experience SST increases exceeding 5 °C. Similarly, St. Anns Bank and Banc-des-Américains are projected to see BT increases of more than 5 °C. Projections indicate no significant changes in bottom current strength which is important for benthic filter feeders in particular. However, a general shoaling in mixed layer depth, driven by rising temperatures and declining salinity, is projected for the MPAs, which may affect food supply to the benthos. Overall, MPAs in the Pacific region show lesser projected climate changes compared to those in the Atlantic and Arctic.

Résumé

Wang, Z., McKee, E., Danielson, R., DeTracey, B., Kenchington, E., Skinner, M., Greenan, B. 2026. Statistical Downscaling of CMIP6 Climate Projections in Areas of Interest – Part I: Marine Protected Areas of Canada's Three Oceans. Can. Tech. Rep. Hydrogr. Ocean Sci. 423: v + 53p.
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Afin de soutenir les efforts de conservation marine, cette étude a appliqué une méthode de réduction d'échelle statistique et de correction des biais à un ensemble de 22 modèles climatiques mondiaux du projet CMIP6 (Coupled Model Intercomparison Project Phase 6). Initialement générés à une résolution horizontale d'environ 100 km, ces modèles ont été affinés pour fournir des projections océaniques à haute résolution pour les 14 zones de protection marine (ZPM) du Canada, à l'échelle d'environ 8 km. En analysant quatre scénarios d'émissions – SSP1-2.6, SSP2-4.5, SSP3-7.0 et SSP5-8.5 – nous avons évalué les changements potentiels de la température, de la salinité, de la profondeur de la couche de mélange et des courants de fond de l'océan sur quatre périodes, jusqu'en 2099. Ces résultats caractérisent les conditions océaniques futures des ZPM situées dans les trois océans du Canada et offrent un aperçu précis des pressions exercées par le climat sur leurs écosystèmes marins. La température de la mer en surface et la température du fond de la mer) devraient augmenter dans les quatre scénarios climatiques pour les 14 ZPM étudiées. Les augmentations les plus importantes sont attendues dans le cadre du scénario SSP5-8.5 durant la période finale (2080-2099). La salinité de surface diminue dans toutes les ZPM, tandis que la salinité de fond tend à augmenter dans les ZPM du Gully, du chenal Laurentien, du banc de Sainte-Anne, et de l'estuaire de la Musquash, ce qui indique l'influence du Gulf Stream sur ces zones. Selon le scénario SSP5-8.5, d'ici la fin du siècle, les ZPM du Banc-des-Américains, de Basin Head, et du banc de Sainte-Anne devraient connaître des hausses de température de la mer en surface supérieures à 5 °C. De même, le banc de Sainte-Anne et Banc-des-Américains devraient enregistrer des hausses de température de fond supérieures à 5 °C. Les projections n'indiquent pas de changements significatifs dans l'intensité des courants de fond, un facteur particulièrement important pour les organismes filtreurs benthiques. Cependant, une diminution générale de la profondeur de la couche de mélange, due à la hausse des températures et à la baisse de la salinité, est prévue dans les ZPM, ce qui pourrait affecter l'apport alimentaire du benthos. En général, les zones de protection marine de la région Pacifique présentent des changements climatiques projetés moins importants que celles de l'Atlantique et de l'Arctique.

1. Introduction

Canada's vast and diverse oceanic territories—the Atlantic, Pacific, and Arctic—stand at the critical nexus of global climate change, acting as both a moderator and a receptor of these shifts. These oceans are profoundly impacted by short-term seasonal and year-to-year climate variability, as well as inexorable, long-term climate trends (Ahmed et al. 2021, Ford et al. 2018, Stadnyk and Déry 2021, Oceana Canada 2024, 2025). As global emissions of greenhouse gases continue, Canada's oceans absorb a massive proportion of this excess energy and gas (Talloni-Álvarez et al. 2019, Wilson et al. 2020). The absorption of heat leads to rising seawater temperatures and, through thermal expansion, contributes to global sea-level rise. Ocean warming is particularly pronounced in the Arctic, where it drives the dramatic decrease in summer sea ice extent. This warming also increases the frequency and intensity of destructive marine heatwaves. The absorption of carbon dioxide (CO₂) diminishes the ocean's CO₂ buffering capacity, lowering the pH and making the waters more acidic (Greenan et al. 2018). This change directly threatens calcifying organisms, such as shellfish, and pteropods, that form the base of many food webs. Warmer water holds less dissolved oxygen, and warming-induced stratification (the separation of water into layers) restricts the mixing of oxygen-rich surface water with deeper layers typically characterised with higher nutrient concentrations. This leads to the expansion of Oxygen Minimum Zones (OMZs), which can suffocate marine life. Ocean currents and large-scale mixing processes serve to redistribute the absorbed heat and carbon from the sea surface to deeper waters. This process, which can take decades or longer, ensures that the resulting physical and chemical changes will persist, leading to significant long-term stratification and altering the fundamental structure of the marine environment. Many marine species are responding to rising temperatures through shifts in their preferred depth and latitudinal distribution (Pinsky et al. 2013, Boyce et al. 2022, Czich et al. 2023, Lawlor et al. 2024, S. Wang et al. 2024). Furthermore, shifts in the phenology (the seasonal timing of biological events), such as earlier spawning or migration, are becoming common (Brickman and Shackell 2024). These rapid ecological changes present a major challenge to conservation. Since evidence of effective adaptation through evolutionary processes remains limited, these ongoing biological shifts may quickly render spatially-fixed protective measures (such as static Marine Protected Areas) less effective and misaligned with the future distribution of the species they were designed to safeguard.

Marine Protected Areas (MPAs) and Other Effective Area-based Conservation Measures (OECMs), which include sites like marine refuges, are cornerstone tools for achieving long-term biodiversity conservation benefits across species, habitats, and marine ecosystems. An MPA is formally defined as a discrete geographical area of the ocean that is legally designated, regulated, and managed to achieve the explicit long-term conservation of nature and associated ecosystem services. MPAs are established with a primary conservation objective(s). While they may permit certain current or future human activities, such activities are strictly controlled and permitted only if they are compatible with and do not compromise the specific ecological features and conservation outcomes for which the area was protected. An OECM is a geographically defined area other than an MPA, which is governed and managed in a way that achieves positive and sustained long-term outcomes for the *in situ* conservation of biodiversity, with associated ecosystem functions and services. MPAs are designated under *Canada's Oceans Act*, while OECMs (marine refuges) are designated under the *Fisheries Act*. The key distinction is that an OECM's primary purpose and management regime may differ significantly from those of an MPA. For example, an OECM may be established primarily for fisheries management, cultural

preservation, or military exclusion. Despite a non-conservation-based primary objective, OECMs may deliver durable conservation co-benefits by safeguarding important species, their habitats, and ecosystems, including ecologically significant or unique aggregations of species such as deep-sea corals and sponges. OECMs are intended to be permanent or in-place long-term, ensuring a sustained and lasting contribution to the overall goals of marine conservation; however, as they are designated under the *Fisheries Act*, they are regularly reviewed and can be readily adapted to changing conditions, giving a degree of flexibility to protected area network design that is not found in MPAs alone. Canada has committed to protect 30% of its marine and coastal areas by 2030 (referred to herein as Canada's Marine Conservation Target), contributing to the Convention on Biological Diversity Kunming-Montreal Global Biodiversity Framework.

The Coupled Model Intercomparison Project Phase 6 (CMIP6) constitutes the latest and most comprehensive effort by the global scientific community to understand and project Earth's climate system. CMIP6 (Eyring et al. 2016) is a vital framework for climate research, driving the assessments of the Intergovernmental Panel on Climate Change (IPCC). CMIP6 utilizes an advanced suite of Earth System Models (ESMs), which are complex numerical representations designed to simulate the intricate interactions between the Earth's key components: (1) Atmosphere - Modelling weather, circulation, and cloud processes; (2) Oceans - Simulating currents, heat uptake, and biogeochemical cycles; (3) Land Surface - Representing hydrology, vegetation, and carbon exchange; and, (4) Cryosphere - Incorporating ice sheets, glaciers, and sea ice dynamics. Building upon earlier phases, CMIP6 provides enhanced capabilities through higher spatial resolution, improved computational efficiency, and more sophisticated representations of key climate processes, such as aerosol-cloud interactions and the carbon cycle.

CMIP6 is organized around a set of Diagnosis, Evaluation, and Characterization of Klima (DECK) experiments (core simulations) and a collection of Model Intercomparison Projects (MIPs) that explore specific climate phenomena (e.g., historical forcings, clouds, ocean processes). The results collectively encompass a vast range of simulations: (1) Historical Simulations - Modelling past climate conditions from the pre-industrial era to the present, essential for model evaluation and attribution studies; and, (2) Future Projections - Simulating potential future climate change under various socio-economic and emissions trajectories.

A significant advancement over the previous CMIP5, which used Representative Concentration Pathways (RCPs), is CMIP6's introduction of a greater diversity of scenarios known as the Shared Socio-economic Pathways (SSPs). The SSPs describe five different ways the world might evolve in the absence of new climate policies, including demographic trends, economic development, and technological advancement (IPCC 2021). These SSPs are coupled with the climate outcomes (the forcing levels) to create a set of integrated scenarios. In this study, we focus on four scenarios (Table 1).

Table 1. Climate scenarios used in this study and their characterization.

Scenario Designation	SSP Narrative Description	Radiative Forcing (W/m²)	Climate Outcome
SSP1-2.6	Sustainable Development	2.6	Low forcing (aligned with 1.5 °C or 2.0 °C targets)

SSP2-4.5	Middle-of-the-Road	4.5	Intermediate forcing
SSP3-7.0	Regional Rivalry	7	High forcing
SSP5-8.5	Fossil-Fueled Development	8.5	Very high forcing (analogous to 'business-as-usual')

The numerical values (2.6, 4.5, 7.0, and 8.5) chosen for the scenarios capture a range of possible futures, and critically, they continue to refer to the global radiative forcing in Watts per meter squared (W/m^2). The values specify the level of warming pressure at the year 2100 relative to pre-industrial conditions.

CMIP6 models provide crucial SSP-forced climate simulations that are globally coherent and free-running (i.e., they operate without the integration of real-time observational data, also known as data assimilation). These global simulations are a fundamental basis for broad climate change impact assessments. A primary limitation of these global models is their relatively coarse spatial resolution (typically ~ 100 km grid spacing). This large scale is insufficient for assessing the detailed, localized impacts on oceanic and highly migratory species, coastal infrastructure, and regional ecosystem dynamics. Furthermore, every global climate model exhibits systematic biases when compared to observations (e.g., Z. Wang et al. 2024). These biases often stem from the parameterization of complex, fine-scale processes that the models cannot explicitly resolve.

To effectively assess local impacts, systematic adjustments are necessary, requiring the application of downscaling and bias correction approaches (e.g., Drenkard et al. 2021). Dynamical downscaling (DD) involves nesting a higher-resolution Regional Climate Model (RCM) within the coarser Global Climate Model (GCM) domain. The RCM uses the GCM output (e.g., atmospheric pressure, temperature) as its boundary conditions. DD is physically consistent and provides high-resolution future climate change signals, but it incurs a large computational cost comparable to running the global model and does not inherently include bias correction; as such, the systematic error from the GCM can propagate into the RCM. A computationally efficient alternative is to leverage advanced statistical methods, which often combine downscaling and bias correction into a single step. While CMIP6 models are free-running, high-resolution ocean reanalysis systems, such as GLORYS12 (Lellouche et al. 2021), do perform systematic data assimilation. This process integrates observations to produce an optimal estimate of the ocean state, making it an excellent reference or “ground truth” dataset for historical conditions. The cutting edge of the Neural Network (NN) Approach involves training the NN to learn the complex relationship (a mapping or parameterization) between the coarse-resolution CMIP6 model variables (predictors) and the corresponding high-resolution, bias-corrected variables from GLORYS12 (predictands) which have a horizontal resolution of $1/12^\circ$ (approximately 8 km). NNs offer good precision and efficiency by design (Danielson et al. 2025). They simultaneously address the scale mismatch (downscaling) and the systematic model error (bias correction). Once the parameterization is trained using historical data, it can be efficiently applied to the long-term SSP climate projections out to the year 2100. This allows for the assessment of local climate change impacts at a higher resolution and with significantly reduced systematic bias across the full ensemble of CMIP6 models. By design, these trained parameterizations are fixed in time in an attempt to preserve and maintain CMIP6 model trends after adjustment. Thus, they rely on the assumption of stationarity—that the relationship between the coarse GCM variables and the fine-scale local variables will remain the same under a future, warmer climate regime. An important consideration when interpreting the results of impact

assessments based on statistically downscaled projections is whether adjustments are designed to be stable and well-behaved (Maraun 2016).

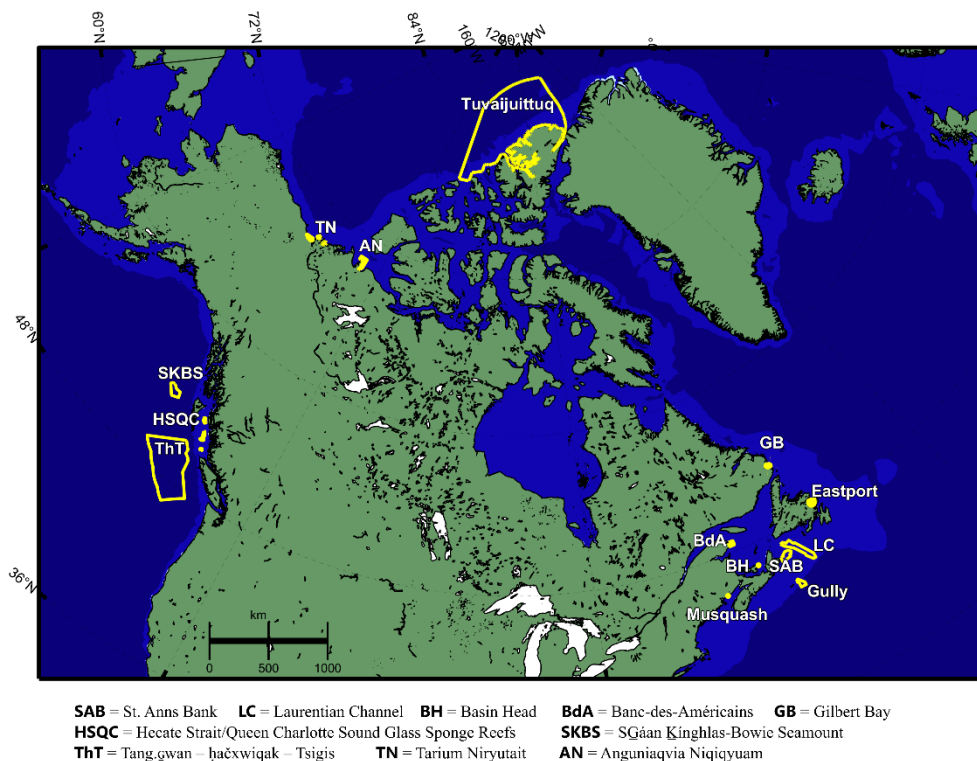


Figure 1. Map outlining the 14 MPAs in Canada as of January 2026.

There are currently 14 *Oceans Act* MPAs across Canada (Figure 1), comprising over 480,000 km² or roughly 8% of Canada's marine and coastal areas, contributing substantially toward the national conservation targets of protecting 25% of marine areas by 2025 and 30% by 2030 (DFO 2025a) (as of late 2024, Canada has conserved approximately 15.5% of its oceans through a combination of MPAs and OECMs (DFO 2025b)). McKee et al. (2025) applied a statistical downscaling approach to investigate the future ocean conditions for the six MPAs in the Maritimes. The current report provides similar projections for the 8 other MPAs in Canada's three oceans, and revisits the Gully MPA on the Scotian Shelf that was previously reported with an erroneous colour bar for salinity (McKee et al. 2025).

Building upon this foundation, the present study applies a similar downscaling methodology along with noise addition to further reduce bias to investigate climate-driven change across all MPAs. In Appendix 2, the projections for the MPAs in the Maritimes using the improved statistical downscaling approach are provided. This comprehensive expansion ensures a national assessment of MPA resilience, covering conservation sites situated in Canada's three distinct ocean regions: the Atlantic, Pacific, and Arctic Oceans.

2. Methodology and datasets

An ESM provides numerical simulations of coupled global biogeochemical and physical systems. Developing these models requires a sustained effort to refine individual components while simultaneously "tuning" the model as a whole. While model development is an iterative, and never truly finished process, ESM tuning typically involves balancing two goals: aligning with process-level knowledge (the underlying biogeochemistry and physics); and, matching emergent behavior (the observed historical outcomes).

While Schmidt et al. (2017) highlight both types of adjustments, either of which could take precedence, they can also be treated as formally complementary (Danielson et al. 2025). This synergy extends to post-simulation processing, in that downscaling and bias correction can be interpreted as complementary stages of model development and tuning (Balaji et al. 2022):

- Downscaling - Necessary because model resolution is inherently limited by computational power; endorsed by CMIP6 through initiatives like Coordinated Regional Climate Downscaling Experiment (Eyring et al. 2016).
- Bias Correction - Critical because, despite their complexity, CMIP6 models are not yet sufficiently constrained by observations to allow for direct use in high-resolution impact studies (Drenkard et al. 2021).

To bridge this gap, offline calibration—mapping CMIP6 simulations to high-resolution reanalysis data—offers a computationally efficient solution. This approach serves two primary functions:

- Parameterizing observational constraints based on the historical period.
- Projecting these constraints onto CMIP6 future scenarios through the year 2100.

2.1 Datasets

(1) CMIP6 Historical Simulations and Projections

The Sixth Phase of CMIP, coordinated by the World Climate Research Programme (WCRP), represents a monumental leap in climate modeling sophistication (Eyring et al. 2016). Central to this phase is the ScenarioMIP experiment, which provides a critical framework for future climate projections.

Under this initiative, numerous global modelling centers contributed historical simulations—constrained by observed natural and anthropogenic forcings—alongside ensemble projections extending to the year 2100. These projections are based on a diverse set of SSPs, representing different potential trajectories for greenhouse gas emissions and land-use changes (Table 1).

In a comprehensive analysis of these outputs, Z. Wang et al. (2024) evaluated an ensemble member from each of 22 distinct Earth System Models (ESMs). These datasets were sourced from the Earth System Grid Federation (ESGF; <https://esgf-node.llnl.gov/search/cmip6>), the primary global repository for standardized climate model data. Further details of these 22 ESMs are given by Z. Wang et al. (2024).

(2) GLORYS12 Reanalysis

The GLORYS12 (v1) product is a state-of-the-art global ocean and sea ice reanalysis, offering an eddy-resolving horizontal resolution of $1/12^\circ$ (approximately 8 km). Developed by Mercator Ocean International, it spans the altimetry era from 1993 to the present. The system employs a reduced-order Kalman filter to synthesize a comprehensive suite of observations into a physical model. This data assimilation includes:

- Satellite Data - Sea level anomalies, sea surface temperature, and sea ice concentration.
- *In-Situ* Profiles - Temperature and salinity data from platforms such as Argo floats and CTD casts (Lellouche et al. 2021, Mercator Ocean International 2022).

The utility of GLORYS12 is underscored by its ability to resolve fine-scale spatiotemporal features where observational density is often lacking. McKee et al. (2023) demonstrated that GLORYS12 bottom temperatures align closely with both *in-situ* observations. This fidelity extends northward; while previous iterations showed consistency with flows along the Labrador Shelf (Wang and Greenan 2013). Andres et al. (2024) successfully utilized GLORYS12 to track the downstream evolution of the Cold Intermediate Layer, filling critical gaps in sparse observational records.

Furthermore, a comparative study of eight reanalyses along the U.S. east coast by Castillo-Trujillo et al. (2023) identified GLORYS12 as a top performer in capturing the Gulf Stream’s mean position and variance. Beyond surface dynamics, the reanalysis maintains high skill at depth—a result of its superior bathymetric representation at high resolution, which ensures that vertical water column properties remain consistent with subsurface observations.

To maintain high observational consistency, GLORYS12 applies strategic adjustments to both its atmospheric forcing and its internal predictive components (Lellouche et al. 2021). Forcing variables, specifically precipitation and radiative fluxes, are corrected toward satellite-derived observations. Simultaneously, the model's prognostic tendencies are nudged via a three-dimensional variational (3DVar) analysis to minimize large-scale biases in temperature and salinity.

The GLORYS12 reanalysis exploits the principle that emergent, observed behaviors can be used to systematically constrain a model's inputs, internal predictions, and final outputs. Consequently, GLORYS12 serves as an ideal calibration reference. Because both GLORYS12 and the ocean component of the CMIP6 ensemble are governed by the same fundamental physical laws, the observational constraints applied to the reanalysis provide a realistic benchmark for the CMIP6 models. While this study focuses specifically on adjusting CMIP6 ocean model outputs, the underlying physical constraints bridge the gap between the two distinct modeling frameworks.

2.2 Methodology

We conceptualize each NN in this study as a spatially local parameterization designed to map coarse CMIP6 climate model outputs to the high-resolution GLORYS12 reanalysis. By utilizing a compact architecture of only 39 free parameters, each network remains computationally efficient and easy to train. However, this fixed, *ad hoc* structure means that the trained weights at individual

nodes function as statistical "black boxes" and do not necessarily correspond to specific physical oceanographic processes.

This calibration is applied independently to six key variables: sea surface temperature (SST), bottom temperature (BT), sea surface salinity (SSS), bottom salinity (BS), mixed layer depth (MLD), and bottom current speed. To provide a robust consensus of future projections and mitigate individual model bias, we employ an ensemble of the 22 CMIP6 models cited above. The data flow of the methodology can be found in Figure 2.

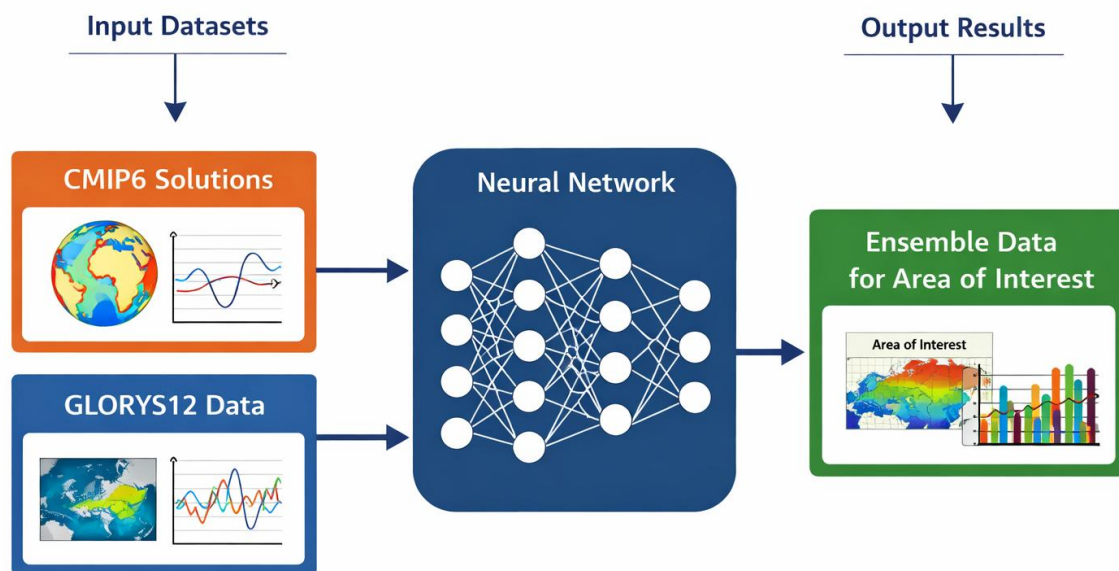


Figure 2. Data flow chart for the generation of high-resolution climate projection data for the areas of interest.

While we applied the statistical downscaling approach from McKee et al. (2025) to Arctic MPAs, the method proved unsuccessful. Significant discrepancies between GLORYS12 data and CMIP6 projections—driven by localized sea-ice formation and dense water production—resulted in numerical instability within the neural network. To improve the performance of the statistical downscaling approach used in McKee et al. (2025), Gaussian noise is introduced to bridge the gap in variability between the CMIP6 and GLORYS12 datasets. Neural network adjustments are performed at each grid point and adding noise ensures that adjustments are made specifically where CMIP6 variability is low relative to GLORYS12 (or vice versa). Following von Storch (1999), the methodology prioritizes adding variance in one dataset over scaling down all variations in another, including the important physical variations that a neural network needs to be trained on. Large differences can lead to unstable neural network training. Introducing noise prevents the model from attempting to train a massive change in variance, resulting in more consistent and predictable outputs. While the local impact is most pronounced, the stabilization of individual grid boxes ensures that the broader MPA-average trends remain robust and reliable by design.

2.2.1 The Downscaling and Calibration Workflow

The transition from coarse-resolution CMIP6 (~100 km) to the refined GLORYS12 grid (~8 km) follows a rigorous five-step pipeline:

Regridding and Climatology

Step 1: Monthly data from all 22 CMIP6 models are interpolated onto the high-resolution GLORYS12 grid.

Step 2: Monthly climatologies are calculated for both GLORYS12 and the CMIP6 models over the historical reference period (1993–2014).

Initial Bias Correction

Step 3: Preliminary correction is performed based on the variable type:

- MLD and bottom current speed - A multiplicative correction factor is derived from the ratio of GLORYS12 to CMIP6 historical simulations and then applied to future scenarios.
- SST, BT, SSS, and BS - An additive anomaly method is used. Monthly CMIP6 anomalies are calculated relative to their own climatology and then superimposed onto the GLORYS12 climatology.

Neural Network Downscaling

Step 4: A localized NN is trained for every model, variable, and grid box.

- Architecture - Each NN consists of 3 input nodes (monthly, centered one-year, and multiyear one-month averages), a hidden layer of four nodes, and 3 output nodes, totaling 39 parameters.
- Training - Networks are trained on historical data (1993–2014) using CMIP6 as input and GLORYS12 as the ground-truth target. Gaussian noise is now added prior to training as this improves the temporal stability of the resulting neural networks, and in turn, the spatial coherence of MPA adjustments.
- Noise addition: the primary reason for adding noise is to bridge the gap in variability between the CMIP6 and GLORYS12 datasets.
 - (a) Grid point-Level Precision - Neural network adjustments are performed at each grid point; adding noise ensures that downscaling is corrected specifically where CMIP6 variability is low relative to GLORYS12 (or vice versa).
 - (b) Adherence to Statistical Rationale - Following von Storch (1999), the methodology prioritizes adding variance over removing or scaling it down, as the latter lacks a sound physical basis for this type of statistical downscaling.
 - (c) Neural Network Robustness - Large differences in variance between datasets often lead to unstable neural network training. Introducing noise prevents the model from attempting to "train" a massive change in variance, resulting in more consistent and predictable outputs.
 - (d) Aggregate Stability - While the local impact is most pronounced, the stabilization of individual grid boxes ensures that the broader MPA-average trends remain robust and reliable by design.

- Projection - The trained models are applied to CMIP6 data for 2015–2099. This process injects the high-resolution spatial structure of GLORYS12 while strictly preserving the underlying climate trends of the original CMIP6 models (Maraun 2016).

Temporal Analysis

Step 5: Finally, we calculate bi-decadal means and climatologies across four future time windows:

- P1: 2020–2039
- P2: 2040–2059
- P3: 2060–2079
- P4: 2080–2099

For each MPA, a spatial domain was selected that included the MPA and surrounding waters such that the spatial extent of the analyses was rectangular. For the Eastport and Gilbert Bay MPAs in the Newfoundland and Labrador bioregion, their locations were too close to the coast and outside of the model domains used for the method. As a result the Eastport (Round Island) MPA could not be assessed and the Gilbert Bay MPA was assessed using summary statistics from a reduced number of cells (see below). This also occurred in the Anguniaqvia Nqiqyuam MPA in the western Arctic, where portions of the MPA were not included in the assessment, while additional area outside of the MPA was. None of the three areas of the Tarium Niryutait Marine Protected Area (TN MPA) could be fully assessed, also due to proximity to shore. In particular, the most easterly MPA had very little supporting data. The three protected areas there were analyzed as one unit with most of the data used for the assessment coming from an area outside of the MPAs to the northwest. In the case of the Pacific’s Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area (HS/QCS MPA), the three MPAs were assessed together in the summary tables.

3. Evaluation of the Methodology

In this section, we demonstrate the performance of our methodology using three MPAs: the Gully in the Atlantic, the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs in the Pacific, and Anguniaqvia Nqiqyuam in the Arctic. Figures 3, 4, and 5 illustrate the improvements achieved for each respective site. Prior to applying the methodology, the performance of the CMIP6 ensembles—covering sea surface temperature, salinity, mixed layer depth, and bottom conditions—varied significantly both within and across the MPAs. Following the application of our approach, the CMIP6 ensembles align closely with GLORYS12 data across all six variables and all three regions. It should be noted that the strong inter-annual variations present in GLORYS12 are not reflected in the CMIP6 ensembles, as the ensemble process prioritizes long-term trends and inherently filters out inter-annual variability.

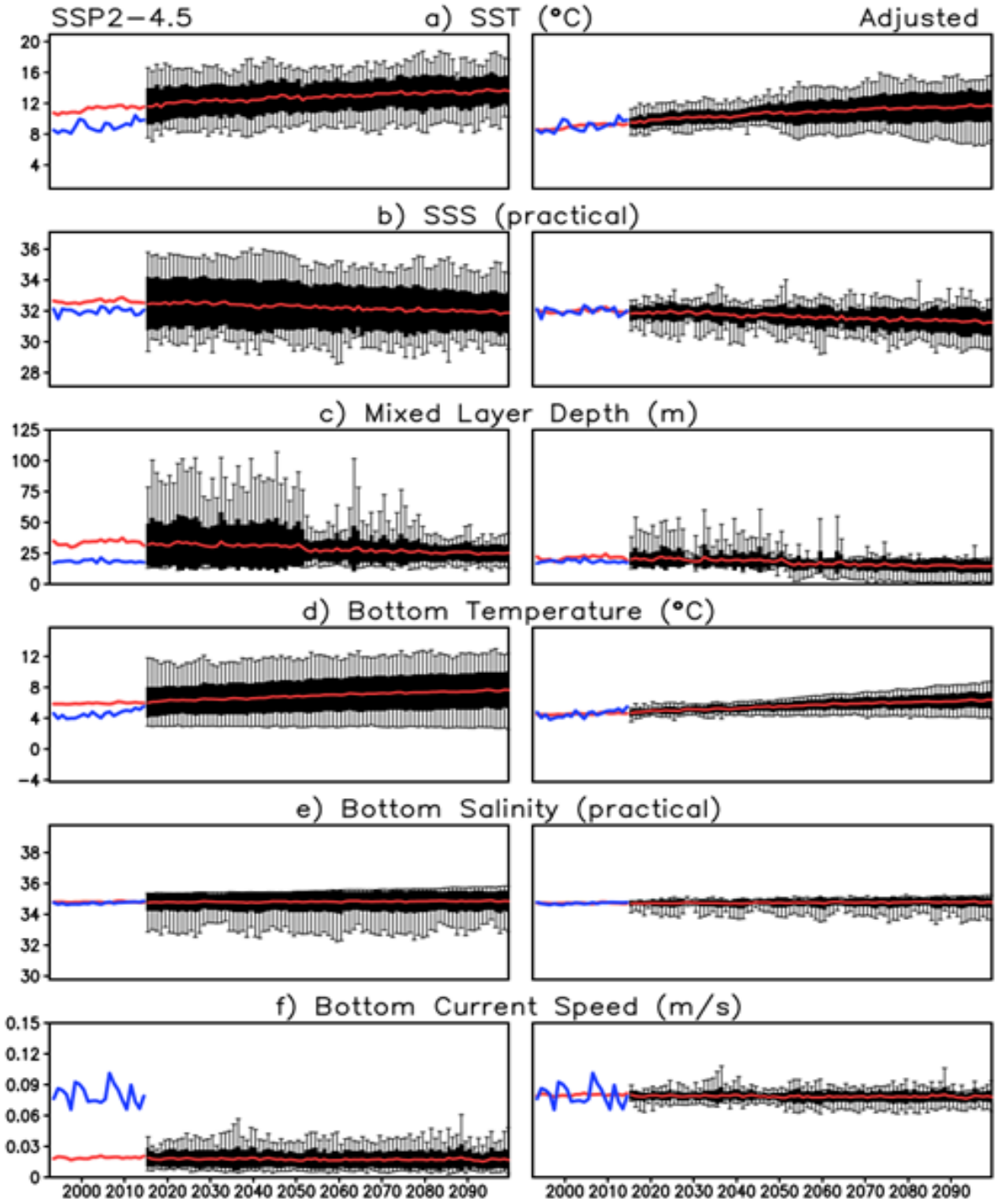


Figure 3. Gully MPA: Timeseries of a) sea surface temperature (SST), b) sea surface salinity (SSS), c) mixed layer depth, d) bottom temperature, e) bottom salinity, and f) bottom current speed for the historical period (1993-2014) from GLORYS12 (blue) and the ensemble average of 22 CMIP6 solutions (red) and SSP2-4.5 projections (2015-2099). Shading is one standard deviation above and below the average and maxima and minima of the 22 CMIP6 solutions are indicated by bar plots. Left panels are the raw CMIP6 data and right panels are the neural-network adjusted data.

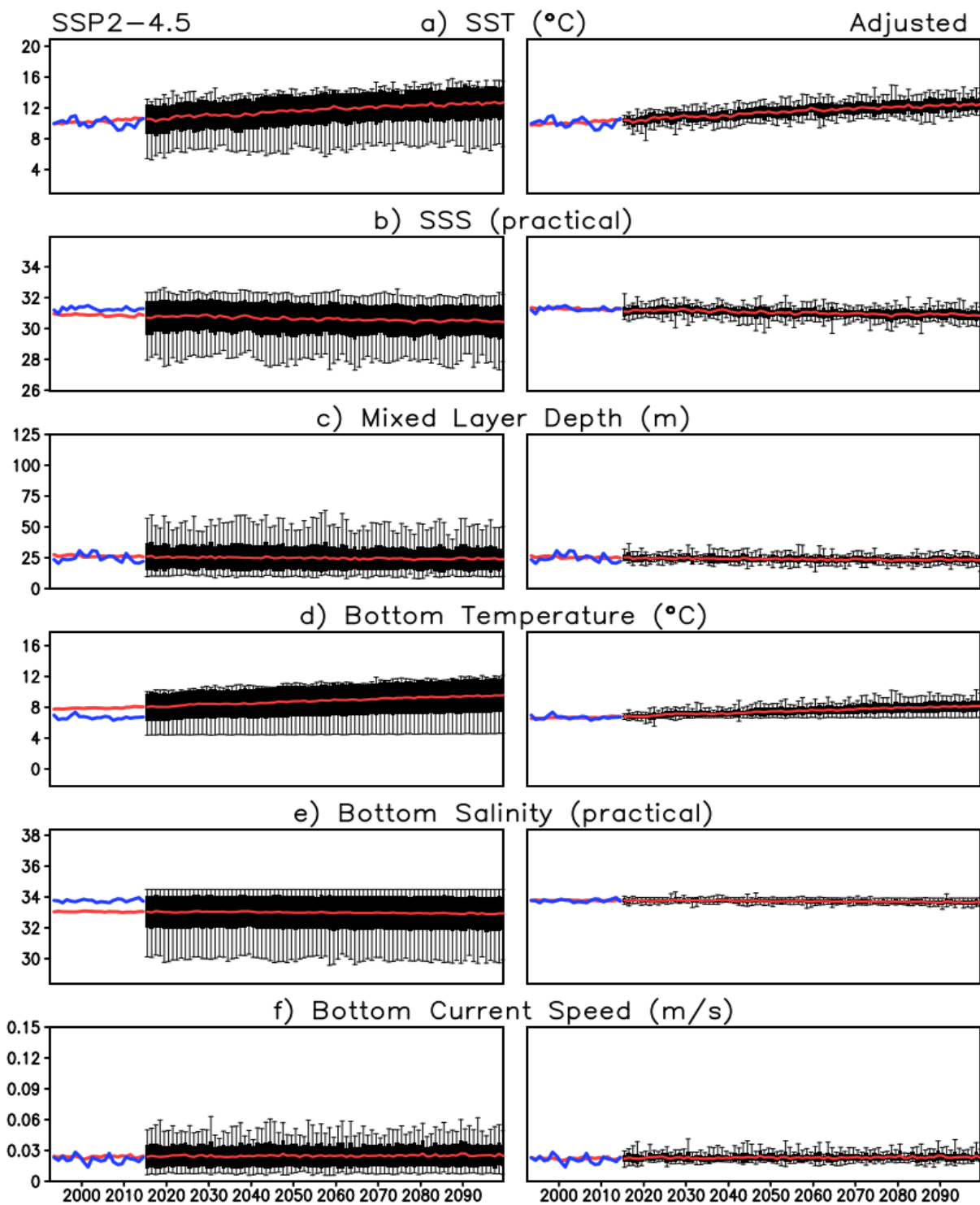


Figure 4. Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA: Timeseries of the sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth, bottom temperature, bottom salinity, and bottom current speed for the historical period (1993-2014) from GLORYS12 (blue) and the ensemble of 22 CMIP6 solutions (red) and projections (2015-2099). Maximum and minimum of the 22 CMIP6 solutions are indicated by bar plots. Left panels: raw data; right panels: neural-network processed data (red).

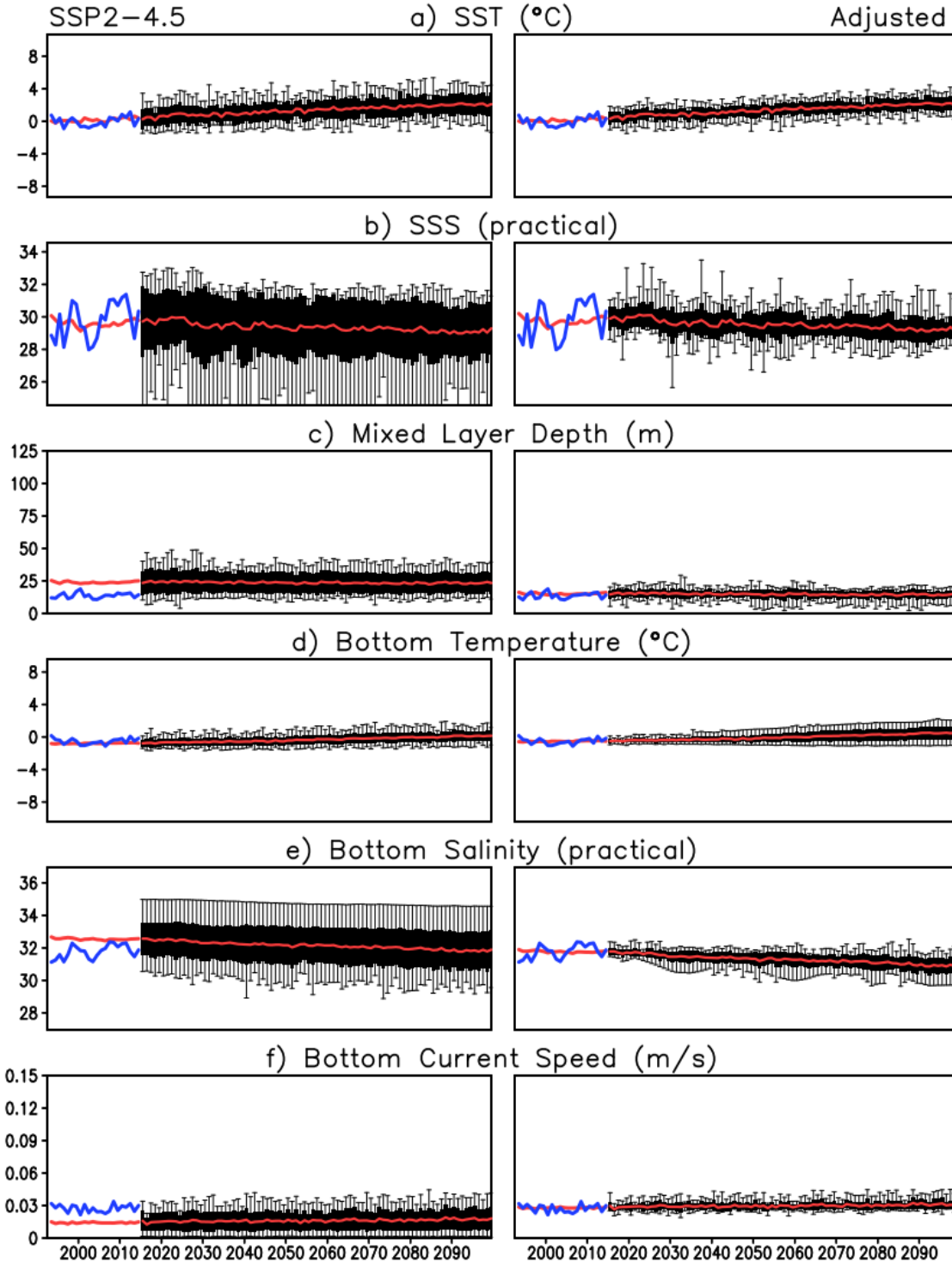


Figure 5. Anguniaqvia Nqiqyuam MPA: Timeseries of the sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth, bottom temperature, bottom salinity, and bottom current speed for the historical period (1993-2014) from GLORYS12 (blue) and the ensemble of 22 CMIP6 solutions (red) and projections (2015-2099). Maximum and minimum of the 22 CMIP6 solutions are indicated by bar plots. Left panels: raw data; right panels: neural-network processed data (red).

4. Results

In this section, we present the results of Methods Steps 1-5, focusing on how future projections differ from the current conditions, represented by the GLORYS12 hindcast. These differences are assessed using bi-decadal means. While MLD and bottom current speed are not depicted in the figures, analysis of these variables was conducted, and the results are presented in the tables in this section. Figures show maps for projections under SSP2-4.5 during 2040-2059.

4.1 The Gully MPA

The Gully MPA is located to the east of Nova Scotia's Sable Island, covering an area of approximately 2,363 km², accounting for 0.04% of the total coverage of the marine conservation targets. The Gully is the largest underwater canyon in the western North Atlantic. Its ecosystem includes shallow sandy banks, a deep-water canyon with feeder canyons incising the steep slopes, and portions of the continental slope and abyssal plain, providing habitat for a wide diversity of species (DFO 2022) (see [The Gully MPA](#)). The Gully's size, shape, and location affect currents and local circulation patterns (Shan et al. 2014).

A CMIP6 model resolution of 1° requires about one cell to cover the Gully MPA region, and after the statistical downscaling to the GLORYS12 grid (Figure 6b), 99 cells are employed. Figure 6 presents maps of the bi-decadal average surface and bottom temperature and salinity conditions for the Gully MPA during the 2040-2059 period under the SSP2-4.5 climate scenario. Also included is a map of the GLORYS12 climatology for temperature (1993-2014)(Figure 6c). Bar plots in the bottom panels (Figure 6d) illustrate how each climate scenario deviates from that climatology in 20-year periods (corresponding values are provided in Table 2). Figure A1 (Appendix 1) presents the spatial temperature changes for the Gully MPA for all of the projected SSPs and periods.

The Gully: SSP2-4.5 2040-2059

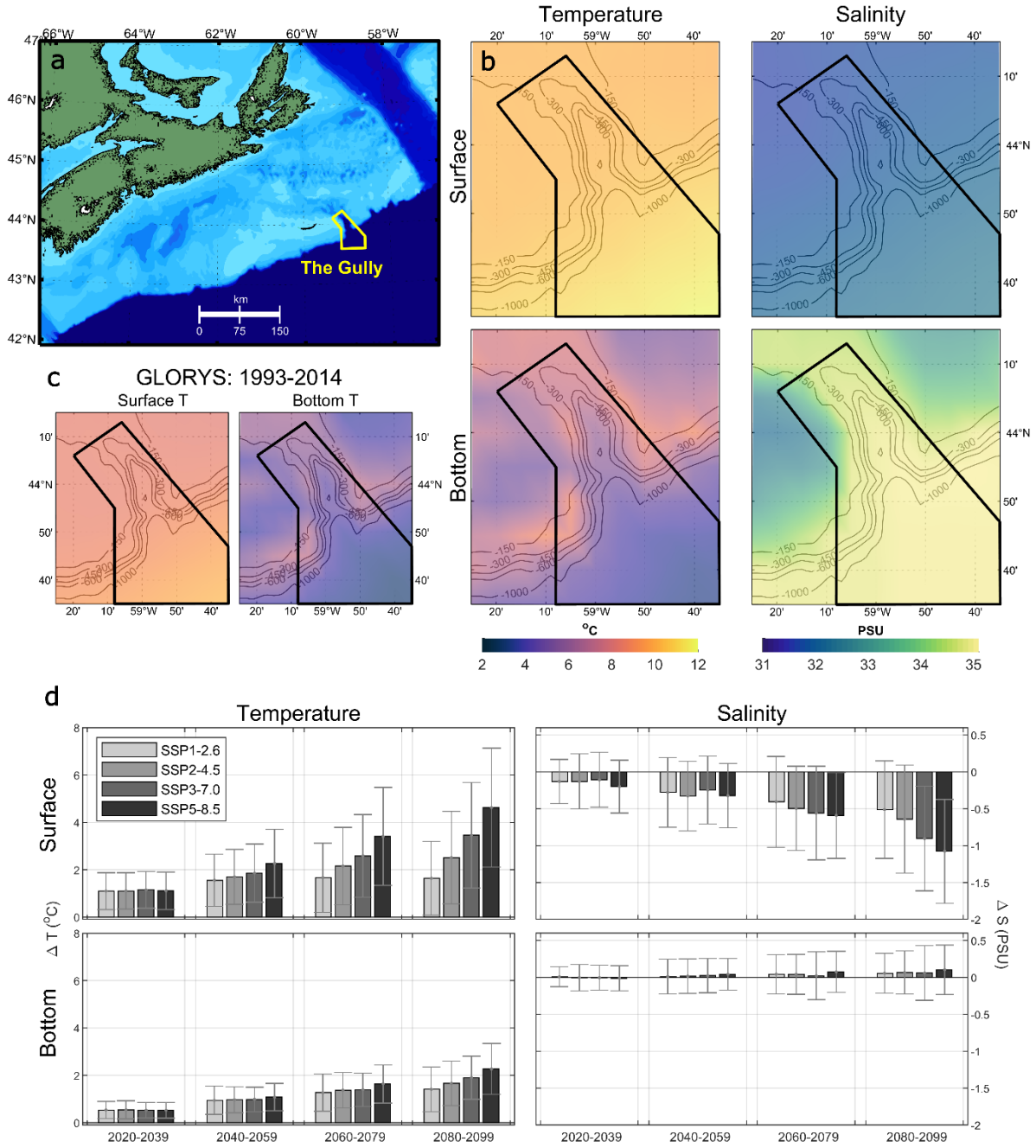


Figure 6. Projected values of temperature and salinity in the Gully MPA and surrounding area. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the

ensembled 22 CMIP6 models. The contours in (b) and (c) are bathymetry and the shading is temperature in °C and salinity in PSU, with a colour bar below.

Table 2. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Gully MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.10 $\pm$ 0.78	1.55 $\pm$ 1.10	1.66 $\pm$ 1.46	1.64 $\pm$ 1.56
	SSP2-4.5	1.10 $\pm$ 0.77	1.70 $\pm$ 1.16	2.15 $\pm$ 1.63	2.51 $\pm$ 1.95
	SSP3-7.0	1.15 $\pm$ 0.78	1.86 $\pm$ 1.22	2.58 $\pm$ 1.74	3.46 $\pm$ 2.23
	SSP5-8.5	1.11 $\pm$ 0.79	2.26 $\pm$ 1.44	3.40 $\pm$ 2.07	4.62 $\pm$ 2.51
BT (°C)	SSP1-2.6	0.53 $\pm$ 0.37	0.94 $\pm$ 0.60	1.27 $\pm$ 0.79	1.41 $\pm$ 0.94
	SSP2-4.5	0.54 $\pm$ 0.38	0.97 $\pm$ 0.55	1.37 $\pm$ 0.75	1.66 $\pm$ 0.94
	SSP3-7.0	0.52 $\pm$ 0.32	0.98 $\pm$ 0.51	1.39 $\pm$ 0.70	1.90 $\pm$ 0.91
	SSP5-8.5	0.52 $\pm$ 0.33	1.08 $\pm$ 0.58	1.63 $\pm$ 0.81	2.27 $\pm$ 1.08
SSS (PSU)	SSP1-2.6	-0.13 $\pm$ 0.30	-0.28 $\pm$ 0.47	-0.41 $\pm$ 0.61	-0.51 $\pm$ 0.66
	SSP2-4.5	-0.13 $\pm$ 0.37	-0.33 $\pm$ 0.47	-0.50 $\pm$ 0.57	-0.64 $\pm$ 0.73
	SSP3-7.0	-0.11 $\pm$ 0.37	-0.24 $\pm$ 0.46	-0.56 $\pm$ 0.64	-0.90 $\pm$ 0.71
	SSP5-8.5	-0.20 $\pm$ 0.36	-0.32 $\pm$ 0.44	-0.59 $\pm$ 0.58	-1.08 $\pm$ 0.70
BS (PSU)	SSP1-2.6	0.01 $\pm$ 0.13	0.01 $\pm$ 0.24	0.04 $\pm$ 0.27	0.06 $\pm$ 0.27
	SSP2-4.5	-0.00 $\pm$ 0.18	0.02 $\pm$ 0.23	0.04 $\pm$ 0.27	0.07 $\pm$ 0.29
	SSP3-7.0	-0.00 $\pm$ 0.17	0.03 $\pm$ 0.23	0.02 $\pm$ 0.32	0.06 $\pm$ 0.37
	SSP5-8.5	-0.01 $\pm$ 0.17	0.04 $\pm$ 0.21	0.07 $\pm$ 0.28	0.10 $\pm$ 0.34
MLD (m)	SSP1-2.6	1.17 $\pm$ 5.15	-1.13 $\pm$ 2.36	-1.75 $\pm$ 4.88	-2.55 $\pm$ 4.74
	SSP2-4.5	1.69 $\pm$ 5.06	-0.30 $\pm$ 2.61	-2.31 $\pm$ 3.92	-3.59 $\pm$ 5.06
	SSP3-7.0	2.82 $\pm$ 8.17	-0.41 $\pm$ 3.14	-3.01 $\pm$ 3.26	-4.56 $\pm$ 4.81
	SSP5-8.5	1.13 $\pm$ 5.34	-1.71 $\pm$ 2.84	-3.79 $\pm$ 4.63	-5.28 $\pm$ 5.17
Bottom Current Speed (m/s)	SSP1-2.6	-0.0010 $\pm$ 0.0028	-0.0024 $\pm$ 0.0039	-0.0021 $\pm$ 0.0044	-0.0018 $\pm$ 0.0043
	SSP2-4.5	-0.0008 $\pm$ 0.0032	-0.0016 $\pm$ 0.0042	-0.0017 $\pm$ 0.0050	-0.0015 $\pm$ 0.0046
	SSP3-7.0	-0.0002 $\pm$ 0.0029	-0.0012 $\pm$ 0.0036	-0.0014 $\pm$ 0.0044	-0.0017 $\pm$ 0.0047
	SSP5-8.5	-0.0010 $\pm$ 0.0030	-0.0017 $\pm$ 0.0042	-0.0018 $\pm$ 0.0051	-0.0018 $\pm$ 0.0053

SST increases by about 1 °C from present conditions in P1, with only small differences among the SSPs (Table 2). Larger increases occur under higher-emission scenarios in later periods. In SSP5-8.5, SST rises by over 2 °C in P2 and reaches approximately 3.4 °C and 4.6 °C above present conditions by P3 and P4, respectively. As projections approach 2100, differences among scenarios become more pronounced, with all scenarios showing continued warming. In contrast, SSP1-2.6 stabilizes by P3, with little change between P3 and P4.

BT (Table 2) follows a similar pattern. In P1, bottom temperature increases by less than 1 °C, with minimal differences among scenarios. Warming intensifies over time, particularly under SSP5-8.5, which shows the largest increase across all periods, exceeding 2 °C by P4. This scenario also shows the greatest increase in P2 (just over 1 °C). After P1, bottom temperature increases progressively from one period to the next for all scenarios.

In terms of SSS (Table 2), changes are small in P1, with little difference among SSP1-2.6, SSP2-4.5, and SSP3-7.0. By P2, SSP5-8.5 shows the largest decrease in salinity, while SSP3-7.0 shows the smallest change. In P3, the largest decreases occur under SSP3-7.0 and SSP5-8.5, whereas SSP1-2.6 shows the smallest decline. By P4, SSP5-8.5 shows a decrease of just over 1 PSU relative to present conditions. Overall, all scenarios exhibit a trend toward lower salinity, with differences among scenarios becoming more evident over time.

BS (Table 2) remains relatively stable across all periods, with only slight increases in P3 and P4. These small net changes likely reflect opposing patterns in different depths of the ocean, where deeper areas become saltier while shallower regions become fresher. By P4, the largest increases occur under SSP5-8.5 (about 0.10 PSU), though differences among scenarios remain minor.

For MLD (Table 2), values generally become more negative over time, indicating a shallowing mixed layer. The largest change occurs under SSP5-8.5 in P4, where MLD is more than 5 m shallower than present conditions. SSP1-2.6 shows the smallest range of changes from P1-P4. In P2, SSP2-4.5 exhibits the smallest change (approximately -0.3 m).

Finally, the bottom current speed (Table 2) remains relatively stable throughout all periods and scenarios, showing minimal change.

Spatial variability in BT in P2, SSP2-4.5 (Figure 6b) shows cooler water in the deeper parts of the canyon below 800 m and in portions of the western shelf. Bottom salinity is fresher on the banks than in the canyon. In contrast spatial variations in SST and SSS are less pronounced.

4.2 Eastport MPA

Located in the Newfoundland-Labrador Shelves Bioregion (DFO 2009), along the northeast coast of Newfoundland, the Eastport MPA is comprised of two geographically distinct “no-take” zones around Round Island and Duck Island. Together, these closures cover approximately 2.1 km² of marine habitat and contribute less than 0.01 % toward Canada’s national marine conservation targets. The Eastport MPA was established at the request of local harvesters and community stakeholders as part of a broader lobster conservation initiative, aimed at maintaining a viable population of American lobster by conserving, protecting, and supporting the sustainable use of key lobster resources and habitat within the surrounding 400 km² Eastport Peninsula Lobster Management Area, as well as ensuring the conservation and protection of threatened or endangered species in the area. The surrounding waters support a diverse marine ecosystem, including groundfish, pelagic fish, shellfish, marine mammals, and aquatic vegetation. Long-term monitoring indicates improvements in lobster size structure and population metrics associated with protective measures and community-led stewardship efforts (see [Eastport MPA](#)).

Figure 7b presents the bi-decadal averages for SST, BT, SSS, and BS for the Eastport MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. The Round Island MPA was not included because it is not covered in the GLORYS12 model data. As the Eastport MPA is small, maps and statistics report for the larger surrounding marine area shown in Figure 7c. Also included is a GLORYS12 climatology (1993–2014)(Figure 7c). Bar plots in the bottom panels (Figure 7d) illustrate

how each climate scenario deviates from that climatology in 20-year periods, with corresponding values provided in Table 3.

SST (Table 3) increases across all periods and SSP scenarios, with the magnitude of warming intensifying toward P4 and under higher-emissions pathways. In P1, SST changes are relatively uniform across scenarios (~ 0.8 – 1.0 °C). By P2–P4, differences among SSPs become more pronounced, with SSP5-8.5 consistently showing the largest increase, rising to nearly 5 °C by P4. Intermediate scenarios (SSP2-4.5 and SSP3-7.0) exhibit progressively larger warming than SSP1-2.6, which remains below ~ 1.5 °C throughout.

BT (Table 3) follows a similar but more constrained pattern. Changes are modest in P1 (~ 0.3 – 0.4 °C) and remain nearly constant under SSP1-2.6 across all periods. Higher-emissions scenarios show steadily increasing BT, with SSP5-8.5 reaching the largest increase in P4 (~ 2.6 °C). SSP3-7.0 and SSP2-4.5 display intermediate warming, indicating an increasing divergence among scenarios after P2.

SSS (Table 3) decreases in all periods and scenarios, indicating a freshening trend. In P1, changes are small and similar across SSPs (around -0.2 to -0.25 PSU). From P2 onward, salinity declines intensify, particularly under higher-emissions scenarios. SSP5-8.5 shows the greatest decrease in each period, reaching approximately -1.5 PSU in P4, while SSP1-2.6 consistently exhibits the smallest magnitude of change.

BS (Table 3) also declines across all periods and scenarios, though the magnitude is generally smaller than at the surface. Differences among SSPs are minimal in P1, but become more distinct by P4, where SSP5-8.5 and SSP3-7.0 show the largest freshening (approaching -1.0 PSU). SSP1-2.6 remains the least changed across all periods.

MLD (Table 3) generally shoals over time, with the strongest reductions occurring under higher-emissions scenarios. Changes are small and variable in P1, but from P2 onward, all scenarios trend toward a shallower mixed layer. SSP1-2.6 shows relatively minor decreases (less than -1 m by P4), whereas SSP5-8.5 exhibits the largest reduction, exceeding -3 m in P4. SSP3-7.0 and SSP2-4.5 display intermediate shoaling. Bottom current speed (Table 3) shows minimal change across all periods and scenarios.

Spatial variability in surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059 is subtle over the model extent and very limited within the Eastport MPA (Figure 7c). The greatest spatial variability is seen in bottom salinity which shows a weak gradient with more saline water to the south and fresher water to the north (Figure 7c).

Eastport: SSP2-4.5 2040-2059

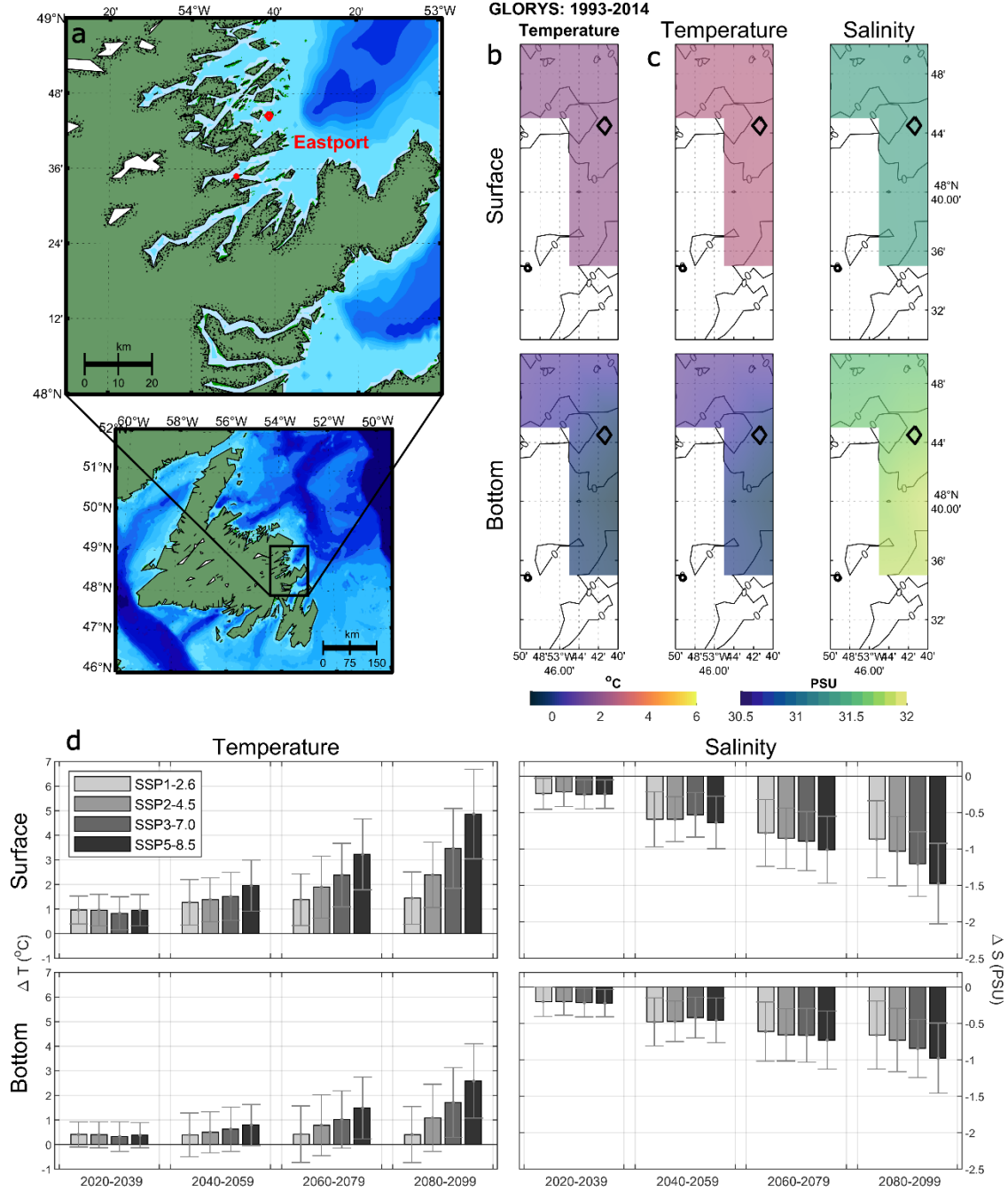


Figure 7. Projected values of temperature and salinity in the Eastport MPA and surrounds. Panels depict a) location, b) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, c) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensemble 22 CMIP6

models. The contours in (b) and (c) are bathymetry and the shading is temperature in °C and salinity in PSU, with a colour bar below.

Table 3. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Eastport MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.96 $\pm$ 0.57	1.28 $\pm$ 0.93	1.38 $\pm$ 1.05	1.45 $\pm$ 1.06
	SSP2-4.5	0.96 $\pm$ 0.64	1.38 $\pm$ 0.89	1.90 $\pm$ 1.26	2.39 $\pm$ 1.33
	SSP3-7.0	0.83 $\pm$ 0.67	1.52 $\pm$ 0.97	2.38 $\pm$ 1.29	3.47 $\pm$ 1.62
	SSP5-8.5	0.96 $\pm$ 0.64	1.96 $\pm$ 1.04	3.23 $\pm$ 1.44	4.87 $\pm$ 1.82
BT (°C)	SSP1-2.6	0.41 $\pm$ 0.51	0.39 $\pm$ 0.89	0.43 $\pm$ 1.15	0.41 $\pm$ 1.14
	SSP2-4.5	0.40 $\pm$ 0.53	0.50 $\pm$ 0.83	0.79 $\pm$ 1.24	1.09 $\pm$ 1.37
	SSP3-7.0	0.33 $\pm$ 0.60	0.63 $\pm$ 0.90	1.02 $\pm$ 1.16	1.71 $\pm$ 1.42
	SSP5-8.5	0.38 $\pm$ 0.51	0.80 $\pm$ 0.83	1.49 $\pm$ 1.26	2.59 $\pm$ 1.51
SSS (PSU)	SSP1-2.6	-0.24 $\pm$ 0.21	-0.59 $\pm$ 0.38	-0.78 $\pm$ 0.46	-0.87 $\pm$ 0.53
	SSP2-4.5	-0.22 $\pm$ 0.20	-0.59 $\pm$ 0.31	-0.85 $\pm$ 0.42	-1.03 $\pm$ 0.48
	SSP3-7.0	-0.25 $\pm$ 0.20	-0.53 $\pm$ 0.31	-0.89 $\pm$ 0.40	-1.21 $\pm$ 0.44
	SSP5-8.5	-0.25 $\pm$ 0.20	-0.64 $\pm$ 0.36	-1.01 $\pm$ 0.46	-1.47 $\pm$ 0.55
BS (PSU)	SSP1-2.6	-0.20 $\pm$ 0.20	-0.48 $\pm$ 0.33	-0.61 $\pm$ 0.41	-0.66 $\pm$ 0.47
	SSP2-4.5	-0.20 $\pm$ 0.19	-0.47 $\pm$ 0.28	-0.66 $\pm$ 0.36	-0.73 $\pm$ 0.43
	SSP3-7.0	-0.22 $\pm$ 0.19	-0.42 $\pm$ 0.28	-0.66 $\pm$ 0.37	-0.84 $\pm$ 0.40
	SSP5-8.5	-0.22 $\pm$ 0.19	-0.46 $\pm$ 0.31	-0.73 $\pm$ 0.40	-0.98 $\pm$ 0.48
MLD (m)	SSP1-2.6	0.06 $\pm$ 1.70	-0.59 $\pm$ 1.93	-0.81 $\pm$ 1.82	-0.83 $\pm$ 1.81
	SSP2-4.5	0.19 $\pm$ 1.63	-0.71 $\pm$ 1.58	-0.97 $\pm$ 1.84	-1.65 $\pm$ 1.86
	SSP3-7.0	0.06 $\pm$ 1.91	-0.58 $\pm$ 2.28	-1.46 $\pm$ 2.62	-2.23 $\pm$ 2.38
	SSP5-8.5	-0.25 $\pm$ 1.77	-1.38 $\pm$ 1.81	-2.02 $\pm$ 2.27	-3.41 $\pm$ 2.76
Bottom Current Speed (m/s)	SSP1-2.6	-0.0001 $\pm$ 0.0057	-0.0011 $\pm$ 0.0073	-0.0019 $\pm$ 0.0072	-0.0029 $\pm$ 0.0070
	SSP2-4.5	0.0010 $\pm$ 0.0058	-0.0003 $\pm$ 0.0070	-0.0016 $\pm$ 0.0073	-0.0018 $\pm$ 0.0073
	SSP3-7.0	0.0009 $\pm$ 0.0055	-0.0000 $\pm$ 0.0070	-0.0007 $\pm$ 0.0076	-0.0009 $\pm$ 0.0079
	SSP5-8.5	0.0017 $\pm$ 0.0061	-0.0006 $\pm$ 0.0073	-0.0013 $\pm$ 0.0075	-0.0011 $\pm$ 0.0082

4.3 Gilbert Bay MPA

The Gilbert Bay MPA is also located in the Newfoundland-Labrador Shelves Bioregion (DFO 2009) along the southeast coast of Labrador in a marine inlet within the NunatuKavut territory. The conservation of Gilbert Bay or ‘Golden’ cod, a genetically distinct population of Atlantic cod, and its habitats, along with the broader Gilbert Bay ecosystem, are the primary objectives of this MPA. Covering approximately 60 km² and contributing less than 0.01% toward Canada’s national marine conservation targets, the Gilbert Bay MPA is home to sea urchins, shellfish (e.g., mussels, scallops, snails, shrimp), demersal and pelagic fish (e.g., herring, northern cod, salmon, eels, smelt, Arctic char), marine plants (e.g., eelgrass, kelp), waterfowl (e.g., black ducks, geese, mergansers), and marine mammals. (see [Gilbert Bay MPA](#)). The preservation of Gilbert Bay and Golden cod is very important to the people of NunatuKavut.

This MPA is on the periphery of the climate model grid, and as such, even after applying the statistical downscaling approach, there is almost no spatial data (three grid points) to depict future climate scenario projections. Data for this MPA are thus shown using line plots (Figure 8b) rather than colour maps. Figure 8b shows annual average conditions for SST, SSS, BT, and BS. Different SSPs reveal little variation from 2015 until around 2040, after which SSP5-8.5 begins to diverge. By the century's end, SSP1-2.6 captures the lowest temperatures and SSP5-8.5 the highest. In terms of salinity, the divergence among SSPs is less apparent, although SSP5-8.5 has the lowest salinity (both SSS and BS) by 2100. Bar plots in the bottom panels (Figure 8c) illustrate how each climate scenario deviates from that climatology in 20-year periods, with corresponding values provided in Table 4.

SST (Table 4) rises in all SSPs and periods. In P1, warming is modest and similar across scenarios (around 0.7–0.8 °C). From P2 onward, scenario separation becomes clearer, with progressively stronger warming under higher emissions. By P4, SST increases range from just over 1 °C in SSP1-2.6 to more than 4 °C in SSP5-8.5, while SSP2-4.5 and SSP3-7.0 show intermediate increases.

BT (Table 4) shows a more subdued but consistent response. Under SSP1-2.6, BT remains relatively stable and slightly decreases over time. In contrast, higher emissions scenarios exhibit steadily increasing bottom warming, with SSP5-8.5 showing the largest rise, exceeding 2 °C by P4. Divergence among scenarios becomes most apparent after P2, with SSP3-7.0 and SSP2-4.5 showing intermediate increases.

SSS (Table 4) decreases across all periods and scenarios, indicating widespread surface freshening. Changes are relatively small and similar in P1 but intensify over time, particularly under higher emissions. SSP5-8.5 exhibits the strongest decline, reaching approximately –1.4 PSU by P4, while SSP1-2.6 consistently shows the least freshening.

BS (Table 4) follows the same overall pattern as SSS but with smaller magnitudes. Freshening increases gradually from P1 to P4, with limited differences among scenarios early on. By P4, SSP5-8.5 shows the greatest decrease (around –0.7 PSU), whereas SSP1-2.6 experiences the smallest change.

Gilbert Bay Marine Protected Area

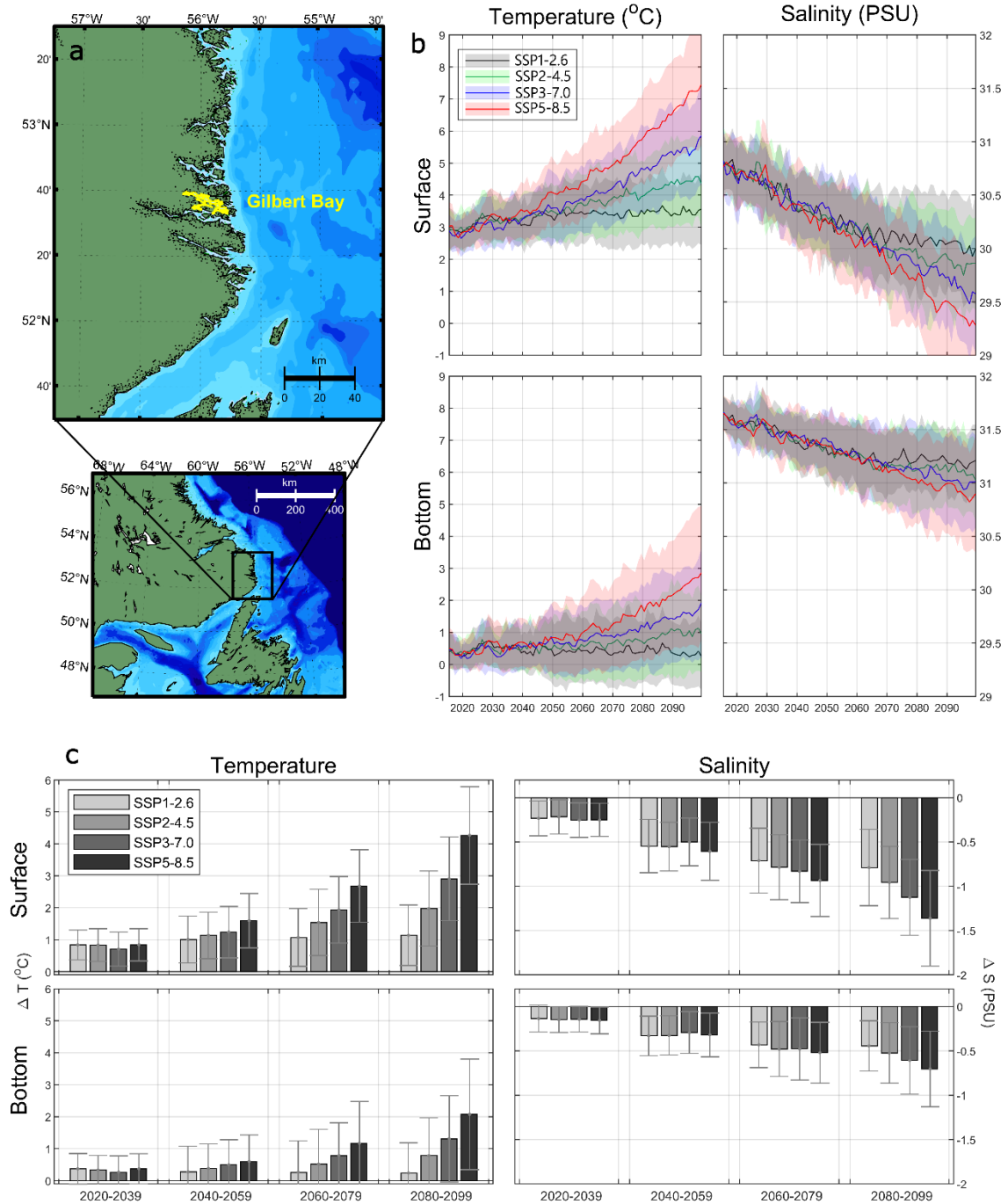


Figure 8. Projected values of temperature and salinity in the Gilbert Bay MPA. Panels depict a) location, b) timeseries of annual average surface and bottom temperature and salinity for the multi-model average (lines) and 22 CMIP6 model standard deviation (shading), and c) changes in 20-year, multi-model, MPA-average anomalies relative to the 1993-2014 GLORYS12 climatologies of surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6 models.

Table 4. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Gilbert Bay MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.84 $\pm$ 0.47	1.00 $\pm$ 0.74	1.07 $\pm$ 0.90	1.14 $\pm$ 0.94
	SSP2-4.5	0.83 $\pm$ 0.51	1.14 $\pm$ 0.73	1.54 $\pm$ 1.03	1.98 $\pm$ 1.17
	SSP3-7.0	0.71 $\pm$ 0.53	1.24 $\pm$ 0.81	1.93 $\pm$ 1.04	2.90 $\pm$ 1.31
	SSP5-8.5	0.84 $\pm$ 0.51	1.59 $\pm$ 0.85	2.68 $\pm$ 1.14	4.26 $\pm$ 1.53
BT (°C)	SSP1-2.6	0.38 $\pm$ 0.48	0.28 $\pm$ 0.80	0.26 $\pm$ 0.99	0.24 $\pm$ 0.95
	SSP2-4.5	0.34 $\pm$ 0.45	0.38 $\pm$ 0.77	0.52 $\pm$ 1.09	0.79 $\pm$ 1.18
	SSP3-7.0	0.27 $\pm$ 0.51	0.50 $\pm$ 0.78	0.78 $\pm$ 1.03	1.31 $\pm$ 1.35
	SSP5-8.5	0.38 $\pm$ 0.47	0.60 $\pm$ 0.83	1.17 $\pm$ 1.31	2.07 $\pm$ 1.73
SSS (PSU)	SSP1-2.6	-0.23 $\pm$ 0.20	-0.55 $\pm$ 0.30	-0.71 $\pm$ 0.36	-0.79 $\pm$ 0.43
	SSP2-4.5	-0.22 $\pm$ 0.19	-0.55 $\pm$ 0.27	-0.79 $\pm$ 0.37	-0.96 $\pm$ 0.41
	SSP3-7.0	-0.25 $\pm$ 0.19	-0.50 $\pm$ 0.27	-0.83 $\pm$ 0.35	-1.13 $\pm$ 0.43
	SSP5-8.5	-0.25 $\pm$ 0.19	-0.61 $\pm$ 0.33	-0.94 $\pm$ 0.41	-1.36 $\pm$ 0.54
BS (PSU)	SSP1-2.6	-0.14 $\pm$ 0.15	-0.33 $\pm$ 0.22	-0.43 $\pm$ 0.26	-0.44 $\pm$ 0.28
	SSP2-4.5	-0.15 $\pm$ 0.15	-0.33 $\pm$ 0.22	-0.48 $\pm$ 0.31	-0.52 $\pm$ 0.34
	SSP3-7.0	-0.14 $\pm$ 0.14	-0.29 $\pm$ 0.24	-0.48 $\pm$ 0.35	-0.61 $\pm$ 0.38
	SSP5-8.5	-0.16 $\pm$ 0.15	-0.32 $\pm$ 0.25	-0.52 $\pm$ 0.34	-0.70 $\pm$ 0.43
MLD (m)	SSP1-2.6	2.36 $\pm$ 2.61	1.44 $\pm$ 2.16	1.18 $\pm$ 2.33	0.41 $\pm$ 2.31
	SSP2-4.5	2.91 $\pm$ 2.93	1.28 $\pm$ 2.74	1.09 $\pm$ 2.98	-0.05 $\pm$ 2.60
	SSP3-7.0	2.86 $\pm$ 2.57	1.37 $\pm$ 2.64	0.47 $\pm$ 2.40	-0.77 $\pm$ 3.22
	SSP5-8.5	2.56 $\pm$ 2.79	0.87 $\pm$ 2.65	-0.35 $\pm$ 2.85	-2.08 $\pm$ 3.56
Bottom Current Speed (m/s)	SSP1-2.6	0.0001 $\pm$ 0.0040	-0.0004 $\pm$ 0.0064	-0.0007 $\pm$ 0.0070	-0.0007 $\pm$ 0.0077
	SSP2-4.5	0.0012 $\pm$ 0.0037	-0.0002 $\pm$ 0.0055	-0.0001 $\pm$ 0.0071	0.0000 $\pm$ 0.0085
	SSP3-7.0	0.0008 $\pm$ 0.0035	0.0001 $\pm$ 0.0049	-0.0000 $\pm$ 0.0073	0.0007 $\pm$ 0.0090
	SSP5-8.5	0.0012 $\pm$ 0.0046	0.0001 $\pm$ 0.0058	-0.0004 $\pm$ 0.0082	0.0009 $\pm$ 0.0107

MLD (Table 4) generally becomes shallower over time, with the strongest reductions occurring under higher emissions scenarios. All SSPs show positive anomalies in P1, but MLD decreases progressively in later periods. SSP5-8.5 exhibits the most pronounced shoaling, shifting from positive values in P1 to a reduction of more than 2 m by P4. SSP3-7.0 and SSP2-4.5 show intermediate declines, while SSP1-2.6 maintains the smallest overall change. Bottom current speed (Table 4) shows little systematic change across periods or scenarios, remaining close to zero throughout all projections.

4.4 Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA

The Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs (HS/QCS) MPA, located in the Northern Shelf Bioregion (DFO 2009), north and south of the entrance to Douglas Channel, British Columbia, protects four glass sponge reefs believed to be over 9,000 years old. Covering

approximately 2,410 km² (about 0.04% of Canada's contribution to marine conservation targets), the HS/QCS MPA was established to protect four globally rare glass sponge reef complexes, which represent the largest and most intact living glass sponge reefs known worldwide. The reef structures form complex, three-dimensional habitats that provide refuge, feeding areas, and nursery habitat for a wide range of marine species, including those of commercial and ecological importance, while also contributing to key ecosystem processes such as water filtration and nutrient cycling. Due to their fragile silica skeletons, extremely slow growth rates, and limited capacity for recovery, glass sponges are highly sensitive to physical disturbances and increased sedimentation, with damage potentially persisting for decades to centuries (see [Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA](#)). The four protected reefs are regulated by three protected area boundaries (Figure 9a). Our analyses assessed all three MPAs (Figure 9a) as one unit.

Figure 9b presents the bi-decadal average surface and bottom temperature and salinity conditions for the HS/QCS MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. Also included is a GLORYS12 climatology (1993–2014)(Figure 9c). Bar plots in the bottom panels (Figure 9d) illustrate how each climate scenario deviates from that climatology in 20-year periods, with corresponding values provided in Table 4. Figure A2 (Appendix 1) presents the spatial temperature changes for the HS/QCS MPA for all of the projected SSPs and periods. A CMIP6 model resolution of 1° requires about 11 cells to cover the MPA, and the statistical downscaling results in the HS/QCS MPA being represented by 784 grid cells.

SST (Table 5) increases by under 1 °C in P1, with all SSP scenarios being fairly similar. SSP2-4.5 experiences the smallest change in P2, and SSP1-2.6 in P3–P4, while SSP5-8.5 shows the largest changes during these periods. The smallest change in P2 is observed in SSP2-4.5, with an increase of about 1.3 °C, while the largest overall increase occurs under SSP5-8.5 in P4, with a rise of over 3.7 °C. Across all SSP scenarios, SST trends warmer by the end of the century.

BT (Table 5) rises steadily across all periods and scenarios. Even the low-emissions pathway shows a notable increase, with SSP1-2.6 exceeding 1 °C by P4. Higher-emissions scenarios display progressively larger warming, culminating in an increase of just over 2 °C under SSP5-8.5 in P4. Divergence among scenarios becomes more pronounced after P2.

SSS (Table 5) decreases throughout all periods, indicating persistent surface freshening. Initial changes in P1 are small and broadly similar across SSPs, but the magnitude of decline grows with time and emissions intensity. SSP5-8.5 exhibits the strongest freshening, reaching nearly –0.7 PSU in P4, while SSP1-2.6 shows comparatively limited change, stabilizing near –0.25 PSU in later periods.

BS (Table 5) shows weaker responses than surface salinity, with changes close to zero in P1 and gradually increasing freshening toward P4. Differences among scenarios remain small, though SSP5-8.5 consistently exhibits the largest decrease, approaching –0.12 PSU by the end of the century.

MLD (Table 5) trends toward shoaling across all scenarios. Under SSP1-2.6, reductions remain modest and variable, generally around –1 m or less. In contrast, SSP5-8.5 shows pronounced

shoaling, exceeding -3 m by P4, with SSP3-7.0 and SSP2-4.5 occupying intermediate ranges. Bottom current speed (Table 5) displays minimal change across all periods and scenarios.

Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs: SSP2-4.5 2040-2059

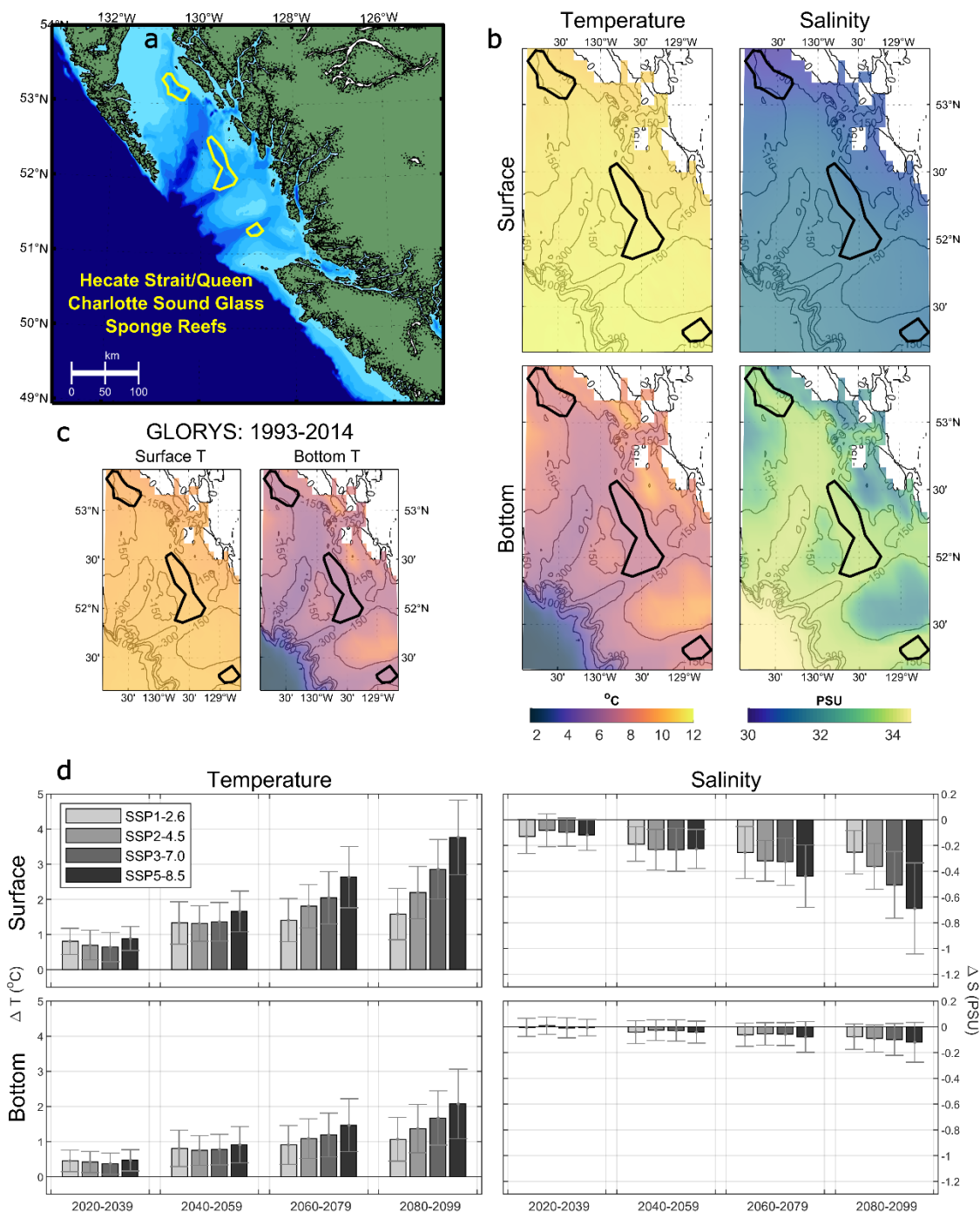


Figure 9. Projected values of temperature and salinity in the HS/QCS MPA and surrounds. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom

temperature and salinity for SSP2-4.5 during 2040-2059, c) GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) spatial distribution of the surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6 models. The contours in (b) and (c) are bathymetry and the shading is temperature in °C and salinity in PSU, with a colour bar below.

Table 5. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the HS/QCS MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.81 $\pm$ 0.37	1.33 $\pm$ 0.60	1.41 $\pm$ 0.61	1.58 $\pm$ 0.73
	SSP2-4.5	0.70 $\pm$ 0.42	1.31 $\pm$ 0.51	1.81 $\pm$ 0.61	2.19 $\pm$ 0.74
	SSP3-7.0	0.64 $\pm$ 0.42	1.36 $\pm$ 0.55	2.05 $\pm$ 0.75	2.86 $\pm$ 0.85
	SSP5-8.5	0.89 $\pm$ 0.34	1.66 $\pm$ 0.58	2.64 $\pm$ 0.87	3.77 $\pm$ 1.06
BT (°C)	SSP1-2.6	0.45 $\pm$ 0.31	0.81 $\pm$ 0.52	0.91 $\pm$ 0.55	1.07 $\pm$ 0.62
	SSP2-4.5	0.42 $\pm$ 0.30	0.75 $\pm$ 0.42	1.09 $\pm$ 0.56	1.37 $\pm$ 0.69
	SSP3-7.0	0.37 $\pm$ 0.30	0.77 $\pm$ 0.43	1.19 $\pm$ 0.62	1.67 $\pm$ 0.77
	SSP5-8.5	0.47 $\pm$ 0.30	0.91 $\pm$ 0.52	1.47 $\pm$ 0.75	2.07 $\pm$ 0.99
SSS (PSU)	SSP1-2.6	-0.13 $\pm$ 0.13	-0.19 $\pm$ 0.13	-0.25 $\pm$ 0.20	-0.25 $\pm$ 0.17
	SSP2-4.5	-0.08 $\pm$ 0.13	-0.23 $\pm$ 0.16	-0.32 $\pm$ 0.16	-0.36 $\pm$ 0.18
	SSP3-7.0	-0.10 $\pm$ 0.11	-0.23 $\pm$ 0.17	-0.33 $\pm$ 0.18	-0.51 $\pm$ 0.26
	SSP5-8.5	-0.12 $\pm$ 0.12	-0.23 $\pm$ 0.15	-0.44 $\pm$ 0.24	-0.69 $\pm$ 0.35
BS (PSU)	SSP1-2.6	-0.00 $\pm$ 0.07	-0.04 $\pm$ 0.09	-0.06 $\pm$ 0.09	-0.08 $\pm$ 0.10
	SSP2-4.5	0.01 $\pm$ 0.07	-0.03 $\pm$ 0.08	-0.05 $\pm$ 0.09	-0.09 $\pm$ 0.10
	SSP3-7.0	-0.01 $\pm$ 0.08	-0.03 $\pm$ 0.08	-0.06 $\pm$ 0.09	-0.10 $\pm$ 0.12
	SSP5-8.5	-0.01 $\pm$ 0.06	-0.04 $\pm$ 0.09	-0.08 $\pm$ 0.12	-0.12 $\pm$ 0.15
MLD (m)	SSP1-2.6	-0.49 $\pm$ 1.08	-0.54 $\pm$ 1.11	-1.04 $\pm$ 1.26	-0.60 $\pm$ 1.13
	SSP2-4.5	-0.43 $\pm$ 1.39	-0.85 $\pm$ 1.57	-1.41 $\pm$ 1.27	-1.52 $\pm$ 1.35
	SSP3-7.0	-0.28 $\pm$ 0.96	-1.06 $\pm$ 1.04	-1.85 $\pm$ 1.37	-2.59 $\pm$ 1.41
	SSP5-8.5	-0.52 $\pm$ 1.08	-1.21 $\pm$ 0.92	-2.15 $\pm$ 1.48	-3.31 $\pm$ 1.82
Bottom Current Speed (m/s)	SSP1-2.6	0.0014 $\pm$ 0.0018	0.0021 $\pm$ 0.0025	0.0020 $\pm$ 0.0023	0.0017 $\pm$ 0.0021
	SSP2-4.5	0.0016 $\pm$ 0.0020	0.0019 $\pm$ 0.0023	0.0018 $\pm$ 0.0020	0.0023 $\pm$ 0.0024
	SSP3-7.0	0.0015 $\pm$ 0.0019	0.0017 $\pm$ 0.0019	0.0017 $\pm$ 0.0017	0.0017 $\pm$ 0.0016
	SSP5-8.5	0.0015 $\pm$ 0.0018	0.0019 $\pm$ 0.0023	0.0022 $\pm$ 0.0020	0.0018 $\pm$ 0.0020

Spatial variability in temperature and salinity was more pronounced in bottom variables in the 2040-2059 projections under SSP2-4.5 than in surface variables with variation in BT and BS associated with depth. The values among MPA closures appear similar in all variables (Figure 9b). The only exception is the most northerly MPA which shows fresher surface waters than the MPAs to the south.

4.5 Tang.gwan – ɥačxwiqak – Tsigis MPA

The Tang.gwan – ɥačxwiqak – Tsigis (TɥT) MPA is located in the Offshore Pacific Bioregion, approximately 150 km west of Vancouver Island, British Columbia, within Canada’s Exclusive Economic Zone (EEZ). Established in 2024, the MPA encompasses approximately 133,017 km², making it Canada’s second-largest MPA. The TɥT MPA protects an extensive array of deep-sea features, including more than 47 seamounts and all known hydrothermal vent systems within Canadian waters, which together support highly productive and specialised marine ecosystems. The primary conservation objective is to preserve the ecological integrity, biodiversity, and unique geological features of the area, including rare and specialised species associated with hydrothermal vent and seamount habitats (see [Tang.gwan – ɥačxwiqak – Tsigis MPA](#)).

Figure 10b presents the bi-decadal average surface and bottom temperature and salinity conditions for the TɥT MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. Also included is a GLORYS12 climatology (1993–2014)(Figure 10c). Bar plots in the bottom panels (Figure 10d) illustrate how each climate scenario deviates from that climatology in 20-year periods, with corresponding values provided in Table 6. There are almost 5,500 grid cells covering the TɥT MPA after implementing applying the statistical downscaling approach.

SST (Table 6) increases across all periods and SSP scenarios. In P1, warming is modest (about 0.6–0.9 °C) and relatively similar across SSPs. From P2 onward, the separation among scenarios widens, with progressively larger increases under higher-emissions pathways. By P4, SST rises from approximately 1.5 °C under SSP1-2.6 to more than 3.5 °C under SSP5-8.5, with SSP2-4.5 and SSP3-7.0 showing intermediate warming. Across all SSP scenarios, SST trends warmer by the end of the century.

BT and BS (Table 6) show minimal change across all periods and SSPs due to the depth of the MPA, with bottom waters remaining largely unaffected by projected climate forcing over the century. While SST exhibits clear warming, the deep-sea environment maintains stable thermal and salinity conditions in all SSP scenarios, with variations generally within measurement uncertainty.

SSS (Table 6) decreases consistently in all scenarios, indicating surface freshening. Changes are small in P1 but increase steadily over time, particularly under higher-emissions pathways. By P4, SSP5-8.5 exhibits the greatest decline (around –0.6 PSU), whereas SSP1-2.6 shows the smallest decrease (approximately –0.2 PSU). The magnitude of freshening scales with emissions intensity, with intermediate scenarios displaying proportional changes between the low- and high-emissions extremes.

MLD (Table 6) shows a pronounced shoaling trend across all scenarios. Reductions are observed even in P1, but they deepen progressively toward P4. SSP5-8.5 shows the strongest shoaling, exceeding –6 m by P4, while SSP3-7.0 and SSP2-4.5 demonstrate substantial but smaller decreases. SSP1-2.6 experiences the smallest overall reduction, though a consistent shoaling signal is evident throughout the century. Bottom current speed (Table 6) remains effectively unchanged across all periods and scenarios. Mean values remain small, showing no systematic increase or decrease over time.

There is very little spatial variation in temperature or salinity for SSP2-4.5 during 2040-2059, with only a weak gradient apparent in SST showing warming to the southeast (Figure 10b).

Tang.ḡwan – ḥačxwiqak – Tsigis: SSP2-4.5 2040-2059

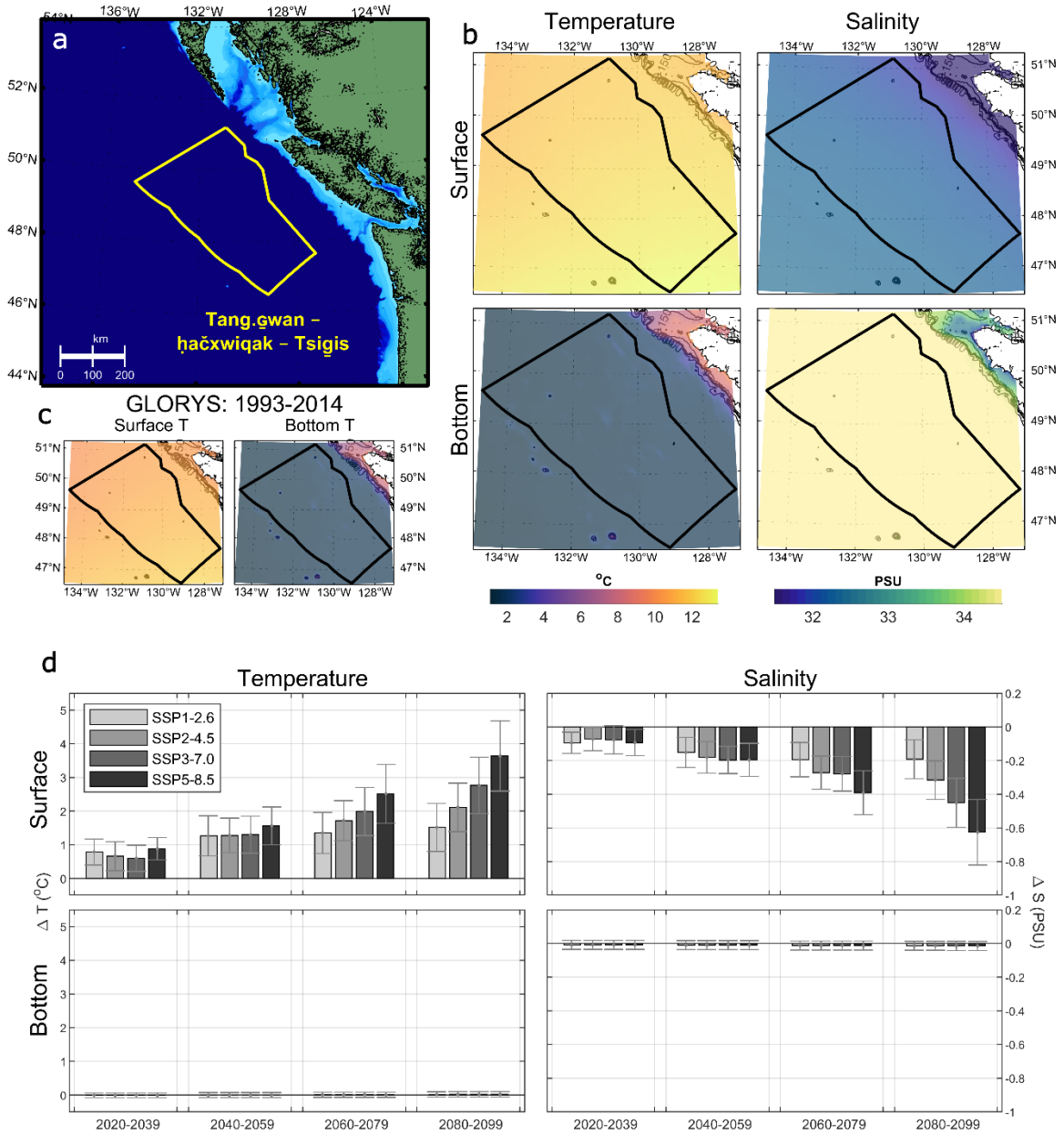


Figure 10. Projected values of temperature and salinity in the ThT MPA and surrounds. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6 models. The shading in (b) and (c) temperature in °C and salinity in PSU, with a colour bar below.

Table 6. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the ThT MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST ($^{\circ}$ C)	SSP1-2.6	0.79 ± 0.39	1.26 ± 0.60	1.35 ± 0.61	1.52 ± 0.71
	SSP2-4.5	0.66 ± 0.43	1.28 ± 0.51	1.72 ± 0.59	2.11 ± 0.72
	SSP3-7.0	0.60 ± 0.39	1.30 ± 0.55	1.99 ± 0.72	2.77 ± 0.84
	SSP5-8.5	0.88 ± 0.33	1.56 ± 0.56	2.51 ± 0.87	3.64 ± 1.04
BT ($^{\circ}$ C)	SSP1-2.6	-0.01 ± 0.07	0.00 ± 0.07	0.01 ± 0.08	0.02 ± 0.08
	SSP2-4.5	-0.01 ± 0.07	0.00 ± 0.07	0.01 ± 0.08	0.02 ± 0.08
	SSP3-7.0	-0.01 ± 0.07	0.00 ± 0.07	0.01 ± 0.08	0.02 ± 0.08
	SSP5-8.5	-0.01 ± 0.07	0.00 ± 0.07	0.01 ± 0.08	0.02 ± 0.08
SSS (PSU)	SSP1-2.6	-0.09 ± 0.06	-0.15 ± 0.09	-0.19 ± 0.10	-0.19 ± 0.12
	SSP2-4.5	-0.07 ± 0.07	-0.18 ± 0.09	-0.27 ± 0.10	-0.32 ± 0.11
	SSP3-7.0	-0.08 ± 0.08	-0.20 ± 0.08	-0.28 ± 0.10	-0.45 ± 0.15
	SSP5-8.5	-0.09 ± 0.08	-0.20 ± 0.10	-0.39 ± 0.13	-0.63 ± 0.19
BS (PSU)	SSP1-2.6	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03
	SSP2-4.5	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03
	SSP3-7.0	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03
	SSP5-8.5	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03
MLD (m)	SSP1-2.6	-1.37 ± 1.22	-2.07 ± 1.27	-1.86 ± 1.43	-1.97 ± 1.67
	SSP2-4.5	-1.28 ± 1.13	-2.42 ± 1.23	-2.96 ± 1.38	-3.03 ± 1.38
	SSP3-7.0	-0.95 ± 1.34	-2.27 ± 1.02	-3.23 ± 1.41	-4.37 ± 1.30
	SSP5-8.5	-1.36 ± 1.32	-2.44 ± 1.35	-4.35 ± 1.52	-6.09 ± 1.88
Bottom Current Speed (m/s)	SSP1-2.6	0.0001 ± 0.0002	0.0001 ± 0.0002	0.0001 ± 0.0003	0.0000 ± 0.0003
	SSP2-4.5	0.0001 ± 0.0004	0.0001 ± 0.0004	0.0000 ± 0.0003	0.0000 ± 0.0004
	SSP3-7.0	0.0001 ± 0.0003	0.0000 ± 0.0003	0.0000 ± 0.0003	0.0000 ± 0.0004
	SSP5-8.5	0.0000 ± 0.0002	0.0001 ± 0.0004	0.0001 ± 0.0003	-0.0000 ± 0.0003

4.6 SGáan Kínglas-Bowie Seamount MPA

The SGáan Kínglas-Bowie (SK-B) Seamount MPA encompasses approximately 6,103 km², contributing roughly 0.11% toward Canada's national marine conservation targets. It was established to conserve and protect the seamounts, surrounding waters, seabed, and subsoil, preserving their unique biodiversity and productivity. The MPA hosts a diverse biological community, including open-ocean species such as salps, deep-water species such as prowlfish and squat lobsters, and intertidal and coastal species, including taaXuu and k'aay. The clarity of the water allows light to penetrate up to 40 m below the surface, supporting large algae such as ngaalaagaas (flattened acid kelp), which can grow to depths of 38 m. Most benthic marine algae typically grow in waters shallower than 20 m, meaning the SK-B seamount represents new depth records for these species. Rising from depths exceeding 3,000 m to within 24 m of the sea surface,

the seamount generates sharp physical gradients and oceanographic conditions that enhance nutrient mixing and biological productivity (see [SGáan Kínghlas-Bowie Seamount MPA](#)).

Seamounts often generate complex circulation features, most notably Taylor columns. These are characterised by closed, typically anticyclonic flow patterns that extend above the summit, creating isolated hydrodynamic environments that can persist for weeks or months. The statistical downscaling approach can preserve the high-resolution flow features inherent in the GLORYS12 product. Consequently, where GLORYS12 captures these Taylor columns, their localized environmental and physical effects remain represented within our downscaled dataset.

Figure 11b presents the bi-decadal average surface and bottom temperature and salinity conditions for the SK-B MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. GLORYS12 climatology (1993–2014) is also included for comparison (Figure 11c). Bar plots in the bottom panels (Figure 11d) illustrate deviations of each climate scenario from this climatology over 20-year periods, with corresponding values provided in Table 7. A CMIP6 model resolution of 1° requires about 7 cells to cover the MPA and the statistical downscaling approach improves the SK-B MPA representation by using 312 grid cells.

SST (Table 7) increases across all periods and SSPs. In P1, warming is modest, about 1.0 °C, and similar among SSPs. From P2 onward, divergence among scenarios becomes more evident, with higher-emissions pathways showing progressively stronger warming. By P4, SST rises to roughly 1.6 °C under SSP1-2.6 and nearly 3.8 °C under SSP5-8.5. Intermediate scenarios (SSP2-4.5 and SSP3-7.0) display proportional increases, reflecting emissions intensity.

BT and BS (Table 7) shows almost no change across all periods and scenarios. Due to the seamount's depth, bottom temperatures remain largely stable, with variations well below 0.1 °C, and differences among SSPs are negligible.

SSS (Table 7) declines across all scenarios, indicating consistent surface freshening. Early changes in P1 are minor but intensify toward P4, particularly under higher-emissions pathways. By P4, SSP5-8.5 exhibits the largest decrease (approximately –0.6 PSU), while SSP1-2.6 shows the smallest change (around –0.2 PSU). Intermediate SSPs show freshening proportional to emissions intensity.

MLD (Table 7) shoals across all scenarios, with the most pronounced reductions observed under higher-emissions pathways. Negative anomalies are present even in P1, but by P4, shoaling exceeds –7 m under SSP5-8.5. SSP3-7.0 and SSP2-4.5 shows intermediate shoaling, while SSP1-2.6 maintains the smallest overall reduction, though a consistent shoaling trend is evident. Bottom current speed (Table 7) displays no coherent trend over time.

Spatial variation over the MPA for SSP2-4.5 during 2040-2059 was weak with some effect of the seamounts shown in BT and BS which appears warmer and fresher over the seamounts than in the surrounding deep waters (Figure 11b).

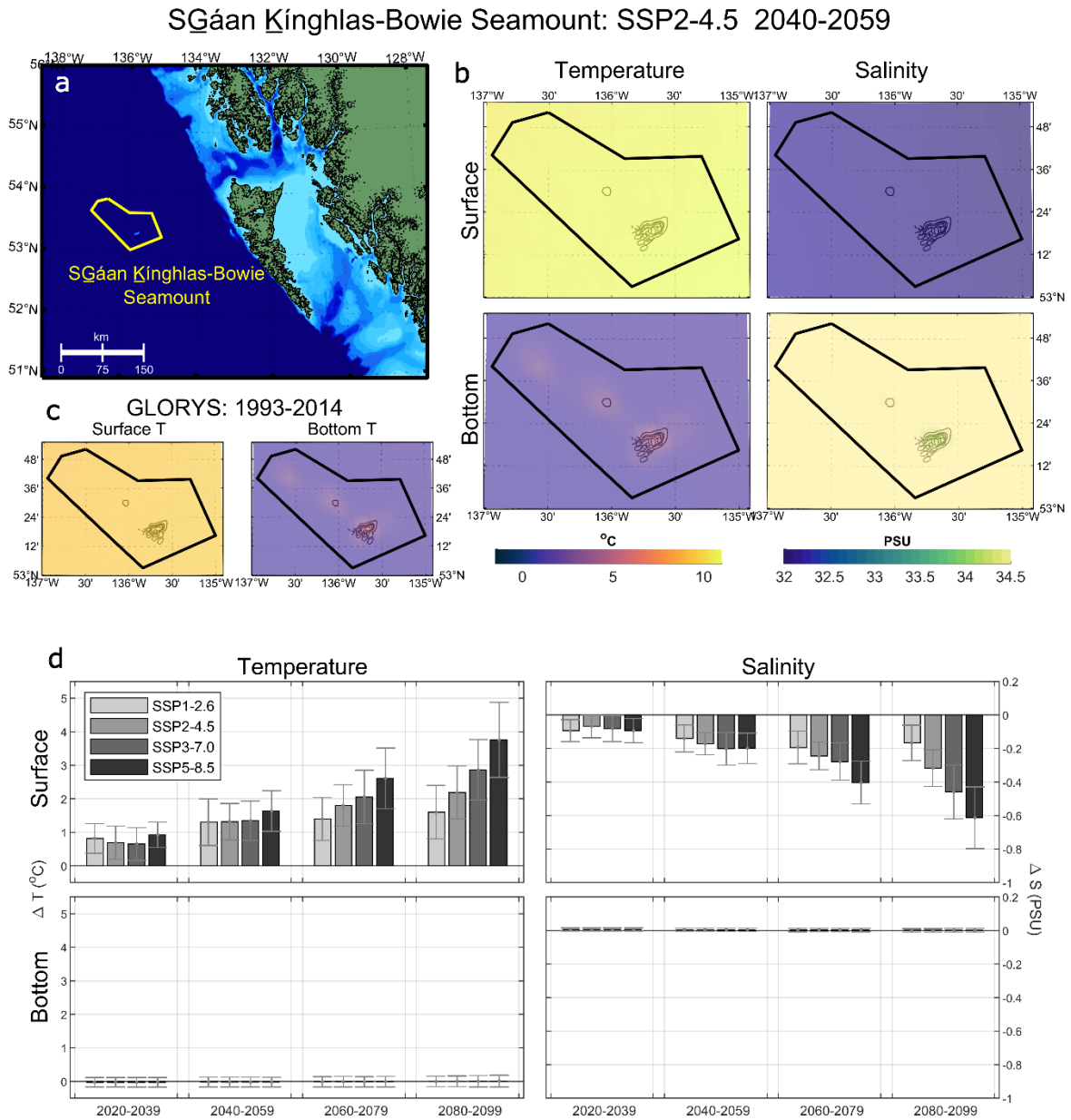


Figure 11. Projected values of temperature and salinity in the SK-B MPA and surrounds. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6 models. The shading in (b) and (c) is temperature in °C and salinity in PSU, with a colour bar below.

Table 7. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the SK-B MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.82 $\pm$ 0.44	1.30 $\pm$ 0.69	1.40 $\pm$ 0.64	1.60 $\pm$ 0.80
	SSP2-4.5	0.69 $\pm$ 0.50	1.32 $\pm$ 0.54	1.80 $\pm$ 0.62	2.19 $\pm$ 0.79
	SSP3-7.0	0.65 $\pm$ 0.49	1.35 $\pm$ 0.59	2.05 $\pm$ 0.80	2.86 $\pm$ 0.90
	SSP5-8.5	0.93 $\pm$ 0.38	1.63 $\pm$ 0.61	2.61 $\pm$ 0.91	3.75 $\pm$ 1.12
BT (°C)	SSP1-2.6	-0.02 $\pm$ 0.14	-0.02 $\pm$ 0.15	-0.01 $\pm$ 0.15	0.00 $\pm$ 0.16
	SSP2-4.5	-0.02 $\pm$ 0.14	-0.02 $\pm$ 0.15	-0.01 $\pm$ 0.16	0.00 $\pm$ 0.16
	SSP3-7.0	-0.02 $\pm$ 0.14	-0.02 $\pm$ 0.15	-0.01 $\pm$ 0.15	0.01 $\pm$ 0.17
	SSP5-8.5	-0.02 $\pm$ 0.14	-0.02 $\pm$ 0.15	-0.01 $\pm$ 0.16	0.01 $\pm$ 0.17
SSS (PSU)	SSP1-2.6	-0.09 $\pm$ 0.07	-0.14 $\pm$ 0.08	-0.19 $\pm$ 0.10	-0.17 $\pm$ 0.11
	SSP2-4.5	-0.07 $\pm$ 0.07	-0.17 $\pm$ 0.07	-0.24 $\pm$ 0.08	-0.32 $\pm$ 0.11
	SSP3-7.0	-0.08 $\pm$ 0.08	-0.20 $\pm$ 0.10	-0.28 $\pm$ 0.11	-0.46 $\pm$ 0.16
	SSP5-8.5	-0.09 $\pm$ 0.07	-0.20 $\pm$ 0.09	-0.40 $\pm$ 0.13	-0.61 $\pm$ 0.18
BS (PSU)	SSP1-2.6	0.01 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01
	SSP2-4.5	0.01 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01
	SSP3-7.0	0.01 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01
	SSP5-8.5	0.01 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01
MLD (m)	SSP1-2.6	-1.43 $\pm$ 1.30	-2.04 $\pm$ 1.09	-2.13 $\pm$ 1.52	-1.69 $\pm$ 1.56
	SSP2-4.5	-1.04 $\pm$ 0.89	-2.72 $\pm$ 1.24	-3.21 $\pm$ 1.58	-3.60 $\pm$ 1.58
	SSP3-7.0	-0.81 $\pm$ 0.88	-2.56 $\pm$ 1.33	-3.84 $\pm$ 1.35	-5.06 $\pm$ 1.68
	SSP5-8.5	-1.04 $\pm$ 0.96	-2.84 $\pm$ 1.43	-5.13 $\pm$ 1.62	-7.30 $\pm$ 2.33
Bottom Current Speed (m/s)	SSP1-2.6	-0.0000 $\pm$ 0.0004	-0.0000 $\pm$ 0.0004	0.0001 $\pm$ 0.0004	-0.0000 $\pm$ 0.0004
	SSP2-4.5	-0.0000 $\pm$ 0.0005	-0.0000 $\pm$ 0.0005	-0.0000 $\pm$ 0.0005	-0.0000 $\pm$ 0.0005
	SSP3-7.0	0.0001 $\pm$ 0.0005	-0.0001 $\pm$ 0.0004	-0.0000 $\pm$ 0.0007	-0.0000 $\pm$ 0.0006
	SSP5-8.5	-0.0000 $\pm$ 0.0004	0.0001 $\pm$ 0.0006	0.0000 $\pm$ 0.0004	-0.0001 $\pm$ 0.0005

4.7 Anguniaqvia Niqiyuam MPA

The Anguniaqvia Niqiyuam (AN) MPA is situated in the Western Arctic Bioregion of the Beaufort Sea, adjacent to Darnley Bay near the community of Paulatuk, Northwest Territories. Established in 2016, it encompasses approximately 2,358 km², contributing about 0.04% toward Canada's national marine conservation targets. The area was designated to maintain the integrity and productivity of the marine environment offshore of the Cape Parry Migratory Bird Sanctuary, and to protect critical habitats for ecologically and culturally significant species, including beluga whales, Arctic char, cod, ringed and bearded seals, polar bears, and seabirds. The MPA also supports the Inuvialuit community of Paulatuk by safeguarding traditional subsistence harvesting, travel routes, and cultural practices. Notably, AN is Canada's first MPA with conservation objectives explicitly based on Indigenous traditional and local knowledge (see [Anguniaqvia Niqiyuam MPA](#)).

Figure 12b presents the bi-decadal average surface and bottom temperature and salinity conditions for the AN MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. Due to the proximity to the coastline, the spatial extent examined did not include some portions of the MPA, while it included some area outside of the MPA to the southeast (Figure 12a). GLORYS12 climatology (1993–2014) is also included (Figure 12c). Bar plots (Figure 12d) illustrate deviations of each climate scenario from this climatology in 20-year periods, with corresponding values provided in Table 8. A CMIP6 model resolution of 1° requires about four cells to cover the MPS. There are 247 grid cells representing the AN MPA after applying the statistical downscaling approach.

SST (Table 8) increases steadily across all SSPs and periods. In P1, warming is modest, around 1.0 °C, and relatively uniform across scenarios. From P2 onward higher-emissions scenarios diverge progressively. By P4, SST under SSP1-2.6 stabilizes near 1.4 °C, whereas SSP2-4.5 reaches about 2.5 °C, SSP3-7.0 about 3.5 °C, and SSP5-8.5 nearly 4.0 °C.

BT (Table 8) shows a gradual warming signal across all periods and scenarios. Early changes are modest, but by P3 and P4, differences among SSPs become more pronounced. SSP5-8.5 exhibits the largest increase, exceeding 1.6 °C by P4, while SSP1-2.6 remains below 0.8 °C. Bottom waters respond more slowly than the surface but show substantial warming under higher-emissions pathways.

SSS (Table 8) transitions from small, variable changes in P1 to consistent freshening in later periods. By P2, all scenarios show negative anomalies, which intensify toward P4. SSP5-8.5 exhibits the strongest surface freshening, exceeding –1 PSU in P4, while SSP1-2.6 shows comparatively modest declines. Intermediate scenarios fall proportionally between these extremes.

BS (Table 8) declines steadily across periods, with freshening magnitude increasing from low to high emissions scenarios. Early reductions in P1 are evident, but by P4, SSP5-8.5 shows the largest decrease (over –1.2 PSU), while SSP1-2.6 remains the least affected. SSP3-7.0 and SSP2-4.5 show intermediate freshening, consistent with their emissions trajectories.

MLD (Table 8) shows relatively weak changes compared to other variables. Positive anomalies persist through most periods, but a gradual shoaling signal emerges under higher-emissions scenarios. By P4, SSP3-7.0 and SSP5-8.5 approach near-zero or slightly negative anomalies, whereas SSP1-2.6 maintains a relatively stable mixed layer depth throughout. Bottom current speed (Table 8) shows minimal change across all SSPs and periods.

Spatial variation in SST and SSS for SSP2-4.5 during 2040-2059 showed weak north-south gradients across the MPA with temperature increasing and salinity decreasing towards the south (Figure 12b). Values for BT and BS showed more pronounced spatial differences within the MPA, particularly for BT where nearshore waters were warmer and fresher (Figure 12 b). Surface temperature was markedly warmer in P2 than in the preceding GLORYS12 prediction period while BT showed a greater differential over the MPA (Figure 12b,c).

Anguniaqvia niqiqyuam: SSP2-4.5 2040-2059

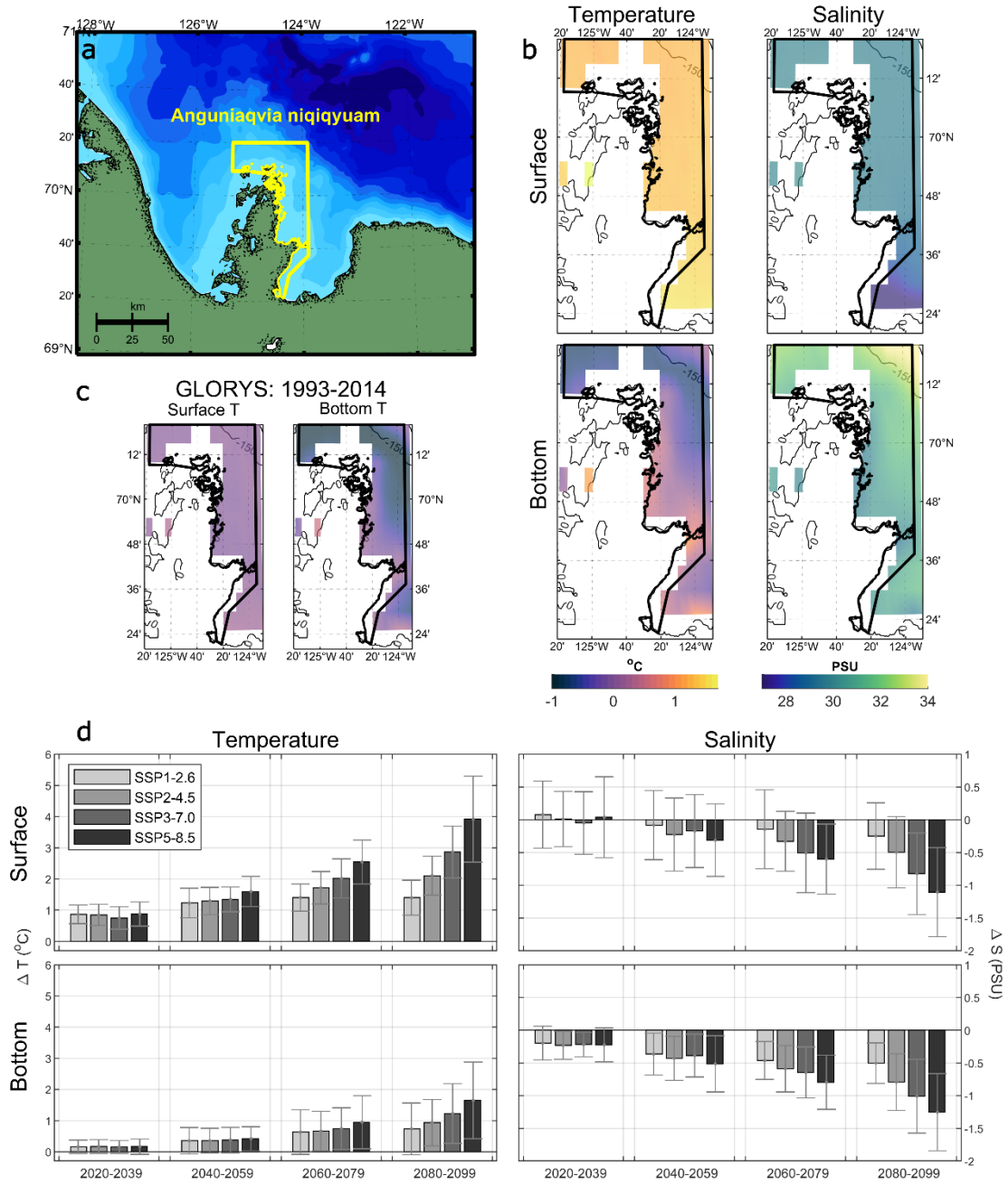


Figure 12. Projected values of temperature and salinity in the AN MPA and surrounds. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6

models. The contours in (b) and (c) are bathymetry and the shading is temperature in °C and salinity in PSU, with a colour bar below.

Table 8. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the AN MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.87 $\pm$ 0.30	1.23 $\pm$ 0.48	1.41 $\pm$ 0.43	1.40 $\pm$ 0.56
	SSP2-4.5	0.85 $\pm$ 0.34	1.30 $\pm$ 0.44	1.72 $\pm$ 0.52	2.11 $\pm$ 0.62
	SSP3-7.0	0.75 $\pm$ 0.36	1.35 $\pm$ 0.40	2.02 $\pm$ 0.63	2.87 $\pm$ 0.83
	SSP5-8.5	0.88 $\pm$ 0.39	1.60 $\pm$ 0.48	2.54 $\pm$ 0.71	3.92 $\pm$ 1.38
BT (°C)	SSP1-2.6	0.16 $\pm$ 0.21	0.35 $\pm$ 0.42	0.63 $\pm$ 0.72	0.73 $\pm$ 0.83
	SSP2-4.5	0.17 $\pm$ 0.22	0.36 $\pm$ 0.40	0.66 $\pm$ 0.64	0.93 $\pm$ 0.75
	SSP3-7.0	0.16 $\pm$ 0.21	0.38 $\pm$ 0.41	0.74 $\pm$ 0.67	1.23 $\pm$ 0.96
	SSP5-8.5	0.17 $\pm$ 0.25	0.42 $\pm$ 0.38	0.95 $\pm$ 0.85	1.65 $\pm$ 1.23
SSS (PSU)	SSP1-2.6	0.08 $\pm$ 0.51	-0.08 $\pm$ 0.53	-0.15 $\pm$ 0.60	-0.25 $\pm$ 0.51
	SSP2-4.5	0.01 $\pm$ 0.42	-0.23 $\pm$ 0.56	-0.33 $\pm$ 0.46	-0.50 $\pm$ 0.54
	SSP3-7.0	-0.05 $\pm$ 0.48	-0.17 $\pm$ 0.56	-0.51 $\pm$ 0.61	-0.82 $\pm$ 0.62
	SSP5-8.5	0.04 $\pm$ 0.62	-0.31 $\pm$ 0.55	-0.60 $\pm$ 0.54	-1.11 $\pm$ 0.68
BS (PSU)	SSP1-2.6	-0.20 $\pm$ 0.26	-0.36 $\pm$ 0.32	-0.46 $\pm$ 0.29	-0.50 $\pm$ 0.31
	SSP2-4.5	-0.23 $\pm$ 0.22	-0.43 $\pm$ 0.34	-0.59 $\pm$ 0.35	-0.79 $\pm$ 0.43
	SSP3-7.0	-0.22 $\pm$ 0.19	-0.39 $\pm$ 0.33	-0.65 $\pm$ 0.39	-1.01 $\pm$ 0.56
	SSP5-8.5	-0.22 $\pm$ 0.26	-0.51 $\pm$ 0.43	-0.79 $\pm$ 0.41	-1.25 $\pm$ 0.59
MLD (m)	SSP1-2.6	1.37 $\pm$ 1.96	1.29 $\pm$ 2.61	1.30 $\pm$ 2.50	1.18 $\pm$ 2.52
	SSP2-4.5	1.49 $\pm$ 2.12	0.93 $\pm$ 2.60	0.65 $\pm$ 2.52	0.69 $\pm$ 2.79
	SSP3-7.0	1.08 $\pm$ 1.88	0.91 $\pm$ 2.45	0.25 $\pm$ 2.89	-0.11 $\pm$ 3.00
	SSP5-8.5	1.12 $\pm$ 2.06	0.64 $\pm$ 2.42	0.23 $\pm$ 2.85	-0.54 $\pm$ 3.31
Bottom Current Speed (m/s)	SSP1-2.6	0.0016 $\pm$ 0.0015	0.0020 $\pm$ 0.0016	0.0022 $\pm$ 0.0023	0.0024 $\pm$ 0.0022
	SSP2-4.5	0.0018 $\pm$ 0.0018	0.0019 $\pm$ 0.0019	0.0026 $\pm$ 0.0024	0.0033 $\pm$ 0.0027
	SSP3-7.0	0.0014 $\pm$ 0.0016	0.0021 $\pm$ 0.0022	0.0030 $\pm$ 0.0025	0.0041 $\pm$ 0.0032
	SSP5-8.5	0.0017 $\pm$ 0.0019	0.0026 $\pm$ 0.0021	0.0036 $\pm$ 0.0032	0.0049 $\pm$ 0.0042

4.8 Tarium Niryutait MPA

The Tarium Niryutait (TN) MPA is located in the Western Arctic Bioregion, encompassing the Mackenzie River Delta and estuary of the Beaufort Sea in the Northwest Territories. Established in 2010, it was the first MPA designated in the Canadian Arctic and consists of three discrete sub-areas, Niaqunnaq, Okeevik, and Kittigaryuit that together cover approximately 1,750 km², contributing about 0.03% toward Canada's national marine conservation targets. The primary conservation objective is to conserve and protect the Eastern Beaufort Sea beluga whale population, one of the largest summering stocks globally, along with other marine species, including anadromous fishes, waterfowl, and seabirds, their critical habitats, and the supporting estuarine ecosystem. The area's unique blend of freshwater influence from the Mackenzie River and marine conditions in the Beaufort Sea creates productive habitats that are seasonally used for feeding, rearing, and other life-history functions by beluga and other species (see [Tarium Niryutait](#)

MPA). None of the three areas could be fully assessed due to proximity to shore. To compensate an area to the northwest of the two most westerly MPAs was included and all areas were summarized together to provide a regional perspective (Figure 13).

Figure 13b presents the bi-decadal average surface and bottom temperature and salinity conditions for the TN MPA region during the 2040–2059 period under the SSP2-4.5 climate scenario. GLORYS12 climatology (1993–2014) is also included (Figure 13c). Bar plots (Figure 13d) show deviations of each climate scenario from the climatology in 20-year periods, with corresponding values provided in Table 9. A CMIP6 model resolution of 1° requires about 10 cells to cover the MPA. The statistical downscaling approach results in 583 grid cells representing the TN MPA region.

SST (Table 9) increases across all SSPs and periods. In P1, warming is modest and relatively uniform, around 0.8–1.0 °C. From P2 onward, emissions pathways produce clearer divergences. By P4, SST under SSP1-2.6 rises to approximately 1.6 °C, whereas SSP2-4.5 reaches about 2.5 °C, SSP3-7.0 approximately 3.5 °C, and SSP5-8.5 nearly 4.8 °C.

BT (Table 9) also shows a clear warming signal, though the increases are somewhat more variable. Across all periods, bottom temperature rises gradually, with the most pronounced warming under SSP5-8.5. By P4, BT in this scenario exceeds 3 °C, while SSP3-7.0 and SSP2-4.5 show intermediate increases. SSP1-2.6 exhibits the smallest warming, remaining above 1 °C by the end of the period.

SSS (Table 9) shows progressive freshening across all periods. Changes are small and variable in P1 but become consistently negative from P2 onward. By P4, SSP5-8.5 exhibits the strongest freshening, exceeding –1 PSU, while SSP1-2.6 shows the least decline. Intermediate SSPs show proportional changes between these extremes.

BS (Table 9) declines across all scenarios, with changes generally smaller than at the surface. Freshening intensifies over time, particularly under higher-emissions scenarios. By P4, SSP5-8.5 records the largest decrease (about –1.0 PSU), whereas SSP1-2.6 remains below –0.4 PSU. Scenario ordering is consistent with surface trends.

MLD (Table 9) shows relatively minor changes, with generally positive anomalies in early periods. Over time, higher-emissions scenarios exhibit a trend toward slight shoaling, while SSP1-2.6 remains comparatively stable. By P4, SSP3-7.0 and SSP5-8.5 approach near-zero or slightly negative anomalies, reflecting modest shoaling under these pathways. Bottom current speed (Table 9) increases consistently across all scenarios and periods.

Spatial variation in temperature and salinity for SSP2-4.5 during 2040-2059 shows gradients in both surface and bottom maps across the spatial extent of the analyses, but less so within the limited coverage of the closed areas (Figure 13b). The closed area to the southwest appears warmer and fresher than the area to the northeast, and SST and BT are warmer in P2 than in the 1993-2014 GLORYS12 projections.

Tarium Niryutait: SSP2-4.5 2040-2059

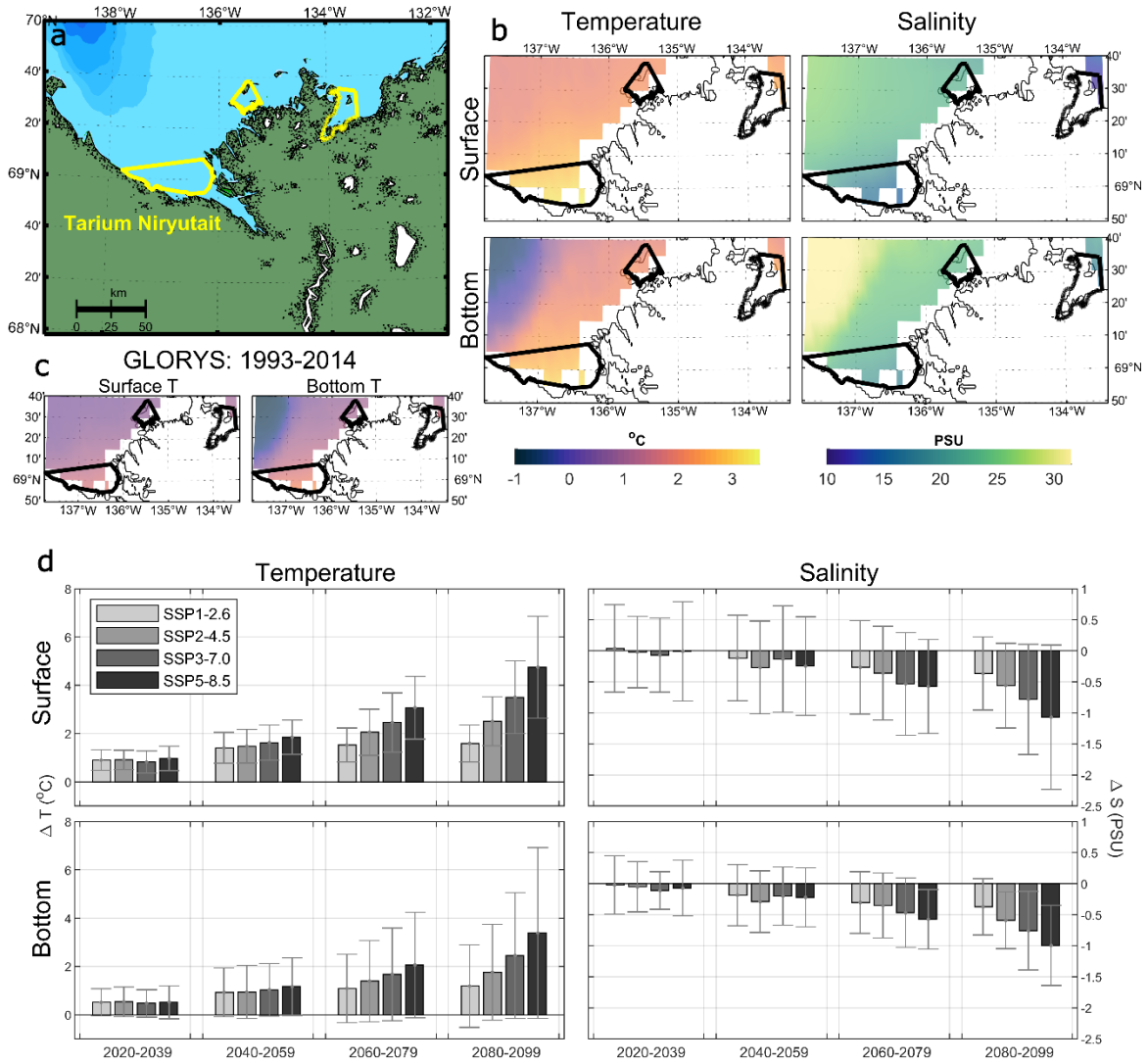


Figure 13. Projected values of temperature and salinity in the TN MPA region. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensembled 22 CMIP6 models. The shading in (b) and (c) is temperature in °C and salinity in PSU, with a colour bar below.

Table 9. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the TN MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.90 $\pm$ 0.42	1.41 $\pm$ 0.64	1.53 $\pm$ 0.71	1.59 $\pm$ 0.76
	SSP2-4.5	0.91 $\pm$ 0.40	1.47 $\pm$ 0.69	2.05 $\pm$ 0.96	2.50 $\pm$ 1.01
	SSP3-7.0	0.82 $\pm$ 0.46	1.62 $\pm$ 0.73	2.46 $\pm$ 1.23	3.50 $\pm$ 1.51
	SSP5-8.5	0.97 $\pm$ 0.51	1.85 $\pm$ 0.71	3.07 $\pm$ 1.29	4.75 $\pm$ 2.11
BT (°C)	SSP1-2.6	0.51 $\pm$ 0.56	0.93 $\pm$ 1.01	1.09 $\pm$ 1.42	1.19 $\pm$ 1.71
	SSP2-4.5	0.54 $\pm$ 0.61	0.94 $\pm$ 1.10	1.39 $\pm$ 1.68	1.76 $\pm$ 1.99
	SSP3-7.0	0.47 $\pm$ 0.57	1.03 $\pm$ 1.09	1.67 $\pm$ 1.92	2.44 $\pm$ 2.60
	SSP5-8.5	0.51 $\pm$ 0.68	1.16 $\pm$ 1.19	2.06 $\pm$ 2.18	3.38 $\pm$ 3.53
SSS (PSU)	SSP1-2.6	0.04 $\pm$ 0.71	-0.12 $\pm$ 0.69	-0.27 $\pm$ 0.75	-0.37 $\pm$ 0.59
	SSP2-4.5	-0.02 $\pm$ 0.58	-0.27 $\pm$ 0.75	-0.36 $\pm$ 0.76	-0.56 $\pm$ 0.68
	SSP3-7.0	-0.07 $\pm$ 0.60	-0.14 $\pm$ 0.86	-0.54 $\pm$ 0.83	-0.79 $\pm$ 0.89
	SSP5-8.5	-0.01 $\pm$ 0.80	-0.25 $\pm$ 0.79	-0.57 $\pm$ 0.76	-1.07 $\pm$ 1.16
BS (PSU)	SSP1-2.6	-0.02 $\pm$ 0.47	-0.19 $\pm$ 0.49	-0.30 $\pm$ 0.50	-0.37 $\pm$ 0.45
	SSP2-4.5	-0.05 $\pm$ 0.40	-0.29 $\pm$ 0.50	-0.35 $\pm$ 0.52	-0.59 $\pm$ 0.46
	SSP3-7.0	-0.11 $\pm$ 0.30	-0.20 $\pm$ 0.47	-0.47 $\pm$ 0.56	-0.76 $\pm$ 0.63
	SSP5-8.5	-0.07 $\pm$ 0.45	-0.22 $\pm$ 0.47	-0.57 $\pm$ 0.48	-1.00 $\pm$ 0.65
MLD (m)	SSP1-2.6	0.31 $\pm$ 0.48	0.25 $\pm$ 0.61	0.22 $\pm$ 0.72	0.35 $\pm$ 0.70
	SSP2-4.5	0.35 $\pm$ 0.48	0.27 $\pm$ 0.61	0.29 $\pm$ 0.61	0.28 $\pm$ 0.57
	SSP3-7.0	0.26 $\pm$ 0.57	0.44 $\pm$ 0.59	0.19 $\pm$ 0.71	0.12 $\pm$ 0.84
	SSP5-8.5	0.34 $\pm$ 0.62	0.32 $\pm$ 0.52	0.27 $\pm$ 0.72	0.17 $\pm$ 0.94
Bottom Current Speed (m/s)	SSP1-2.6	0.0005 $\pm$ 0.0012	0.0011 $\pm$ 0.0017	0.0007 $\pm$ 0.0016	0.0010 $\pm$ 0.0019
	SSP2-4.5	0.0004 $\pm$ 0.0011	0.0008 $\pm$ 0.0014	0.0017 $\pm$ 0.0021	0.0019 $\pm$ 0.0023
	SSP3-7.0	0.0007 $\pm$ 0.0012	0.0011 $\pm$ 0.0015	0.0016 $\pm$ 0.0021	0.0028 $\pm$ 0.0035
	SSP5-8.5	0.0003 $\pm$ 0.0011	0.0013 $\pm$ 0.0017	0.0024 $\pm$ 0.0026	0.0037 $\pm$ 0.0037

4.9 Tuvaijuittuq MPA

The Tuvaijuittuq MPA is located in the Arctic Ocean, off the northwest coast of Ellesmere Island, Nunavut, extending from the low-water mark to the outward boundary of Canada's EEZ. Designated in 2019, it encompasses approximately 319,411 km², representing about 5.55% of Canada's contribution to national marine conservation targets and making it the largest MPA in Canada by surface area. The MPA provides interim protection to a region characterised by some of the oldest and thickest multi-year sea ice in the Arctic. The area includes the water column, seabed, subsoil (to 5 m depth), and sea ice, extending from the low-water mark to the EEZ boundary, providing a framework for future management of ice-dependent ecosystems (see [Tuvaijuittuq MPA](#)).

Figure 14b presents the bi-decadal average surface and bottom temperature and salinity conditions for the Tuvaijuittuq MPA during the 2040–2059 period under the SSP2-4.5 climate scenario. GLORYS12 climatology (1993–2014) is also included (Figure 14c). Bar plots in the bottom

panels (Figure 14d) illustrate deviations of each climate scenario from the climatology in 20-year periods, with corresponding values provided in Table 10. The statistical downscaling approach provides almost 60,000 grid cells in the Tuvaijuittuq MPA region.

SST (Table 10) shows minimal change in P1, ranging from roughly 0.10 °C across all scenarios. Differences among SSPs become evident by P3 and P4. By the final period, SST rises to approximately 0.3 °C in SSP1-2.6, 0.6 °C in SSP2-4.5, 1.2 °C in SSP3-7.0, and over 2.0 °C in SSP5-8.5. The warming is gradual and scales with emissions intensity.

BT (Table 10) also increases steadily but remains low in magnitude. In P1, bottom temperature changes are around 0.05–0.06 °C. By P4, BT rises to approximately 0.6 °C in SSP1-2.6, 0.7 °C in SSP2-4.5, 0.9 °C in SSP3-7.0, and about 1.1 °C in SSP5-8.5. The pattern indicates progressive warming under higher emissions, although bottom waters warm more slowly than surface waters.

SSS (Table 10) exhibits consistent freshening across all periods. Initial decreases in P1 range from –0.86 to –0.82 PSU, intensifying through subsequent periods. By P4, SSP1-2.6 reaches –1.29 PSU, while SSP5-8.5 approaches –2.0 PSU. Freshening scales with emissions, with SSP3-7.0 and SSP2-4.5 showing intermediate declines.

BS (Table 10) decreases more gradually than surface salinity. Across all periods, bottom salinity shows progressive freshening under higher-emissions scenarios, reaching approximately –0.23 PSU in SSP5-8.5 by P4, while SSP1-2.6 remains around –0.15 PSU. The pattern mirrors that observed at the surface but with reduced amplitude.

MLD (Table 10) shows modest negative changes over time, ranging from about –0.5 to –1.0 m. Differences among SSPs are minor, and no strong monotonic trend is apparent, suggesting limited sensitivity of the mixed layer depth in this high-Arctic region. Bottom current speed (Table 10) exhibits minimal change throughout all periods and scenarios.

Spatial variation showed weak gradients in SST and BT for SSP2-4.5 during 2040-2059, with inshore areas being less fresh, while BT varied with depth with the warmer waters inshore (Figure 14b). This BT differential was more pronounced in P2 than for the 1993-2014 period (Figure 14b,c).

Tuvaijuittuq: SSP2-4.5 2040-2059

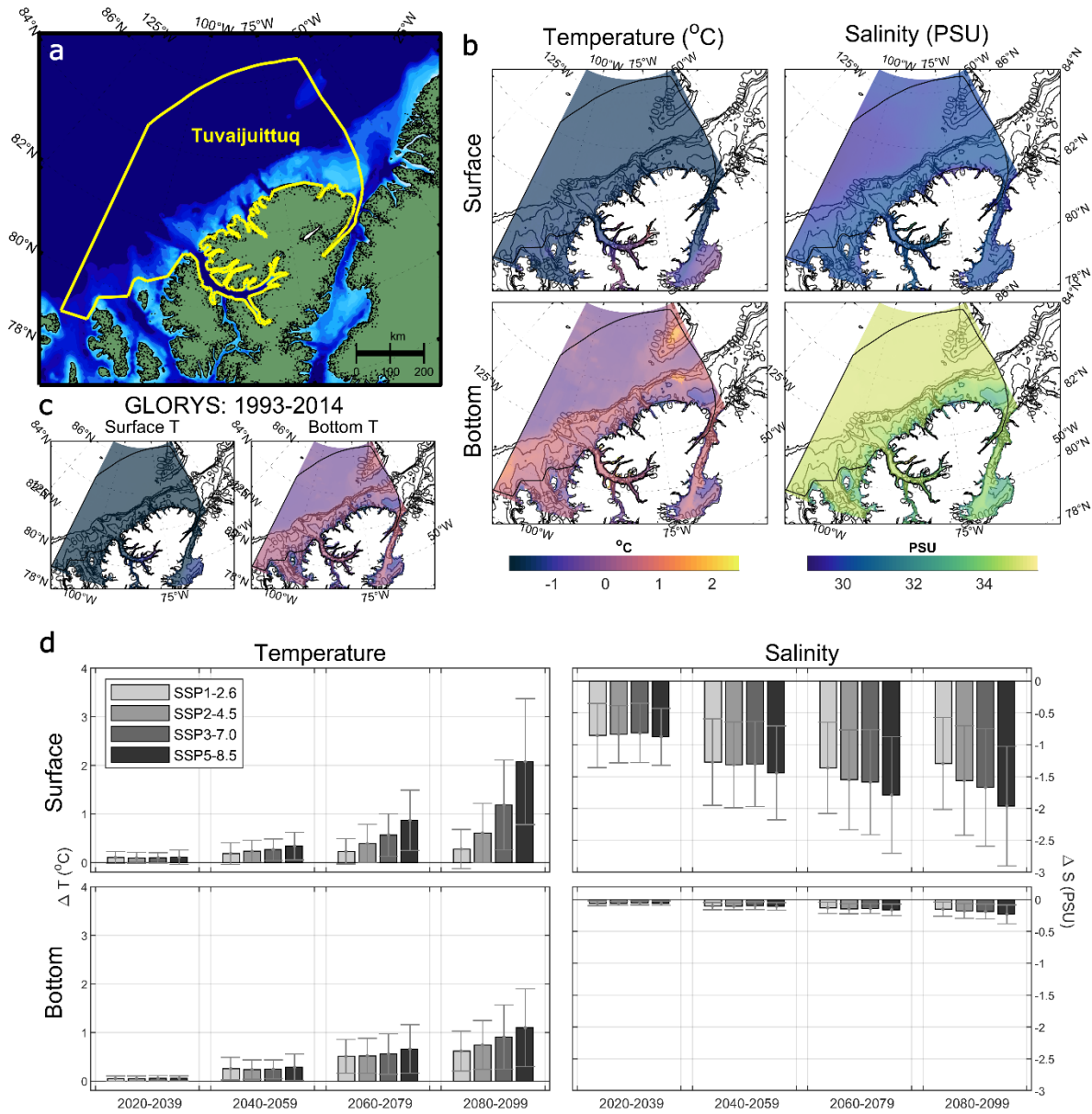


Figure 14. Projected values of temperature and salinity in the Tuvaijuittuq MPA. Panels depict a) location, b) spatial distribution of the 20-year, multi-model average surface and bottom temperature and salinity for SSP2-4.5 during 2040-2059, c) spatial distribution of the GLORYS12 climatologies of surface and bottom temperature for 1993-2014, and d) changes in 20-year, multi-model, MPA-average anomalies relative to (c) surface and bottom temperature and salinity for four SSP scenarios, with the error bars representing the standard deviation of the ensemble 22 CMIP6 models. The contours in (b) and (c) are bathymetry and the shading is temperature in °C and salinity in PSU, with a colour bar below.

Table 10. Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Tuvaijuittuq MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the ensembled 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	0.10 $\pm$ 0.12	0.18 $\pm$ 0.22	0.23 $\pm$ 0.26	0.28 $\pm$ 0.40
	SSP2-4.5	0.10 $\pm$ 0.11	0.23 $\pm$ 0.22	0.39 $\pm$ 0.39	0.61 $\pm$ 0.61
	SSP3-7.0	0.10 $\pm$ 0.11	0.26 $\pm$ 0.22	0.57 $\pm$ 0.44	1.18 $\pm$ 0.93
	SSP5-8.5	0.11 $\pm$ 0.15	0.34 $\pm$ 0.29	0.87 $\pm$ 0.62	2.08 $\pm$ 1.29
BT (°C)	SSP1-2.6	0.05 $\pm$ 0.05	0.25 $\pm$ 0.23	0.51 $\pm$ 0.35	0.62 $\pm$ 0.41
	SSP2-4.5	0.05 $\pm$ 0.05	0.24 $\pm$ 0.20	0.52 $\pm$ 0.36	0.74 $\pm$ 0.50
	SSP3-7.0	0.06 $\pm$ 0.05	0.24 $\pm$ 0.19	0.56 $\pm$ 0.42	0.91 $\pm$ 0.66
	SSP5-8.5	0.06 $\pm$ 0.05	0.29 $\pm$ 0.27	0.66 $\pm$ 0.50	1.10 $\pm$ 0.80
SSS (PSU)	SSP1-2.6	-0.86 $\pm$ 0.50	-1.27 $\pm$ 0.68	-1.37 $\pm$ 0.72	-1.29 $\pm$ 0.72
	SSP2-4.5	-0.84 $\pm$ 0.45	-1.32 $\pm$ 0.67	-1.55 $\pm$ 0.78	-1.56 $\pm$ 0.86
	SSP3-7.0	-0.82 $\pm$ 0.46	-1.30 $\pm$ 0.67	-1.59 $\pm$ 0.82	-1.67 $\pm$ 0.92
	SSP5-8.5	-0.88 $\pm$ 0.45	-1.44 $\pm$ 0.74	-1.79 $\pm$ 0.92	-1.96 $\pm$ 0.94
BS (PSU)	SSP1-2.6	-0.06 $\pm$ 0.04	-0.10 $\pm$ 0.06	-0.13 $\pm$ 0.09	-0.15 $\pm$ 0.11
	SSP2-4.5	-0.06 $\pm$ 0.03	-0.11 $\pm$ 0.05	-0.15 $\pm$ 0.08	-0.18 $\pm$ 0.12
	SSP3-7.0	-0.05 $\pm$ 0.03	-0.10 $\pm$ 0.06	-0.14 $\pm$ 0.08	-0.19 $\pm$ 0.12
	SSP5-8.5	-0.06 $\pm$ 0.04	-0.11 $\pm$ 0.06	-0.16 $\pm$ 0.09	-0.23 $\pm$ 0.15
MLD (m)	SSP1-2.6	-0.50 $\pm$ 3.42	-0.59 $\pm$ 3.76	-0.64 $\pm$ 3.95	-0.81 $\pm$ 3.75
	SSP2-4.5	-0.51 $\pm$ 3.09	-0.50 $\pm$ 3.85	-0.89 $\pm$ 3.89	-1.00 $\pm$ 4.05
	SSP3-7.0	-0.59 $\pm$ 3.14	-0.93 $\pm$ 3.69	-0.97 $\pm$ 4.18	-1.15 $\pm$ 4.37
	SSP5-8.5	-0.68 $\pm$ 3.12	-1.04 $\pm$ 3.82	-0.82 $\pm$ 4.26	-1.00 $\pm$ 4.55
Bottom Current Speed (m/s)	SSP1-2.6	0.0009 $\pm$ 0.0013	0.0017 $\pm$ 0.0018	0.0012 $\pm$ 0.0013	0.0009 $\pm$ 0.0016
	SSP2-4.5	0.0009 $\pm$ 0.0011	0.0018 $\pm$ 0.0017	0.0020 $\pm$ 0.0018	0.0016 $\pm$ 0.0018
	SSP3-7.0	0.0009 $\pm$ 0.0010	0.0018 $\pm$ 0.0019	0.0024 $\pm$ 0.0022	0.0027 $\pm$ 0.0025
	SSP5-8.5	0.0010 $\pm$ 0.0013	0.0020 $\pm$ 0.0017	0.0024 $\pm$ 0.0021	0.0032 $\pm$ 0.0029

5. Discussion

This report examines climate projections for Canada's 14 MPAs in the Atlantic, Arctic and Pacific Oceans, complementing and updating a previous report (McKee et al. 2025) and completing an assessment of all MPAs to the extent possible with our approach. A neural network was employed to model the complex relationships between the GLORYS12 ocean reanalysis and results from 22 CMIP6 models. Among the six variables investigated, MLD and bottom current speed were expected to exhibit higher uncertainty within the GLORYS12 product. This is because GLORYS12 caps minimum MLD at 10 m, potentially introducing bias during the training phase, as CMIP6 models do not impose this lower limit. Furthermore, because GLORYS12 utilizes a z-level vertical coordinate system, its ability to resolve bottom currents is inherently limited. While the Atlantic Meridional Overturning Circulation (AMOC) is widely projected to weaken due to climate change (Wang et al. 2019), our analysis shows that bi-decadal changes in bottom current speeds across the Atlantic MPAs remain negligible. This suggests these specific areas may not be sensitive to AMOC variations, though it is important to note that other regions may still experience significant bottom current weakening linked to AMOC deceleration.

Sea ice represents a critical stressor for Arctic ecosystems and is the primary pressure identified for the Tuvaijuittuq and Anguniaqvia Niqiqyuam MPAs (Fol et al. 2025, Huntington et al. 2021, Lalonde et al. 2022, Steiner et al. 2021). Despite its importance, sea ice was excluded from the current analysis due to several technical constraints. First, the GLORYS12 reanalysis tends to underestimate summer sea ice concentration, largely due to errors in atmospheric forcing. Second, while CMIP6 models offer improved sensitivity to CO₂ emissions and better seasonal cycle capture than previous generations, they still exhibit significant inter-model spread. Notably, these models often underestimate the rapid decline in September sea-ice extent and tend to overestimate ice drift speeds. These cumulative biases in both the reference data and the climate models make it difficult to generate the high-confidence projections required for these specific MPAs and most severely affect salinity projections.

For the ThT MPA in the Pacific Regions, alterations in deep-ocean circulation represent an important climate threat. While this study finds minimal changes in bottom-current speeds, it is important to note that shifts in circulation direction—which were not assessed here—remain a critical unknown. Conversely, the Musquash Estuary MPA is most vulnerable to sea-level rise and coastal erosion (McKee et al. 2025). Although these primary threats fall outside the scope of this work, the observed trends of ocean warming and freshening presented here suggest that compound stressors may occur in those regions.

6. Conclusion

This report characterises future oceanic conditions across the 14 Marine Protected Areas found in Canada's three oceans in order to provide a comprehensive national summary. To characterise these environments, we analyzed six key variables: sea surface and bottom temperature, sea surface and bottom salinity, mixed layer depth, and bottom current speed.

Both sea surface temperature and sea bottom temperature are projected to rise across all four climate scenarios for the 14 MPAs. The largest increases occur under the SSP5-8.5 scenario during the final period (2080–2099), while the SSP1-2.6 scenario shows the most moderate changes throughout the century.

While surface salinity is declining across all study areas, bottom salinity is trending upward in specific regions, including the Scotian Shelf, the Gulf of St. Lawrence, and the Gulf of Maine. This divergence suggests a significant influence from the Gulf Stream in these specific locations.

Under the SSP5-8.5 scenario by the end of the century, Banc-des-Américains, Basin Head and St. Anns Bank are projected to experience SST increases exceeding 5 °C. Similarly, St. Anns Bank and Banc-des-Américains are projected to see BT increases of more than 5 °C. St. Anns Bank and Banc-des-Américains appear to be the most vulnerable MPAs in terms of absolute temperature increase.

When looking at the relative change ($\frac{\Delta T}{T}$) with regards to temperature, MPAs in the Arctic, the Newfoundland/Labrador region, and Banc-des-Américains are projected to face the most significant climate impacts.

Generally, MPAs in the Pacific region show less vulnerability to projected climate changes compared to those in the Atlantic and Arctic.

Projections indicate no significant changes in bottom current strength. Consequently, filter-feeding species are unlikely to be impacted by alterations in flow velocity.

Projections indicate a general decrease in mixed layer depth driven by rising temperatures and declining salinity, although the maximum depth is dictated by the GLORYS12 framework and so may not be fully documented here. This trend suggests enhanced stratification, which may reduce the vertical transport of nutrients, and oxygen to deeper layers.

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8. References

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9. Appendix 1– Spatial Changes

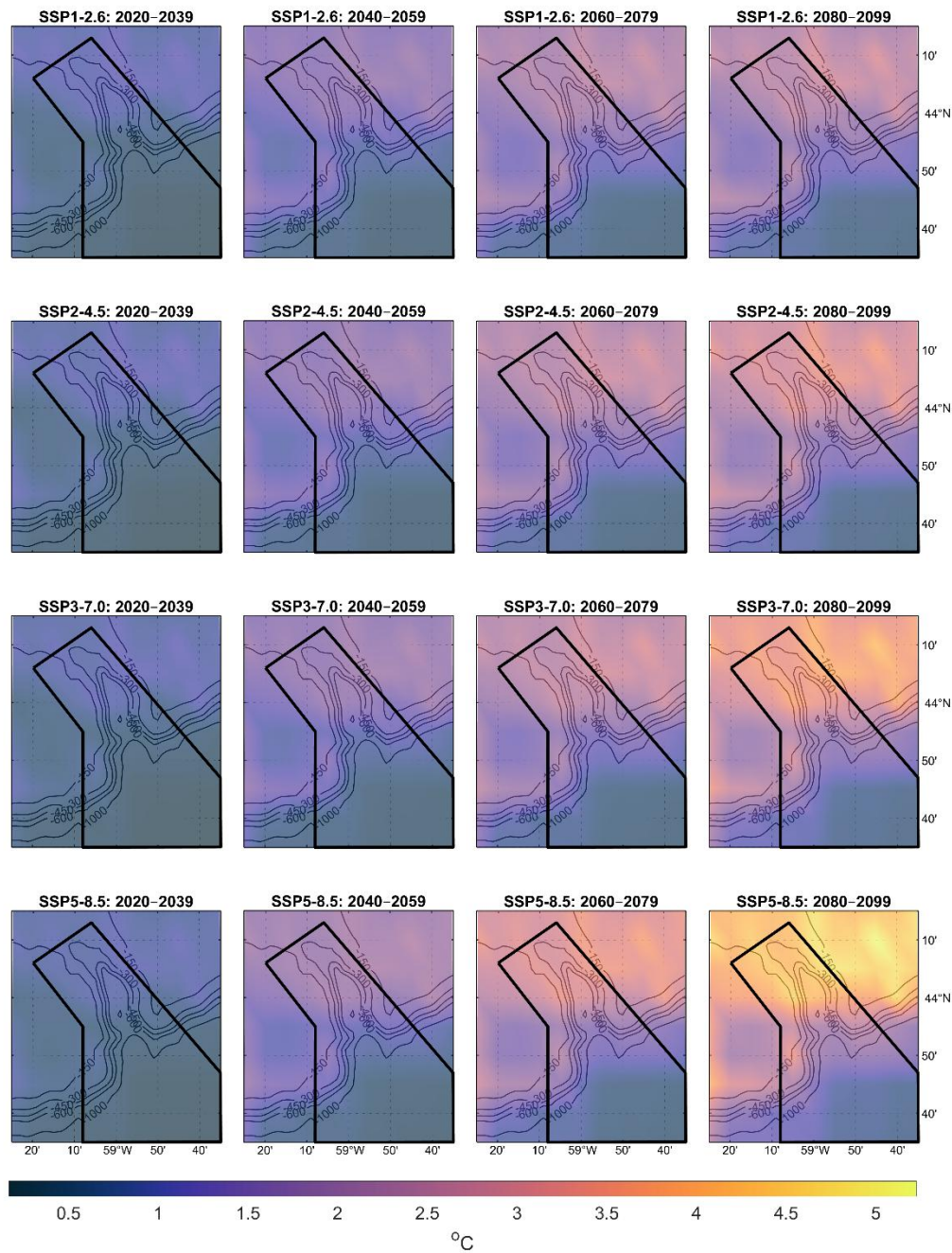


Figure A1. Projected temperature changes in the Gully MPA across all SSPs and periods where the rows represent the SSPs and the columns represent the periods. The contours are bathymetry and the shading is temperature in °C, with a colour bar below.

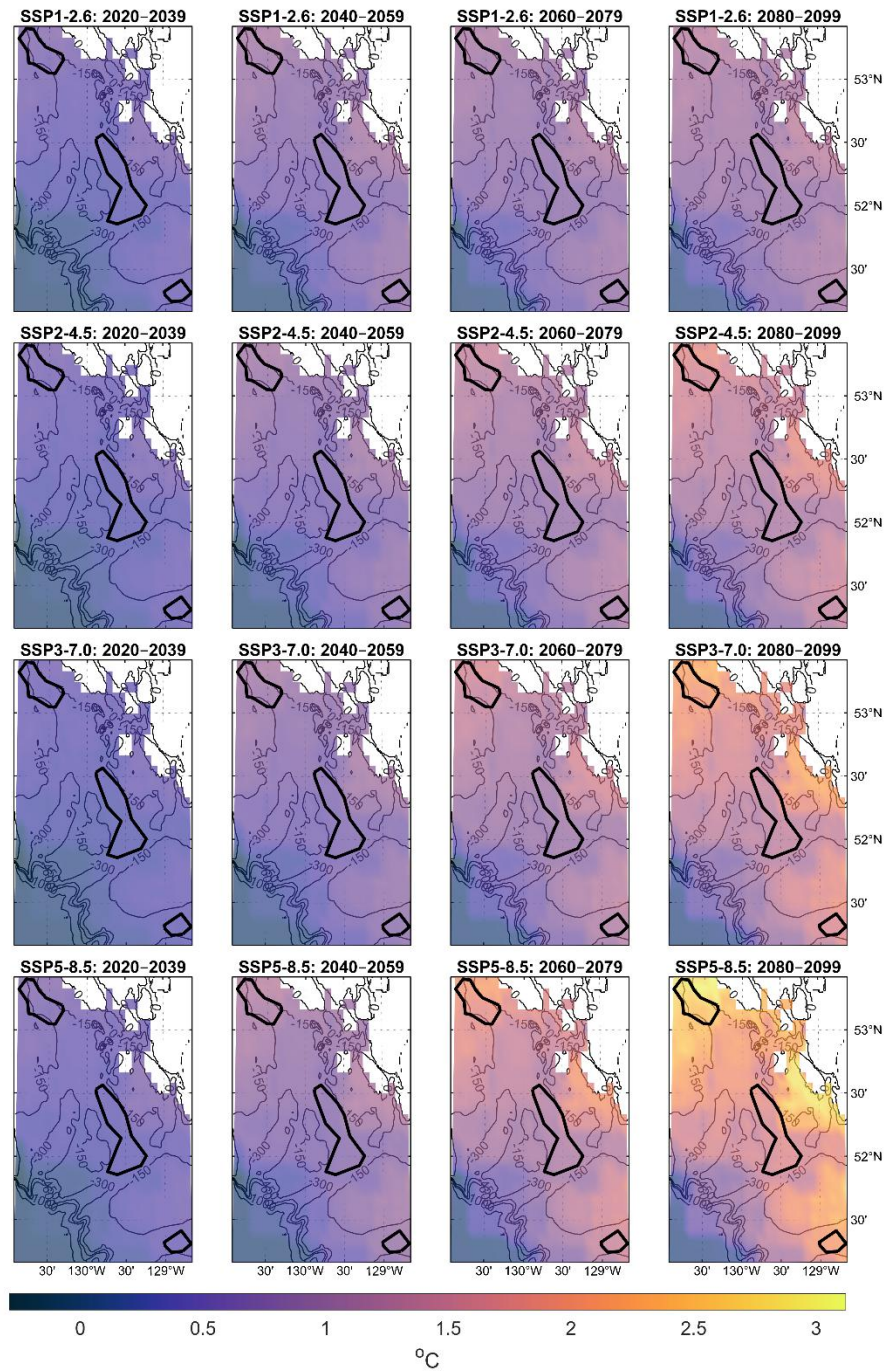


Figure A2. Projected temperature changes in the HS/QCS MPA across all SSPs and periods where the rows represent the SSPs and the columns represent the periods. The contours are bathymetry and the shading is temperature in °C, with a colour bar below.

10. Appendix 2– MPAs in the Maritimes

To address localized variability discrepancies between CMIP6 and GLORYS12 datasets, we incorporate noise at the grid point level. By augmenting variance rather than attempting to scale it down, we ensure neural network stability during training and improve downscaling accuracy at the local scale, which subsequently yields more stable trend estimates for MPA averages. Details about the noise addition approach can be found in Section 2.2.

The following are tables including data from the MPAs covered in the previous report (McKee et al. 2025) which have been updated using the improved methodology utilized in this report. It should be noted that the spatial patterns of salinity and temperature shown in the plots of McKee et al. (2025) are preserved.

Laurentian Channel MPA

Table A1: Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Laurentian Channel MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.20 $\pm$ 0.65	1.69 $\pm$ 0.97	1.88 $\pm$ 1.21	1.94 $\pm$ 1.25
	SSP2-4.5	1.14 $\pm$ 0.65	1.85 $\pm$ 0.97	2.40 $\pm$ 1.37	2.86 $\pm$ 1.51
	SSP3-7.0	1.12 $\pm$ 0.71	1.92 $\pm$ 1.07	2.82 $\pm$ 1.42	3.84 $\pm$ 1.71
	SSP5-8.5	1.17 $\pm$ 0.73	2.38 $\pm$ 1.14	3.65 $\pm$ 1.58	5.12 $\pm$ 1.99
BT (°C)	SSP1-2.6	1.09 $\pm$ 0.79	1.95 $\pm$ 1.09	2.40 $\pm$ 1.18	2.59 $\pm$ 1.32
	SSP2-4.5	1.02 $\pm$ 0.69	1.99 $\pm$ 0.88	2.72 $\pm$ 1.12	3.20 $\pm$ 1.28
	SSP3-7.0	1.03 $\pm$ 0.69	1.91 $\pm$ 0.92	2.84 $\pm$ 1.02	3.76 $\pm$ 1.20
	SSP5-8.5	1.03 $\pm$ 0.73	2.21 $\pm$ 1.06	3.34 $\pm$ 1.23	4.54 $\pm$ 1.47
SSS (PSU)	SSP1-2.6	-0.20 $\pm$ 0.21	-0.40 $\pm$ 0.26	-0.52 $\pm$ 0.34	-0.63 $\pm$ 0.41
	SSP2-4.5	-0.21 $\pm$ 0.21	-0.44 $\pm$ 0.33	-0.64 $\pm$ 0.36	-0.75 $\pm$ 0.44
	SSP3-7.0	-0.20 $\pm$ 0.21	-0.38 $\pm$ 0.28	-0.68 $\pm$ 0.37	-0.97 $\pm$ 0.45
	SSP5-8.5	-0.24 $\pm$ 0.21	-0.46 $\pm$ 0.29	-0.77 $\pm$ 0.37	-1.16 $\pm$ 0.44
BS (PSU)	SSP1-2.6	0.04 $\pm$ 0.21	0.08 $\pm$ 0.33	0.12 $\pm$ 0.37	0.14 $\pm$ 0.42
	SSP2-4.5	0.02 $\pm$ 0.23	0.07 $\pm$ 0.36	0.12 $\pm$ 0.43	0.19 $\pm$ 0.44
	SSP3-7.0	0.02 $\pm$ 0.22	0.07 $\pm$ 0.35	0.14 $\pm$ 0.45	0.21 $\pm$ 0.54
	SSP5-8.5	0.03 $\pm$ 0.21	0.12 $\pm$ 0.33	0.21 $\pm$ 0.43	0.31 $\pm$ 0.50
MLD (m)	SSP1-2.6	-0.30 $\pm$ 1.75	-1.51 $\pm$ 2.28	-1.55 $\pm$ 1.93	-2.12 $\pm$ 2.78
	SSP2-4.5	-0.20 $\pm$ 1.22	-1.25 $\pm$ 1.57	-1.90 $\pm$ 2.30	-2.65 $\pm$ 3.48
	SSP3-7.0	-0.06 $\pm$ 2.32	-1.19 $\pm$ 1.32	-2.65 $\pm$ 3.22	-3.50 $\pm$ 3.45
	SSP5-8.5	-0.34 $\pm$ 1.72	-1.87 $\pm$ 1.63	-3.25 $\pm$ 3.31	-4.36 $\pm$ 3.86
Bottom Current Speed (m/s)	SSP1-2.6	-0.0006 $\pm$ 0.0016	-0.0006 $\pm$ 0.0025	-0.0007 $\pm$ 0.0030	-0.0007 $\pm$ 0.0034
	SSP2-4.5	-0.0005 $\pm$ 0.0017	-0.0004 $\pm$ 0.0026	-0.0007 $\pm$ 0.0029	-0.0009 $\pm$ 0.0032
	SSP3-7.0	-0.0005 $\pm$ 0.0017	-0.0006 $\pm$ 0.0022	-0.0005 $\pm$ 0.0031	-0.0009 $\pm$ 0.0033
	SSP5-8.5	-0.0008 $\pm$ 0.0018	-0.0008 $\pm$ 0.0026	-0.0008 $\pm$ 0.0034	-0.0010 $\pm$ 0.0036

St. Anns Bank MPA

Table A2: Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the St. Anns Bank MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.26 $\pm$ 0.65	1.83 $\pm$ 0.98	2.04 $\pm$ 1.21	2.11 $\pm$ 1.26
	SSP2-4.5	1.21 $\pm$ 0.63	1.97 $\pm$ 0.96	2.61 $\pm$ 1.37	3.07 $\pm$ 1.47
	SSP3-7.0	1.19 $\pm$ 0.71	2.06 $\pm$ 1.09	3.04 $\pm$ 1.42	4.13 $\pm$ 1.70
	SSP5-8.5	1.26 $\pm$ 0.74	2.56 $\pm$ 1.14	3.90 $\pm$ 1.57	5.46 $\pm$ 1.95
BT (°C)	SSP1-2.6	1.29 $\pm$ 0.90	2.17 $\pm$ 1.20	2.69 $\pm$ 1.32	2.90 $\pm$ 1.34
	SSP2-4.5	1.20 $\pm$ 0.80	2.26 $\pm$ 1.02	3.02 $\pm$ 1.25	3.63 $\pm$ 1.32
	SSP3-7.0	1.17 $\pm$ 0.76	2.19 $\pm$ 1.04	3.22 $\pm$ 1.22	4.30 $\pm$ 1.44
	SSP5-8.5	1.17 $\pm$ 0.82	2.61 $\pm$ 1.20	3.92 $\pm$ 1.38	5.22 $\pm$ 1.52
SSS (PSU)	SSP1-2.6	-0.22 $\pm$ 0.24	-0.40 $\pm$ 0.29	-0.49 $\pm$ 0.38	-0.59 $\pm$ 0.42
	SSP2-4.5	-0.20 $\pm$ 0.24	-0.42 $\pm$ 0.35	-0.61 $\pm$ 0.38	-0.71 $\pm$ 0.48
	SSP3-7.0	-0.18 $\pm$ 0.23	-0.36 $\pm$ 0.32	-0.64 $\pm$ 0.45	-0.93 $\pm$ 0.56
	SSP5-8.5	-0.25 $\pm$ 0.27	-0.44 $\pm$ 0.32	-0.73 $\pm$ 0.44	-1.15 $\pm$ 0.52
BS (PSU)	SSP1-2.6	0.06 $\pm$ 0.26	0.09 $\pm$ 0.39	0.16 $\pm$ 0.44	0.19 $\pm$ 0.46
	SSP2-4.5	0.04 $\pm$ 0.29	0.11 $\pm$ 0.43	0.15 $\pm$ 0.50	0.26 $\pm$ 0.49
	SSP3-7.0	0.04 $\pm$ 0.27	0.11 $\pm$ 0.42	0.18 $\pm$ 0.53	0.28 $\pm$ 0.64
	SSP5-8.5	0.03 $\pm$ 0.28	0.18 $\pm$ 0.38	0.29 $\pm$ 0.49	0.36 $\pm$ 0.56
MLD (m)	SSP1-2.6	0.75 $\pm$ 1.93	0.19 $\pm$ 1.06	0.30 $\pm$ 1.36	0.07 $\pm$ 1.50
	SSP2-4.5	0.78 $\pm$ 1.28	0.32 $\pm$ 1.24	0.12 $\pm$ 1.29	-0.57 $\pm$ 1.91
	SSP3-7.0	0.81 $\pm$ 2.08	0.22 $\pm$ 1.39	-0.40 $\pm$ 2.01	-0.99 $\pm$ 2.18
	SSP5-8.5	0.73 $\pm$ 1.75	-0.06 $\pm$ 1.10	-0.96 $\pm$ 1.89	-1.81 $\pm$ 2.44
Bottom Current Speed (m/s)	SSP1-2.6	-0.0010 $\pm$ 0.0022	-0.0016 $\pm$ 0.0025	-0.0018 $\pm$ 0.0024	-0.0020 $\pm$ 0.0025
	SSP2-4.5	-0.0007 $\pm$ 0.0021	-0.0009 $\pm$ 0.0025	-0.0013 $\pm$ 0.0025	-0.0018 $\pm$ 0.0026
	SSP3-7.0	-0.0007 $\pm$ 0.0020	-0.0011 $\pm$ 0.0023	-0.0015 $\pm$ 0.0029	-0.0019 $\pm$ 0.0028
	SSP5-8.5	-0.0006 $\pm$ 0.0022	-0.0015 $\pm$ 0.0027	-0.0018 $\pm$ 0.0031	-0.0021 $\pm$ 0.0032

Basin Head MPA

Table A3: Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Basin Head MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.29 $\pm$ 0.47	1.92 $\pm$ 0.65	2.13 $\pm$ 0.85	2.20 $\pm$ 0.89
	SSP2-4.5	1.25 $\pm$ 0.45	2.04 $\pm$ 0.65	2.69 $\pm$ 0.88	3.25 $\pm$ 0.90
	SSP3-7.0	1.20 $\pm$ 0.54	2.10 $\pm$ 0.75	3.21 $\pm$ 0.89	4.41 $\pm$ 1.11
	SSP5-8.5	1.35 $\pm$ 0.53	2.69 $\pm$ 0.79	4.11 $\pm$ 1.05	5.75 $\pm$ 1.22
BT (°C)	SSP1-2.6	1.08 $\pm$ 0.43	1.59 $\pm$ 0.70	1.75 $\pm$ 0.83	1.86 $\pm$ 0.92
	SSP2-4.5	1.02 $\pm$ 0.51	1.62 $\pm$ 0.74	2.14 $\pm$ 0.89	2.58 $\pm$ 0.93
	SSP3-7.0	0.93 $\pm$ 0.56	1.60 $\pm$ 0.62	2.44 $\pm$ 0.74	3.30 $\pm$ 0.88
	SSP5-8.5	1.02 $\pm$ 0.52	2.07 $\pm$ 0.70	3.11 $\pm$ 0.95	4.24 $\pm$ 1.01
SSS (PSU)	SSP1-2.6	-0.19 $\pm$ 0.24	-0.33 $\pm$ 0.34	-0.38 $\pm$ 0.39	-0.45 $\pm$ 0.44
	SSP2-4.5	-0.16 $\pm$ 0.31	-0.32 $\pm$ 0.42	-0.49 $\pm$ 0.46	-0.57 $\pm$ 0.53
	SSP3-7.0	-0.14 $\pm$ 0.27	-0.28 $\pm$ 0.38	-0.52 $\pm$ 0.58	-0.74 $\pm$ 0.69
	SSP5-8.5	-0.21 $\pm$ 0.31	-0.35 $\pm$ 0.36	-0.59 $\pm$ 0.56	-0.96 $\pm$ 0.63
BS (PSU)	SSP1-2.6	-0.14 $\pm$ 0.21	-0.29 $\pm$ 0.31	-0.36 $\pm$ 0.37	-0.42 $\pm$ 0.42
	SSP2-4.5	-0.14 $\pm$ 0.28	-0.28 $\pm$ 0.35	-0.42 $\pm$ 0.44	-0.49 $\pm$ 0.51
	SSP3-7.0	-0.15 $\pm$ 0.24	-0.23 $\pm$ 0.34	-0.39 $\pm$ 0.50	-0.58 $\pm$ 0.58
	SSP5-8.5	-0.18 $\pm$ 0.27	-0.27 $\pm$ 0.30	-0.47 $\pm$ 0.47	-0.72 $\pm$ 0.57
MLD (m)	SSP1-2.6	0.17 $\pm$ 0.54	0.09 $\pm$ 0.66	0.12 $\pm$ 0.69	0.22 $\pm$ 0.67
	SSP2-4.5	0.14 $\pm$ 0.56	0.23 $\pm$ 0.67	0.14 $\pm$ 0.72	0.09 $\pm$ 0.70
	SSP3-7.0	0.19 $\pm$ 0.62	0.10 $\pm$ 0.65	0.03 $\pm$ 0.79	-0.02 $\pm$ 0.94
	SSP5-8.5	0.25 $\pm$ 0.59	0.04 $\pm$ 0.71	-0.19 $\pm$ 0.78	-0.35 $\pm$ 0.94
Bottom Current Speed (m/s)	SSP1-2.6	0.0015 $\pm$ 0.0024	0.0010 $\pm$ 0.0026	0.0007 $\pm$ 0.0032	0.0012 $\pm$ 0.0046
	SSP2-4.5	0.0018 $\pm$ 0.0030	0.0015 $\pm$ 0.0028	0.0011 $\pm$ 0.0036	0.0006 $\pm$ 0.0032
	SSP3-7.0	0.0016 $\pm$ 0.0027	0.0011 $\pm$ 0.0030	0.0010 $\pm$ 0.0040	-0.0002 $\pm$ 0.0038
	SSP5-8.5	0.0014 $\pm$ 0.0026	0.0007 $\pm$ 0.0024	-0.0003 $\pm$ 0.0036	-0.0007 $\pm$ 0.0047

Banc-des-Américains MPA

Table A4: Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Banc-des-Américains MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.14 $\pm$ 0.51	1.76 $\pm$ 0.70	1.98 $\pm$ 0.82	2.06 $\pm$ 0.90
	SSP2-4.5	1.09 $\pm$ 0.45	1.86 $\pm$ 0.64	2.52 $\pm$ 0.93	3.07 $\pm$ 0.97
	SSP3-7.0	1.05 $\pm$ 0.54	1.91 $\pm$ 0.76	2.98 $\pm$ 0.99	4.12 $\pm$ 1.15
	SSP5-8.5	1.16 $\pm$ 0.53	2.43 $\pm$ 0.87	3.83 $\pm$ 1.15	5.42 $\pm$ 1.35
BT (°C)	SSP1-2.6	1.10 $\pm$ 0.62	1.91 $\pm$ 0.94	2.39 $\pm$ 1.17	2.55 $\pm$ 1.25
	SSP2-4.5	1.10 $\pm$ 0.71	2.03 $\pm$ 1.00	2.80 $\pm$ 1.25	3.36 $\pm$ 1.27
	SSP3-7.0	1.01 $\pm$ 0.66	1.98 $\pm$ 0.95	2.93 $\pm$ 1.06	4.02 $\pm$ 1.29
	SSP5-8.5	1.02 $\pm$ 0.66	2.39 $\pm$ 1.03	3.71 $\pm$ 1.39	5.01 $\pm$ 1.33
SSS (PSU)	SSP1-2.6	-0.26 $\pm$ 0.34	-0.45 $\pm$ 0.46	-0.49 $\pm$ 0.50	-0.60 $\pm$ 0.56
	SSP2-4.5	-0.21 $\pm$ 0.32	-0.41 $\pm$ 0.48	-0.63 $\pm$ 0.49	-0.71 $\pm$ 0.58
	SSP3-7.0	-0.22 $\pm$ 0.35	-0.36 $\pm$ 0.40	-0.63 $\pm$ 0.60	-0.91 $\pm$ 0.69
	SSP5-8.5	-0.23 $\pm$ 0.35	-0.44 $\pm$ 0.38	-0.76 $\pm$ 0.55	-1.24 $\pm$ 0.67
BS (PSU)	SSP1-2.6	-0.07 $\pm$ 0.23	-0.13 $\pm$ 0.33	-0.12 $\pm$ 0.43	-0.14 $\pm$ 0.46
	SSP2-4.5	-0.06 $\pm$ 0.26	-0.12 $\pm$ 0.40	-0.15 $\pm$ 0.50	-0.13 $\pm$ 0.51
	SSP3-7.0	-0.08 $\pm$ 0.25	-0.09 $\pm$ 0.38	-0.16 $\pm$ 0.49	-0.18 $\pm$ 0.59
	SSP5-8.5	-0.10 $\pm$ 0.25	-0.07 $\pm$ 0.32	-0.11 $\pm$ 0.51	-0.22 $\pm$ 0.56
MLD (m)	SSP1-2.6	0.77 $\pm$ 0.97	0.64 $\pm$ 0.99	0.62 $\pm$ 1.30	0.61 $\pm$ 1.13
	SSP2-4.5	0.66 $\pm$ 1.13	0.72 $\pm$ 1.18	0.55 $\pm$ 1.04	0.30 $\pm$ 1.04
	SSP3-7.0	0.69 $\pm$ 1.08	0.57 $\pm$ 1.01	0.37 $\pm$ 1.26	0.16 $\pm$ 1.29
	SSP5-8.5	0.72 $\pm$ 1.06	0.47 $\pm$ 1.09	0.12 $\pm$ 1.21	-0.19 $\pm$ 1.44
Bottom Current Speed (m/s)	SSP1-2.6	0.0001 $\pm$ 0.0006	0.0000 $\pm$ 0.0010	0.0002 $\pm$ 0.0012	0.0005 $\pm$ 0.0015
	SSP2-4.5	0.0001 $\pm$ 0.0006	0.0003 $\pm$ 0.0010	0.0003 $\pm$ 0.0012	0.0002 $\pm$ 0.0015
	SSP3-7.0	-0.0001 $\pm$ 0.0007	0.0001 $\pm$ 0.0008	-0.0001 $\pm$ 0.0011	-0.0001 $\pm$ 0.0015
	SSP5-8.5	-0.0001 $\pm$ 0.0008	0.0002 $\pm$ 0.0011	0.0001 $\pm$ 0.0014	-0.0001 $\pm$ 0.0019

Musquash Estuary MPA

Table A5: Projected changes (anomaly $\pm$ standard deviation) in oceanic conditions in the Musquash Estuary MPA from 2020-2099 for four climate scenarios, based on 20-year average periods. P1: 2020-2039; P2: 2040-2059; P3: 2060-2079; P4: 2080-2099. The anomaly is relative to GLORYS12 (1993-2014) and the standard deviation is that of the 22 CMIP6 models.

		P1	P2	P3	P4
SST (°C)	SSP1-2.6	1.07 $\pm$ 0.51	1.57 $\pm$ 0.68	1.74 $\pm$ 0.86	1.76 $\pm$ 0.91
	SSP2-4.5	1.03 $\pm$ 0.49	1.67 $\pm$ 0.65	2.21 $\pm$ 0.91	2.60 $\pm$ 1.12
	SSP3-7.0	1.04 $\pm$ 0.55	1.78 $\pm$ 0.78	2.58 $\pm$ 1.02	3.58 $\pm$ 1.43
	SSP5-8.5	1.08 $\pm$ 0.55	2.24 $\pm$ 0.96	3.36 $\pm$ 1.23	4.64 $\pm$ 1.63
BT (°C)	SSP1-2.6	0.70 $\pm$ 0.65	1.20 $\pm$ 0.85	1.44 $\pm$ 1.01	1.46 $\pm$ 0.94
	SSP2-4.5	0.63 $\pm$ 0.62	1.25 $\pm$ 0.92	1.69 $\pm$ 1.17	2.06 $\pm$ 1.24
	SSP3-7.0	0.64 $\pm$ 0.61	1.27 $\pm$ 0.88	1.95 $\pm$ 1.23	2.73 $\pm$ 1.55
	SSP5-8.5	0.76 $\pm$ 0.64	1.60 $\pm$ 1.05	2.47 $\pm$ 1.47	3.61 $\pm$ 2.00
SSS (PSU)	SSP1-2.6	0.05 $\pm$ 0.24	0.01 $\pm$ 0.30	-0.03 $\pm$ 0.30	-0.07 $\pm$ 0.34
	SSP2-4.5	0.06 $\pm$ 0.24	-0.01 $\pm$ 0.30	-0.06 $\pm$ 0.39	-0.20 $\pm$ 0.43
	SSP3-7.0	0.05 $\pm$ 0.19	0.06 $\pm$ 0.29	-0.05 $\pm$ 0.42	-0.17 $\pm$ 0.43
	SSP5-8.5	0.01 $\pm$ 0.25	0.05 $\pm$ 0.34	-0.12 $\pm$ 0.37	-0.43 $\pm$ 0.53
BS (PSU)	SSP1-2.6	0.04 $\pm$ 0.15	0.06 $\pm$ 0.20	0.08 $\pm$ 0.28	0.05 $\pm$ 0.30
	SSP2-4.5	0.05 $\pm$ 0.12	0.11 $\pm$ 0.29	0.08 $\pm$ 0.33	0.10 $\pm$ 0.36
	SSP3-7.0	0.05 $\pm$ 0.13	0.12 $\pm$ 0.27	0.14 $\pm$ 0.36	0.17 $\pm$ 0.49
	SSP5-8.5	0.06 $\pm$ 0.15	0.15 $\pm$ 0.21	0.20 $\pm$ 0.30	0.21 $\pm$ 0.43
MLD (m)	SSP1-2.6	3.69 $\pm$ 3.85	3.58 $\pm$ 3.26	3.27 $\pm$ 3.23	3.43 $\pm$ 3.16
	SSP2-4.5	3.97 $\pm$ 3.78	3.50 $\pm$ 3.50	3.23 $\pm$ 3.02	2.80 $\pm$ 2.84
	SSP3-7.0	3.98 $\pm$ 3.74	3.51 $\pm$ 3.16	3.09 $\pm$ 3.10	2.78 $\pm$ 2.71
	SSP5-8.5	3.55 $\pm$ 3.52	3.47 $\pm$ 3.33	2.72 $\pm$ 2.76	2.27 $\pm$ 2.41
Bottom Current Speed (m/s)	SSP1-2.6	0.0008 $\pm$ 0.0025	0.0011 $\pm$ 0.0027	0.0006 $\pm$ 0.0026	0.0014 $\pm$ 0.0028
	SSP2-4.5	0.0007 $\pm$ 0.0029	0.0007 $\pm$ 0.0028	0.0008 $\pm$ 0.0025	0.0012 $\pm$ 0.0040
	SSP3-7.0	0.0005 $\pm$ 0.0025	0.0008 $\pm$ 0.0025	0.0009 $\pm$ 0.0025	0.0015 $\pm$ 0.0040
	SSP5-8.5	0.0002 $\pm$ 0.0022	0.0008 $\pm$ 0.0028	0.0012 $\pm$ 0.0032	0.0014 $\pm$ 0.0049