CUMULATIVE IMPACT MONITORING FRAMEWORK

An operational framework to guide NWT CIMP's work to understand cumulative impacts and support effective resource management in the Northwest Territories

January | 2025

Government of
Northwest Territories

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English

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French

Kīspin ki nitawihtīn ē nīhīyawihk ōma ācimōwin, tipwāsinān.
Cree

Tłı̨chǫ yatı k'ę̀è. Dı wegodı newǫ dè, gots'o gonede.
Tłı̨chǫ

ʔerıhtł'ís Dëne Sųłıné yatı t'a huts'elkër xa beyáyatı theɔ ɂą ɔat'e, nuwe ts'ën yółtı.
Chipewyan

Edı gondı dehgáh got'ı̨e zhatıé k'ę́é edatł'éh enahddhę nıde naxets'é edahłí.
South Slavey

K'áhshó got'ı̨ne xədə k'é hederı ɔedı̨htl'é yerınıwę nídé dúle.
North Slavey

Jii gwandak izhii ginjìk vat'atr'ijąhch'uu zhit yinohthan jì', diits'àt ginohkhìi.
Gwich'in

Uvanittuaq ilitchurisukupku Inuvialuktun, ququaqluta.
Inuvialuktun

ᑕᒃᑯᐊ ᑎᑎᖅᑲᐃᑦ ᐱᓕᒍᐃᖏᑦ ᐃᓄᒃᑎᑐᓕᖅᓱᒪᓗᑎᒃ, ᐅᐸᑦᑎᓂᓄᑦ ᐅᖅᑲᓕᔪᓂᓚᖅᑐᑦ.
Inuktitut

Hapkua titiqqat pijumagupkit Inuinnaqtun, uvaptinnut hivajarlutit.
Inuinnaqtun

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Acronyms

CIMF – Cumulative Impact Monitoring Framework
ECC – Department of Environment and Climate Change, Government of Northwest Territories
GNWT – Government of Northwest Territories
MVRMA – *Mackenzie Valley Resource Management Act*
NERB – NWT Environmental Research Bulletin
NRV – Natural range of variation
NWT CIMP – Northwest Territories Cumulative Impact Monitoring Program
VC – Valued component

Summary

Cumulative impacts are the combined effects that human activities and natural processes have on our environment. The *Mackenzie Valley Resource Management Act*, Part 6, and the Gwich'in, Sahtù, and Tłı̨chǫ Land Claim Agreements require monitoring and assessment of cumulative impacts in the Northwest Territories (NWT). The NWT Cumulative Impact Monitoring Program's (NWT CIMP) role is to fulfill these requirements by furthering understanding of cumulative impacts and environmental trends to support effective resource management decision-making in the NWT. NWT CIMP has developed the Cumulative Impact Monitoring Framework (CIMF) to better meet these needs.

The CIMF is an operational guide for NWT CIMP to develop science monitoring and research that can predict cumulative impacts and support effective resource management decision-making in the NWT. The NWT's vast geographic scale and remoteness require that NWT CIMP's resources are directed towards developing a predictive understanding of cumulative impacts, rather than conducting comprehensive long-term monitoring.

Long-term monitoring is primarily conducted by other entities which allows NWT CIMP the flexibility to adapt to decision-maker needs. The CIMF is intended to guide NWT CIMP science program activities and coordination with other entities that conduct long-term monitoring on Valued Components (VCs). The CIMF has been developed to work within NWT CIMP's current human resource and financial capacity limits.

The CIMF's approach consists of four core elements: *Prioritization*, *Monitoring and Research*, *Analysis*, and *Reporting* as highlighted below.

Prioritization: NWT CIMP co-develops research and monitoring priorities with the NWT CIMP Steering Committee and decision-makers which includes both identifying the valued components (VCs) and revising the Blueprint Priorities on a 5-year cycle. Currently, there are three VCs: caribou, water, and fish.

Monitoring and Research: NWT CIMP provides funding for priority projects and facilitates the use of standardized methods and data management practices in the NWT. NWT CIMP also conducts field monitoring and research to address high priority questions to understand the impact of multiple environmental stressors at a broader level than is typically possible within the scope of funded projects.

Analysis: NWT CIMP leads assessments of the natural range of variation, and statistical modelling to evaluate the effects of multiple stressors. Using validated statistical models, NWT CIMP works with resource managers to develop forecasts for the valued components under relevant management scenarios. Scientific data for these analyses will be consolidated from as many publicly available data sources as possible (e.g., NWT CIMP projects, Land and Water Boards, other GNWT programs).

Reporting: NWT CIMP aims to provide information for use during decision-making processes and to the public, including communities. Plain language reporting is produced for all NWT CIMP led or funded projects (e.g., NWT Environmental Research Bulletins [NERBs]). NWT CIMP contributes technical information to larger public reports (e.g., NWT State of the Environment, and status and trend reports). New research, analyses, and synthesis reviews are posted on the NWT Discovery Portal and should be published in academic journals to ensure technical details are validated by the scientific community for later use by decision-makers. NWT CIMP also provides specific information and tools to support decision-making processes, both within formalized regulatory and environmental assessment processes and informal discussions.

Introduction

The Northwest Territories Cumulative Impact Monitoring Program (NWT CIMP) defines **cumulative impacts** as the combined effects that human activities and natural processes have on our environment. The cumulative impact of multiple natural and human-caused (anthropogenic) stressors often cannot be predicted in isolation. Cumulative impacts of multiple stressors may be greater (synergistic) or less (antagonistic) than expected by the sum of their individual effects (additive), requiring consideration of multiple stressors at the same time (Crain et al. 2008, Galic et al. 2018, Orr et al. 2020). For example, with rapid climate warming, there has been an increasing occurrence and intensity of wildfires in NWT's boreal forest in combination with permafrost thaw (Vitt et al. 2000, Helbig et al. 2016, Li et al. 2021). These natural changes interact with changes made by human developments, such as oil and gas and highway infrastructure, potentially negatively affecting valued components (VCs).

Cumulative impact monitoring and analysis are necessary for understanding and predicting how the environment will respond to future disturbances, which informs decision-making. The successful management of our natural resources depends on our ability to detect and address these cumulative impacts within a suitable timeframe (Likens and Lindenmayer 2018). Cumulative impact monitoring and assessment is legally required under the *Mackenzie Valley Resource Management Act* (MVRMA), Part 6, and the Gwich'in, Sahtù, and Tłı̨chǫ Land Claim Agreements.

NWT CIMP's role is to fulfill these requirements by furthering the collective understanding of cumulative impacts and environmental trends to support effective resource management decision-making. Over the past decade, the Mackenzie Valley Environmental Impact Review Board, Indigenous governments and Indigenous organizations, and the independent auditors conducting the 2020 and 2025 NWT Environmental Audit have all called for the development and implementation of a framework to improve the GNWT's ability to monitor, assess, and predict cumulative impacts. In response, NWT CIMP has developed the Cumulative Impact Monitoring Framework (CIMF) to guide NWT CIMP program activities and coordination with other ECC programs and those of other departments, governments or organizations that conduct long-term monitoring on the VCs.

The CIMF at a Glance

The CIMF outlines NWT CIMP's approach to detect and understand cumulative impacts in the NWT in collaboration with other programs with a responsibility for the VCs. With a territory encompassing 1.14 million square kilometers, and a population of ~45 thousand, limitations in capacity and funding require that NWT CIMP focus on developing a predictive understanding of the cumulative impacts, rather than conducting comprehensive long-term monitoring. Long-term monitoring is typically focused on evaluating the current state of the environment and identifying trends through time (e.g., caribou herd size and location, water quantity and quality trends, fisheries stock assessment) and is conducted by other entities. In contrast, a predictive understanding of

cumulative impacts requires determining what causes those trends so that we can predict future environmental states and trends, and this is NWT CIMP's focus.

The CIMF consists of four elements that include iterative feedback loops. This enables prioritization, monitoring and research, analysis, and reporting requirements to evolve and meaningfully inform northern resource management decision-making. NWT CIMP expects that when we can predict cumulative impacts for the current VCs, priorities may shift to new VCs.

The CIMF approach (Figure 1) includes:

1) **Prioritization –** how we identify the most important questions to ask.

2) **Monitoring and Research –** how we collect data needed to identify cumulative impacts to the VCs.

3) **Analysis –** how we collate and analyze data and use the results to develop predictions of expected cumulative impacts to the VCs.

4) **Reporting–** how/where we share monitoring and analysis information and tools.

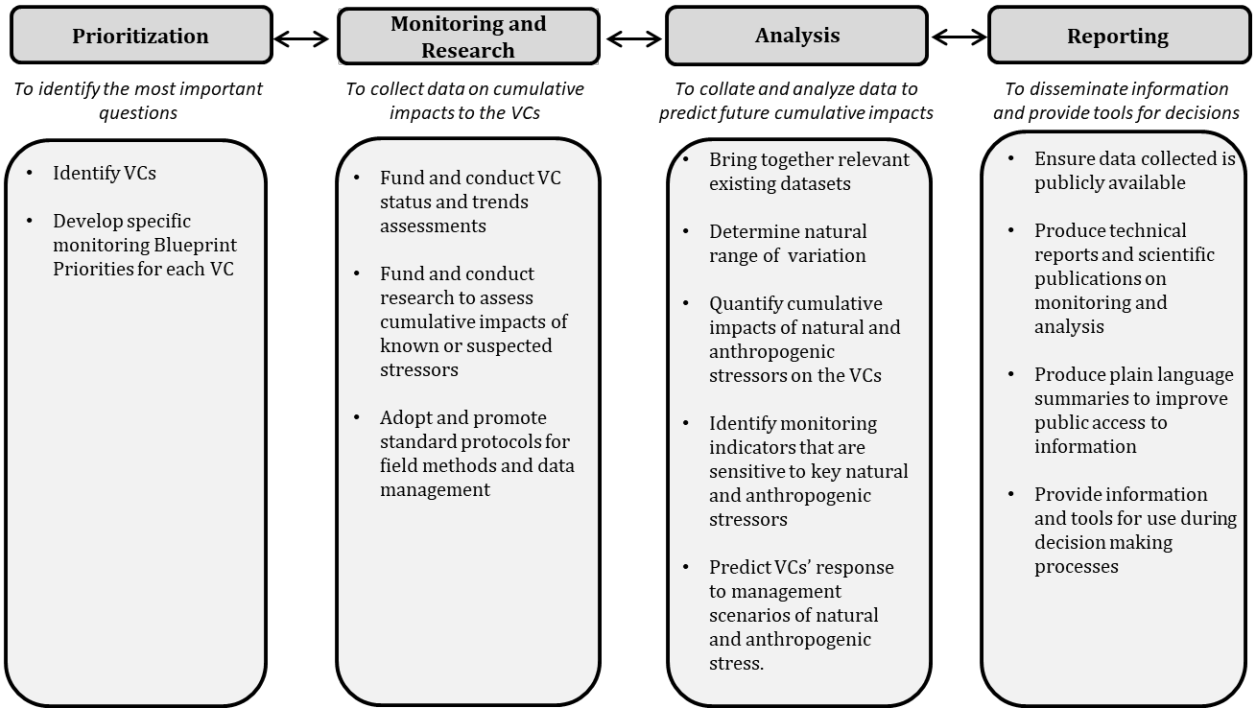

Figure 1: Main elements of the CIMF are Prioritization, Monitoring and Research, Analysis, and Reporting.

The CIMF is intended to serve as high level guidance for NWT CIMP program activities and coordination with other ECC programs and those of other departments, governments or organizations that conduct long-term monitoring on the VCs.

The management of cumulative impacts within the NWT is a shared responsibility of the GNWT and co-management partners. NWT CIMP is not a decision-maker but contributes to decision-making processes by providing information and tools. NWT CIMP relies on decision-maker participation during the Prioritization phase to identify priority questions that contribute to current northern resource management decisions. NWT CIMP and partners report the answers to these questions widely through plain language and technical reporting allowing for NWT CIMP conducted and funded work to be used in decision-making. Additionally, NWT CIMP produces and maintains specialized reporting products and tools that easily support the inclusion of cumulative impact information into specific decisions (e.g., Inventory of Landscape Change, CBGC ALCES Online forecasts).

At present, the CIMF is limited to scientific information. Traditional Knowledge[1] uses different methods, but can also follow a similar framework of Prioritization, Monitoring and Research, Analysis, and Reporting. A separate operational guide may be developed that defines how NWT CIMP furthers the NWT's collective understanding of cumulative impacts and environmental trends to support effective resource management decision-making, considering Traditional Knowledge, should the Steering Committee and Indigenous partners support this work. The protocols to collect and use Traditional Knowledge for management decisions and the Traditional Knowledge itself may look very different depending on geographic area and community priorities. Some Indigenous governments and Indigenous organizations are also already developing their own independent Traditional Knowledge CIMFs that reflect these specific contexts. Many Indigenous governments and Indigenous organizations have also developed Traditional Knowledge agreements, policies, and guidelines. All work involving Traditional Knowledge should follow the relevant policies and guidelines.

1. Prioritization

Given the large geographic area of the NWT, limits in capacity and resources, and countless unanswered questions surrounding cumulative impacts, the foundational element of the CIMF is prioritization. By identifying the most important questions and challenges, NWT CIMP directs resources towards monitoring and research that is likely to meaningfully impact NWT resource management. Prioritization guides all subsequent elements of the

[1] Traditional Knowledge is knowledge and values, which have been acquired through experience, observation, from the land or from spiritual teachings, and handed down from one generation to another (1997) Government of the Northwest Territories Traditional Knowledge Policy Implementation Framework. While "traditional knowledge" is the term used in the Policy, ECC is currently using the term Indigenous Knowledge, to be more inclusive of all knowledge holders, and to more specifically recognize the knowledge that has been and is currently being created by Indigenous peoples, groups, and organizations. Where possible knowledge will be referred to using the preferred terminology of the knowledge holder or community.

CIMF by identifying the VCs and informing NWT CIMP's monitoring and research priorities (Blueprints). The NWT CIMP Steering Committee plays an integral role in prioritization and includes representatives from Indigenous, federal, and territorial governments as well as co-management boards.

VCs are selected in partnership with NWT co-management boards, resource managers, and the NWT CIMP Steering Committee because of their importance to NWT residents. In the early 2000's, NWT CIMP developed a long list of VCs. Recognizing that the many VCs were hindering the program's ability to make strategic progress on answering priority questions, in 2011, NWT CIMP used a survey and multi-partner workshop results to identify three priority VCs: **caribou**, **water**, and **fish**. These VCs were confirmed by the Steering Committee, and they remain the program's focus today. As priorities change, VCs can and should be updated; the Steering Committee considers the VCs at regular intervals. Given continued importance of the VCs and the expectation that VCs will be updated, long-term monitoring is and will continue to be conducted by other entities (e.g. ECC-Wildlife Research and Management (caribou), ECC-Water Monitoring and Management (water) and Fisheries and Oceans Canada (fish)). Additionally, every five years, NWT CIMP sends a survey to key partners and decision-makers to help determine whether current priorities are meeting partners' needs. See the Funding Guide for a list of resource management decision-makers in the NWT.

NWT CIMP collaboratively develops specific monitoring and research priorities, in the form of Blueprints, for each VC (caribou, water, and fish) and Traditional Knowledge in partnership with the same partners identified above. By identifying the specific questions needed to affect decision-making, the Blueprints provide a roadmap for NWT CIMP monitoring and research actions. This includes working directly with co-management partners to identify the reporting products and tools that will best support the consideration of cumulative impacts in upcoming decisions. Priority stressors identified in the survey help ensure the Blueprints reflect partner priorities. The Blueprints inform project leads of monitoring and research priorities of key decision-makers and resource managers. They describe information needed to better understand cumulative impacts and help to guide reporting needs for a variety of audiences for effective decision-making. It is expected that as questions are answered, development phases progress (captured on the Inventory of Landscape Change), or new concerning trends emerge, monitoring and research priorities will change to reflect risk. To reflect these shifting priorities, the Blueprints are reviewed every five years.

2. Monitoring and Research

Stemming from the Blueprint Priorities, NWT CIMP conducts and funds monitoring and research on the VCs. Monitoring initiatives are typically designed to evaluate the baseline or current state of the environment and identify any trends through time. Cumulative impact research is designed to systematically investigate cumulative impacts and generate new knowledge. Notably, the line between monitoring and research is fuzzy and data collected for one purpose often supports the other.

Most monitoring and research guided by the CIMF is conducted by researchers outside of NWT CIMP through the NWT CIMP funding program, but NWT CIMP staff also lead monitoring and research projects directly. Information about the funding process including instructions, templates, guidance and protocols is available online (NWT CIMP Apply for Funding). Funded projects must address current Blueprint priorities, must benefit NWT CIMP partners, and be well designed to meet their proposed objectives. Additionally funded projects are strongly encouraged to be led by or work with Indigenous communities, enhancing community capacity. Northern project leadership, training and community capacity building are encouraged through CIMP funding, but nonetheless, currently expertise from outside the territory is often required. NWT CIMP leads monitoring and research on high priority questions about the cumulative impacts of multiple stressors at a broader regional scale, to fill knowledge gaps and to better predict future cumulative impacts.

Whether conducted or funded by NWT CIMP, monitoring and research initiatives should be designed in such a way that they can effectively answer the questions stemming from the Blueprints. This requires careful study design, and the use of standardized methods and data management systems. The methods used depend on the VC and questions/objectives being answered. Each VC is assessed through **environmental indicators**, measures that track the VC's condition, that are reliably measured in the field, and that respond in a predictable way to the stressors of interest. Decision-makers sometimes dictate which environmental indicators are of interest for specific VCs. NWT CIMP can provide input into selecting and standardizing regulatory environmental indicators by identifying indicators which are reliably measured and are expected to be impacted by the stressors in question by creating specialized reporting products (e.g., Standards for Reporting Water Quality Information in the NWT). If specific environmental indicators have been identified by decision-makers, NWT CIMP's Blueprints and cumulative impact monitoring will be/are adjusted to reflect these decisions.

Standard use of environmental indicators, protocols for field methods, and data management ensures consistency and comparability between datasets and allows results from multiple projects to contribute to a broader understanding of cumulative impacts across the NWT. Standard protocols outline consistent rules for the collection, recording, managing, analysis and reporting of data that contribute to the measurement or observation of environmental indicators. NWT CIMP uses, identifies, and promotes standard protocols and environmental indicators whenever possible. Standard protocols are published annually in the Science Project Funding Guide. Use of standard protocols allows data from many sources to be collected and consolidated for analysis of cumulative impacts at a broad spatial scale. Many communities have or are developing their own monitoring and where possible projects should work with communities to ensure compatibility.

ECC operates several long-term monitoring programs assessing impacts to VCs. NWT CIMP will continue to work with the responsible divisions to support the interpretation of this work through cumulative impact analysis and, when appropriate, to incorporate this data

into the CIMF analyses. When possible, short-term monitoring and research should use methods consistent with relevant long-term monitoring programs.

Guidance for predictive cumulative impacts monitoring and research

1. *Adequate Sample Sizes*
   Study design and site selection for monitoring and research require careful consideration of the objectives. Sample sizes should be sufficient to meet monitoring and research objectives. For example, a monitoring program with the objective to be able to detect a 10% annual increase within 5 years, requires less sampling effort than one that must be able to detect a 10% annual increase within 2 years. NWT CIMP supports the use of power analysis and simulations to evaluate the study design's ability to meet the monitoring objectives.

2. *Careful site selection during environmental trend monitoring*
   Most monitoring programs are designed to *either* quantify conditions (e.g., aerial population surveys, environmental trend monitoring), *or* monitor for impacts (e.g., Aquatic effects monitoring programs). However, when feasible, site selection for monitoring work should be designed in such a way as to inform on both the state of the environment and the cumulative impacts of environmental stressors at play (i.e., support research efforts). For example, sites selected across a multivariate gradient of environmental conditions can still be representative of the study area average conditions if additional effort is put towards study design before monitoring begins (e.g., Gillespie et al. 2017). For monitoring across large spatial areas, regional stratification should be ecologically relevant or based on management criteria (e.g.., ecoregions, watersheds, calving grounds). NWT CIMP can provide tools for site selection to address these challenges (e.g. Halton Iterative Partitioning site selection tool; Van Dam-Bates 2020).

3. *Suggested use of multifactorial or gradient study designs for research*
   Study design is equally important for research initiatives investigating the cumulative impacts of multiple stressors. To disentangle and quantify the impacts of multiple stressors, the study design should cover a multivariate gradient of stressors (Danz et al. 2005) and/or use a multifactorial design (e.g., across multiple categories of stressors; Carvalho et al. 2016). These gradient and multifactorial study designs are particularly useful if it is hypothesized that synergistic effects may occur. However, depending on the research questions, other study designs may be more appropriate, and NWT CIMP encourages creative and new approaches.

4. *Consideration of scale*
   There is a need for monitoring and research at multiple spatial and ecological scales to assess cumulative impacts. The spatial scale at which cumulative impacts are evaluated varies and is dependent upon the VC (Arciszewski and Munkittrick 2015, Leps et al. 2015, Burgazzi et al. 2020). Cumulative impacts at the individual scale

often do not serve as proxies for higher level ecological scales (i.e., population or community) due to trade-offs in physiology and life history at higher levels (Galic et al. 2018). In addition, analysis at different ecological scales often requires multiple methods (Hodgson and Halpern 2019). When possible, the CIMF adopts the spatial and ecological scales already defined through existing ECC initiatives, such as the Boreal Caribou Range Planning Framework and Bathurst Caribou Range Plan.

3. Analysis

Analyzing the cumulative impacts of multiple stressors can be extremely challenging. Cumulative impacts are often not the sum of each individual stressor's effect, and instead may be greater (synergistic) or less (antagonistic) than expected by their sum (additive) (Crain et al. 2008, Galic et al. 2018, Orr et al. 2020). Statistical modeling offers an opportunity to use scientific data collected through different forms of monitoring and then link monitored outcomes to natural and anthropogenic stressors. Models serve as data-driven representations of the ecosystem that can make predictions about the cumulative impacts of multiple stressors.

NWT CIMP uses an adaptive modeling approach to analyse cumulative impacts in the NWT. This modeling approach has three objectives:

1) Quantify the natural range of variation (NRV) in environmental indicators across the landscape where appropriate.
2) Assess which stressors are affecting the VCs, quantify each stressors' individual impact, and the cumulative impacts of combined stressors to tease apart synergistic and additive effects.
3) Forecast how VCs will respond to management scenarios of future natural and anthropogenic stressors, and if the data allows, compare forecasted conditions to management objectives.

Ecological systems are naturally dynamic, and conditions vary through both space and time. NRV refers to the spatial and temporal variation in baseline conditions during a time when the ecosystem was untouched by anthropogenic stressors (Kilgour et al. 1998a). There are many natural stressors that have dramatic effects on ecological conditions (e.g., forest fires); effects of these natural stressors are incorporated into the NRV. This can be challenging when natural stressors are interacting with anthropogenic stressors. However, there are different methods for calculating the NRV (Landres et al. 1999, Munkittrick et al. 2009, Kilgour et al. 2017, Munkittrick and Arciszewski 2017), the appropriateness of which depend on the VC, management objective, environmental indicator, scale and data available.

NWT CIMP builds models using known landscape characteristics and measured stressors at monitored locations to explain observed data on VCs (e.g., water quality parameters, caribou herd population sizes, forest stand age). Models are designed to ask specific questions about the system such as:

1) Which environmental indicators are most sensitive to each stressor?
2) How do natural and anthropogenic stressors affect the VCs individually and are there thresholds below which the stressors do not have an impact?
3) How do different combinations of natural and anthropogenic stressors interact to cumulatively impact a particular VC? Are there additive, synergistic, or antagonistic effects?
4) Are there gaps in monitoring that need to be filled to understand how important combinations of stressors will affect the VCs?

Data for these models should be collated from many sources, including NWT CIMP collected or funded data, long-term monitoring programs, and other external sources, when and where possible. Integrating data sources requires that data collection methods are compatible and modelling techniques can account for and address any lingering discrepancies. To support model development, NWT CIMP and the GNWT Centre for Geomatics have developed the Inventory of Landscape Change, a geospatial catalogue of disturbances and other changes on the landscape. It is updated annually to provide information on the current and historic development that has occurred in the NWT for inclusion in analysis.

Model validation, where the model's ability to predict observed patterns in the data is tested, is a crucial component of statistical modeling. Following the quote, "all models are wrong, but some are useful" (George Box), a good model should fit the data well and explain a large portion of the variation by accurately representing ecological relationships. There are many methods for model validation using cross validation techniques based on existing data (Roberts et al. 2017, Yates et al. 2023) that test the model's ability to predict future data.

A key component of model validation is identifying gaps in monitoring and research. Models can produce a reliable understanding of the response variable when the predictor variables are within the range of data used to develop the model (Wenger and Olden 2012, Yates et al. 2018, Ploton et al. 2020). For example, if a statistical model was developed using boreal lake monitoring data, we should be skeptical of predictions this model makes for tundra lakes. Some gaps in monitoring and research are obvious, but other gaps emerge only in a multi-stressor context such as if a particular combination of stressors is expected to interact synergistically or antagonistically, but that combination of stressors is not observed. If these gaps hinder decision-making, they may be targeted for future work during Prioritization.

After building a model and validating that it represents a system accurately, NWT CIMP uses these models to predict the state of VCs across similar landscapes and/or to forecast future changes to VCs under various management scenarios (e.g., proposed development scenarios). Model predictions can be used to create tools, such as cumulative impact risk maps (e.g., Micheletti et al. 2021, Raymundo et al. 2024). Risk maps can display areas

where stressor(s) would impact VCs, the severity of the impact, and the level of (un)certainty. Areas that model predictions identified as high risk would in turn be candidates for increased monitoring, research, or management actions.

Analysis itself is adaptive, such that the underlying structure of the model and the covariates evolve and improve to reflect current understandings of how the ecosystem functions. For example, both Traditional Knowledge and scientific knowledge have long pointed to insect harassment as an important cause of caribou calf mortality, but insect harassment is not typically included in statistical population models due to lack of insect monitoring data. If information about insect abundance or activity became available, models could be revised to incorporate this stressor and evaluate its effects on caribou populations.

4. Reporting

NWT CIMP is committed to releasing timely and accurate information in a consistent, transparent, and reliable manner. Reporting analytical results to key decision-makers, partners, community members, and the public is crucial for making effective and evidenced-based decisions, as well as ensuring an informed public. As required through the CIMP funding process, prior to any public reporting, community partners should be given the opportunity to validate and contribute to the interpretation presented in the public documents. Where interpretations of results differ, both should be presented. Reporting should appropriately acknowledge the contributions of all partners. For both NWT CIMP-funded and NWT CIMP-led projects, results are reported at multiple stages:

1) Open access raw data
2) Technical reporting and scientific publications
3) Plain language reporting (e.g., NWT Environmental Research Bulletins, project videos)
4) Specialized reporting and tools for decision-makers

All data collected during monitoring and research should be publicly available in accessible and user-friendly formats. NWT CIMP has developed a Data Management Internal Operational Guideline and publicly available Data Management Requirements. These guidelines apply to all NWT CIMP funded projects collecting scientific data and provides guidance on data management and long-term data storage options. In collaboration with the GNWT Centre for Geomatics, NWT CIMP operates the NWT Discovery Portal, a comprehensive online source for NWT environmental monitoring knowledge, where cumulative impact monitoring data may be stored publicly. Additionally, all water quality data collected through NWT CIMP funded projects are made publicly accessible through the Mackenzie Datastream, an open access data hub for water quality data in the Mackenzie Valley. However, there may be situations where scientific data cannot be shared publicly due to privacy, security, legal concerns, or other sensitivities. Common examples include personal information or exact locations of Species at Risk.

Analysis of the NRV and the past, present, and future effects of stressors on the VCs is reported to a technical audience through both scientific publications and technical reports. Scientific publication in a peer-reviewed academic journal is an extremely important step to validate and disseminate research. Additionally, to improve overall quality of monitoring and research, work on new models, particularly those using new or unusual modeling methods, and new monitoring programs is submitted for academic peer review and publication.

Technical results from ongoing monitoring or routinely updated modeling efforts using existing methods are reported routinely to co-management partners and made publicly available. These technical reports convey how monitoring results compare to defined management objectives. There are a variety of avenues for this. The NWT State of the Environment Report (released every four years) provides updated trends in environmental quality where available, and details how various stressors are contributing to cumulative impacts. For many of the VCs, VC specific status and trend reports are also produced (e.g., species status reports and progress reports).

In addition to technical reports, plain language reporting is essential for ensuring that the public can access and understand key research and monitoring. Technical reports are accompanied by Plain Language Summaries. The NWT Environmental Research Bulletin (NERB), a high-level plain-language summary of key findings, or a project video are two options. For decision-makers, these plain language products serve as an accessible gateway into more technical products, including technical reporting and manuscripts, and specialized tools designed explicitly for use by decision-makers. Technical information is provided to decision-makers within formalized regulatory and environmental assessment processes and informal discussions as requested.

The management of cumulative impacts within the NWT is a shared responsibility of the GNWT and co-management partners. NWT CIMP is not a decision-maker but contributes to decision-making processes by providing information and tools for use during decision-making processes. During regulatory processes, technical results are put forward by both proponents and regulatory specialists to evaluate the impacts of the project and develop appropriate monitoring and mitigation plans and conditions.

NWT CIMP produces and maintains specialized reporting products and tools that are geared toward allowing decision-makers to easily incorporate cumulative impact information into specific decisions. For example, NWT CIMP maintains the bathymetric and cumulative water withdrawal layers on the Inventory of Landscape Change which can be used during Water Licensing to ensure that the cumulative water withdrawal across multiple active Water Licenses does not negatively impact the waterbody. Through Prioritization, NWT CIMP works with co-management boards to identify the reporting products and tools that will best support the consideration of cumulative impacts in upcoming decisions. NWT CIMP products and tools can be used by any intervenor in a process (e.g., an Indigenous government, proponents).

In addition to providing information and tools about current cumulative impacts, NWT CIMP is committed to providing tools for decision-makers, project proponents, and regulatory participants that support forecasting future cumulative impacts. When making decisions, managers consider the cumulative impacts of natural and anthropogenic stressors under relevant management scenarios (Bennett et al. 2003, Mahmoud et al. 2009, Petchey et al. 2015). Incorporating the best available information on how past conditions and processes are likely to affect ecological systems, through the NRV and an understanding of the cumulative impacts of natural stressors, supports informed decision-making (Kilgour et al. 1998b). Furthermore, validated models are used to develop specialized predictions quantifying the outcomes of management scenario alternatives, though there are many challenges and uncertainties to this process (Bennett et al. 2003, Oliver and Roy 2015). Decision-makers then evaluate these scenario predictions based on management objectives. A clear understanding of the expected cumulative impacts of each management decision on the VCs also informs monitoring conditions set during regulatory processes. For example, NWT CIMP supported development of the CBGC ALCES Online which was designed to meet the needs of NWT Renewable Resources Boards to evaluate forecasted impacts of future development and land use scenarios on the barren-ground caribou herds. This product is used primarily by the boards.

Conclusions

NWT CIMP defines cumulative impacts as the combined effects that human activities and natural processes have on our environment. As the cumulative impacts of multiple natural and anthropogenic stressors can be greater or less than their individual effects, cumulative impact monitoring is necessary for predicting how the environment will respond to future disturbances. NWT CIMP has developed the CIMF to guide NWT CIMP's assessment of cumulative impacts and environmental trends in support of effective resource management decision-making. Prioritization, Monitoring and Research, Analysis, and Reporting make up the four core elements of NWT CIMP's approach to detect and understand cumulative impacts in the NWT.

Glossary

Additive Cumulative Impact – The effect of multiple stressors that is expected based on the sum of their individual effects.

Antagonistic Cumulative Impact – The effect of multiple stressors is less than expected based on the sum of their individual effects.

Anthropogenic Stressor – A environmental stressor that is caused by human activity. Examples include harvest, development, forestry, and climate change.

Baseline Conditions – The environmental conditions before any anthropogenic stressors occurred, against which future environmental changes can be compared (revised from NWT CIMP 2015).

Cumulative Impacts – Cumulative impacts are the combined effects that human activities and natural processes have on our environment.

Cumulative Impacts Assessment – A systematic process of identifying, analyzing, and evaluating cumulative impacts (Canadian Council of Ministers of the Environment 2014).

Decision-point – A pre-agreed monitoring condition that specifies management action (i.e., if the monitoring indicators show x, y, and z, we will follow this course of action). Decision-points may be informed by the natural range of variation, ecological thresholds, human health, societal values, or other criteria.

Environmental Indicator – a measure that tracks the condition of a valued component (NWT CIMP 2015) that can be reliably measured in the field and responds in a predictable way to the stressors of interest.

Management Action – A specific action initiated when a monitoring program identifies that a decision point has been reached. Management actions may include special studies, operational changes, or implementing mitigation activities to stabilize or reverse a change in environmental conditions (revised from Wek'èezhìi Land and Water Board 2010).

Management Objective – The desired conditions, often determined by baseline conditions and stakeholder values, which guides decision-making.

Natural Stressor – A stressor that occurs naturally in the environment, absent human intervention. Examples include extreme weather events, predation, disease.

Natural Range of Variation – Spatial and temporal variation in ecological conditions during a time when the ecosystem was untouched by anthropogenic stressors.

Protocol – Detailed methods for the collection, recording, managing, and reporting of data that contribute to the measurement or observation of environmental indicators (Aboriginal Affairs and Northern Development Canada 2012).

Stressor – A chemical, biological, or environmental stimulus or event that shifts environmental conditions outside of the preferred conditions. Stressors may be natural or anthropogenic, though the distinction between natural and anthropogenic

stressors can blurred in the case of cumulative impacts (e.g., climate change mediated wildfires).

Synergistic Cumulative Impact **–** The effect of multiple stressors is greater than expected based on the sum of their individual effects.

Threshold – A limit of tolerance to a stressor beyond which a very small change in the level of stressor causes a large response (i.e., a tipping point). The response may or may not be reversible.

Valued Component– Biological, physical, and human components of our environment that NWT CIMP identifies as ecologically, socially, or economically important selected in partnership with NWT land and water regulators, subject-matter experts, and the NWT CIMP Steering Committee.

References

Aboriginal Affairs and Northern Development Canada. 2012. CIMP Key Terms and Definitions.

Arciszewski, T. J., and K. R. Munkittrick. 2015. Development of an adaptive monitoring framework for long-term programs: An example using indicators of fish health. Integrated Environmental Assessment and Management 11:701–718.

Arciszewski, T. J., K. R. Munkittrick, G. J. Scrimgeour, M. G. Dubé, F. J. Wrona, and R. R. Hazewinkel. 2017. Using adaptive processes and adverse outcome pathways to develop meaningful, robust, and actionable environmental monitoring programs. Integrated Environmental Assessment and Management 13:877–891.

Bennett, E., S. Carpenter, G. Peterson, G. Cumming, M. Zurek, and P. Pingali. 2003. Why global scenarios need ecology. Frontiers in Ecology and the Environment 1:322–329.

Burgazzi, G., A. Laini, O. Ovaskainen, M. Saccò, R. Stubbington, and P. Viaroli. 2020. Communities in high definition: Spatial and environmental factors shape the micro-distribution of aquatic invertebrates. Freshwater Biology 65:2053–2065.

Canadian Council of Ministers of the Environment. 2014. Canada-wide Definitions and Principles for Cumulative Effects.

Carvalho, S. B., J. Gonçalves, A. Guisan, and J. P. Honrado. 2016. Systematic site selection for multispecies monitoring networks. Journal of Applied Ecology 53:1305–1316.

Crain, C. M., K. Kroeker, and B. S. Halpern. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11:1304–1315.

Danz, N. P., R. R. Regal, G. J. Niemi, V. J. Brady, T. Hollenhorst, L. B. Johnson, G. E. Host, J. M. Hanowski, C. A. Johnston, T. Brown, J. Kingston, and J. R. Kelly. 2005. Environmentally stratified sampling design for the development of Great Lakes environmental indicators. Environmental Monitoring and Assessment 102:41–65.

Galic, N., L. L. Sullivan, V. Grimm, and V. E. Forbes. 2018. When things don't add up: quantifying impacts of multiple stressors from individual metabolism to ecosystem processing. Ecology Letters 21:568–577.

Gillespie, M. A. K., M. Baude, J. Biesmeijer, N. Boatman, G. E. Budge, A. Crowe, J. Memmott, R. D. Morton, S. Pietravalle, S. G. Potts, D. Senapathi, S. M. Smart, and W. E. Kunin. 2017. A method for the objective selection of landscape-scale study regions and sites at the national level. Methods in Ecology and Evolution 8:1468–1476.

Helbig, M., C. Pappas, and O. Sonnentag. 2016. Permafrost thaw and wildfire: Equally important drivers of boreal tree cover changes in the Taiga Plains, Canada. Geophysical Research Letters 43:1598–1606.

Hodgson, E. E., and B. S. Halpern. 2019. Investigating cumulative effects across ecological scales. Conservation Biology 33:22–32.

Kilgour, B. W., K. M. Somers, T. J. Barrett, K. R. Munkittrick, and A. P. Francis. 2017. Testing against "normal" with environmental data. Integrated Environmental Assessment and Management 13:188–197.

Kilgour, B. W., K. M. Somers, and D. E. Matthews. 1998a. Using the normal range as a criterion for ecological significance in environmental monitoring and assessment. Ecoscience 5:542–550.

Kilgour, B. W., K. M. Somers, and D. E. Matthews. 1998b. Using the normal range as a criterion for ecological significance in environmental monitoring and assessment. Écoscience 5:542–550.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the Use of Natural Variability Concepts in Managing Ecological Systems. Ecological Applications 9:1179–1188.

Leps, M., J. D. Tonkin, V. Dahm, P. Haase, and A. Sundermann. 2015. Disentangling environmental drivers of benthic invertebrate assemblages: The role of spatial scale and riverscape heterogeneity in a multiple stressor environment. Science of The Total Environment 536:546–556.

Li, X.-Y., H.-J. Jin, H.-W. Wang, S. S. Marchenko, W. Shan, D.-L. Luo, R.-X. He, V. Spektor, Y.-D. Huang, X.-Y. Li, and N. Jia. 2021. Influences of forest fires on the permafrost environment: A review. Advances in Climate Change Research 12:48–65.

Likens, G., and D. Lindenmayer. 2018. Effective Ecological Monitoring. Csiro Publishing.

Lindenmayer, D. B., and G. E. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology & Evolution 24:482–486.

Mahmoud, M., Y. Liu, H. Hartmann, S. Stewart, T. Wagener, D. Semmens, R. Stewart, H. Gupta, D. Dominguez, F. Dominguez, D. Hulse, R. Letcher, B. Rashleigh, C. Smith, R. Street, J. Ticehurst, M. Twery, H. van Delden, R. Waldick, D. White, and L. Winter. 2009. A formal framework for scenario development in support of environmental decision-making. Environmental Modelling & Software 24:798–808.

Micheletti, T., F. E. C. Stewart, S. G. Cumming, S. Haché, D. Stralberg, J. A. Tremblay, C. Barros, I. M. S. Eddy, A. M. Chubaty, M. Leblond, R. F. Pankratz, C. L. Mahon, S. L. Van Wilgenburg, E. M. Bayne, F. Schmiegelow, and E. J. B. McIntire. 2021. Assessing Pathways of Climate Change Effects in SpaDES: An Application to Boreal Landbirds of Northwest Territories Canada. Frontiers in Ecology and Evolution 9.

Munkittrick, K. R., and T. J. Arciszewski. 2017. Using normal ranges for interpreting results of monitoring and tiering to guide future work: A case study of increasing polycyclic aromatic compounds in lake sediments from the Cold Lake oil sands (Alberta, Canada) described in Korosi et al. (2016). Environmental Pollution 231:1215–1222.

Munkittrick, K. R., C. J. Arens, R. B. Lowell, and G. P. Kaminski. 2009. A review of potential methods of determining critical effect size for designing environmental monitoring programs. Environmental Toxicology and Chemistry 28:1361–1371.

NWT CIMP. 2015. NWT CIMP Dictionary. Government of Northwest Territories.

Oliver, T. H., and D. B. Roy. 2015. The pitfalls of ecological forecasting. Biological Journal of the Linnean Society 115:767–778.

Orr, J. A., R. D. Vinebrooke, M. C. Jackson, K. J. Kroeker, R. L. Kordas, C. Mantyka-Pringle, P. J. Van den Brink, F. De Laender, R. Stoks, M. Holmstrup, C. D. Matthaei, W. A. Monk, M. R. Penk, S. Leuzinger, R. B. Schäfer, and J. J. Piggott. 2020. Towards a unified study of multiple stressors: divisions and common goals across research disciplines. Proceedings of the Royal Society B: Biological Sciences 287:20200421.

Petchey, O. L., M. Pontarp, T. M. Massie, S. Kéfi, A. Ozgul, M. Weilenmann, G. M. Palamara, F. Altermatt, B. Matthews, J. M. Levine, D. Z. Childs, B. J. McGill, M. E. Schaepman, B. Schmid, P. Spaak, A. P. Beckerman, F. Pennekamp, and I. S. Pearse. 2015. The ecological forecast horizon, and examples of its uses and determinants. Ecology Letters 18:597–611.

Ploton, P., F. Mortier, M. Réjou-Méchain, N. Barbier, N. Picard, V. Rossi, C. Dormann, G. Cornu, G. Viennois, N. Bayol, A. Lyapustin, S. Gourlet-Fleury, and R. Pélissier. 2020. Spatial validation reveals poor predictive performance of large-scale ecological mapping models. Nature Communications 11:4540.

Raymundo, A., T. Micheletti, S. Haché, D. Stralberg, F. E. C. Stewart, J. A. Tremblay, C. Barros, I. M. S. Eddy, A. M. Chubaty, M. Leblond, C. L. Mahon, S. L. Van Wilgenburg, E. M. Bayne, F. Schmiegelow, T. D. S. Docherty, E. J. B. McIntire, and S. G. Cumming. 2024. Climate-sensitive forecasts of marked short-term and long-term changes in the distributions or abundances of Northwestern boreal landbirds. Climate Change Ecology 7:100079.

Roberts, D. R., V. Bahn, S. Ciuti, M. S. Boyce, J. Elith, G. Guillera-Arroita, S. Hauenstein, J. J. Lahoz-Monfort, B. Schröder, W. Thuiller, D. I. Warton, B. A. Wintle, F. Hartig, and C. F. Dormann. 2017. Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. Ecography 40:913–929.

Vitt, D. H., L. A. Halsey, and S. C. Zoltai. 2000. The changing landscape of Canada's western boreal forest: the current dynamics of permafrost. Canadian Journal of Forest Research 30:283–287.

Wek'èezhìi Land and Water Board. 2010. Guidelines for Adaptive Management - a Response Framework for Aquatic Effects Monitoring.

Wenger, S. J., and J. D. Olden. 2012. Assessing transferability of ecological models: an underappreciated aspect of statistical validation. Methods in Ecology and Evolution 3:260–267.

Yates, K. L., P. J. Bouchet, M. J. Caley, K. Mengersen, C. F. Randin, S. Parnell, A. H. Fielding, A. J. Bamford, S. Ban, A. M. Barbosa, C. F. Dormann, J. Elith, C. B. Embling, G. N. Ervin, R. Fisher, S. Gould, R. F. Graf, E. J. Gregr, P. N. Halpin, R. K. Heikkinen, S. Heinänen, A. R. Jones, P. K. Krishnakumar, V. Lauria, H. Lozano-Montes, L. Mannocci, C. Mellin, M. B. Mesgaran, E. Moreno-Amat, S. Mormede, E. Novaczek, S. Oppel, G. O. Crespo, A. T. Peterson, G. Rapacciuolo, J. J. Roberts, R. E. Ross, K. L. Scales, D. Schoeman, P. Snelgrove, G. Sundblad, W. Thuiller, L. G. Torres, H. Verbruggen, L. Wang, S. Wenger, M. J. Whittingham, Y. Zharikov, D. Zurell, and A. M. M. Sequeira. 2018. Outstanding Challenges in the Transferability of Ecological Models. Trends in Ecology & Evolution 33:790–802.

Yates, L. A., Z. Aandahl, S. A. Richards, and B. W. Brook. 2023. Cross validation for model selection: A review with examples from ecology. Ecological Monographs 93:e1557.