Scenario-Based Optimal Diet Modelling to Evaluate Climate Change Impacts on Food Systems in Two Coastal First Nations in British Columbia

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PREFACE

Abstract

Coastal First Nations in British Columbia maintain strong local food systems grounded in land- and sea-based knowledge, harvesting practices, and community sharing networks that support cultural continuity and nutritional wellbeing. Intersecting colonial, socioeconomic, and environmental pressures—now intensified by climate change—are reshaping the availability, accessibility, and safety of key seafood species, while market foods in remote communities are often costly, lower quality, and dependent on vulnerable supply chains. This thesis develops and applies a community-informed, scenario-based dietary optimization framework to examine how climate-driven ecological change interacts with local food environments to shape feasible diets in two coastal First Nations case studies: Skidegate and Tla'amin.

Using mixed methods and co-development with community partners, this framework was implemented using goal-programming–based dietary optimization models parameterized with 24-hour dietary recalls, food frequency questionnaires, retail food price surveys, traditional food costing, and methylmercury (MeHg) contaminant data. Three scenarios were assessed for females and males separately: (i) baseline diets reflecting current food environments; (ii) projected low-mitigation climate change impacts on seafood availability; and (iii) a high-mitigation adaptation scenario. Model outputs were evaluated in terms of nutrient adequacy, affordability, cultural acceptability (traditional versus market food composition), and MeHg exposure trade-offs.

Results demonstrate that diets meeting nutrient requirements under observed cost, availability, and consumption-pattern constraints are structurally limited by local food

environments, and that climate-driven constraints on seafood availability can meaningfully reduce diet feasibility, particularly when nutrient-dense traditional foods function as high-leverage nutrient carriers. Findings highlight that Skidegate and Tla'amin differ in which constraints most strongly bind (e.g., affordability, market food access, and species-specific seafood availability), indicating that regional projections alone are insufficient for adaptation planning. Overall, this thesis shows that community-specific parameterization and participatory model development are essential for producing decision-relevant modelling insights that can support culturally grounded food security and climate adaptation strategies in coastal First Nations.

Résumé

Les Premières Nations côtières de la Colombie-Britannique maintiennent des systèmes alimentaires locaux solides, ancrés dans les savoirs liés à la terre et à la mer, les pratiques de récolte et les réseaux de partage communautaires qui soutiennent la continuité culturelle et le bien-être nutritionnel. Des pressions coloniales, socioéconomiques et environnementales qui se recoupent — aujourd'hui intensifiées par les changements climatiques — transforment la disponibilité, l'accessibilité et la salubrité d'espèces clés de produits de la mer, tandis que les aliments du marché dans les communautés éloignées sont souvent coûteux, de moindre qualité et dépendants de chaînes d'approvisionnement vulnérables. Cette thèse développe et applique un cadre d'optimisation alimentaire fondé sur des scénarios et co-élaboré avec les communautés afin d'examiner comment les changements écologiques liés au climat interagissent avec les environnements alimentaires locaux pour façonner des régimes alimentaires réalisables dans deux études de cas de Premières Nations côtières : Skidegate et Tla'amin.

À l'aide de méthodes mixtes et d'une co-élaboration avec des partenaires communautaires, ce cadre a été mis en œuvre au moyen de modèles d'optimisation alimentaire fondés sur la programmation par objectifs, paramétrés à partir de rappels alimentaires de 24 heures, de questionnaires de fréquence alimentaire, d'enquêtes sur les prix des aliments au détail, de l'évaluation des coûts des aliments traditionnels et de données sur les contaminants au méthylmercure (MeHg). Trois scénarios ont été évalués séparément pour les femmes et les hommes : (i) des régimes de référence reflétant les environnements alimentaires actuels ; (ii) des impacts projetés des changements climatiques dans un scénario de faible atténuation sur la disponibilité des produits de la mer ; et (iii) un scénario d'adaptation dans un contexte de forte atténuation. Les résultats des modèles ont été évalués en fonction de l'adéquation nutritionnelle, de l'abordabilité, de l'acceptabilité culturelle (composition des aliments traditionnels par rapport aux aliments du marché) et des compromis liés à l'exposition au MeHg.

Les résultats démontrent que les régimes alimentaires satisfaisant aux besoins nutritionnels dans les limites observées de coûts, de disponibilité et de modes de consommation sont structurellement contraints par les environnements alimentaires locaux, et que les contraintes liées au climat sur la disponibilité des produits de la mer peuvent réduire de manière significative la faisabilité des régimes alimentaires, en particulier lorsque les aliments traditionnels riches en nutriments constituent des vecteurs nutritionnels à fort levier. Les résultats montrent également que Skidegate et Tla'amin diffèrent quant aux contraintes qui s'avèrent les plus déterminantes (par exemple l'abordabilité, l'accès aux aliments du marché et la disponibilité d'espèces marines spécifiques), ce qui indique que les projections régionales à elles seules sont insuffisantes pour la planification de l'adaptation. Dans l'ensemble, cette thèse démontre que la paramétrisation propre aux communautés et le développement participatif des modèles sont

essentiels pour produire des analyses de modélisation pertinentes pour la prise de décision et soutenir des stratégies de sécurité alimentaire et d'adaptation climatique culturellement ancrées dans les Premières Nations côtières.

Ethics Statement:

Research presented in this thesis conforms to all ethical standards. This thesis falls under the direct work of the Climate Change and Food Security for Four First Nations, and thus under the Ethics certificate granted to the University of Ottawa (H-03-20-5546).

Structure of Thesis:

This thesis is split into five chapters. A description of the five chapters is outlined below.

Chapter 1: Introduces and provides the groundwork and standing for this thesis work, including the research objectives. This chapter provides a foundation for this thesis's contributions to the advancement of knowledge.

Chapter 2: Supplies a detailed methodology to the process and development of the optimal models. This chapter discusses the use of co-development within the development of the modelling framework and model parameterization.

Chapter 3: This chapter provides an exploration of the food environment for Skidegate and provides detailed modelling results for all three objectives for Skidegate Nation.

Chapter 4: This chapter provides an exploration of the food environment for Tla'amin and provides detailed modelling results for all three objectives for Tla'amin Nation.

Chapter 5: Concludes the thesis by comparing the food system structurally constraints for both communities. As well, examines the modelling limitations, and the future implications of this thesis.

Statement of Authorship:

Chapter 1: RC [1]formulated the research objectives and drafted the chapter. LC and TF provided supervision, intellectual support, feedback, and editorial review.

Chapter 2: RC designed the framework, conducted the interviews, formulated the models and drafted the chapter. TF provided methodological guidance related to the development of the modelling framework and model parameterization processes. LC and TF oversaw research activities and provided feedback and editorial review.

Chapter 3: RC conducted the statistical analysis and all modelling analyses, interpretation for Skidegate Nation and drafted the chapter. LC and TF oversaw research activities and provided feedback and editorial review.

Chapter 4: Drafted by RC. RC conducted the Tla'amin food environment statistical analysis and all modelling analyses and interpretation for Tla'amin Nation. LC and TF oversaw research activities and provided feedback and editorial review.

Chapter 5: Drafted by RC. RC led the synthesis of findings, discussion of limitations, and implications. LC and TF oversaw research activities and provided feedback and editorial review.

[1] RC: Ramneek Cheema, LC- Dr. Laurie Chan, and TK – Dr. Tiff-Annie Kenny

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Acronyms:

BC - British Columbia

CCFS4N – Climate Change and Food Security for Four First Nations

CNF – Canadian Nutrient File

CWB – Community Wellbeing Index

FAO – Food and Agriculture Organization

FFQ – Food Frequency Questionnaire

FN – First Nation

FNFNES – First Nation Food, Nutrition and Environment Survey

MeHg – Methylmercury

MF- Market Foods

MUFA- Monounsaturated fatty acids

NRCD - nutrition-related chronic diseases

POP- Persistent Organic Pollutants

PUFA- Polyunsaturated fatty acids

RAE- Retinol activity equivalents

RCP – Representative Concentration Pathway

TDMI – Total Departure Mean Intake

TF – Traditional Foods

TEK- Traditional Ecological Knowledge

USDA – United State Department of Agriculture

WHO- World Health Organization

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Chapter 1 –Introduction and Context

1. 1 Background

1.1.1 Indigenous Peoples' Food Systems

Food systems are defined as dynamic networks of social, economic, and environmental interactions that shape how food is produced, accessed and consumed. Indigenous People's food systems are grounded in long-standing relationships with local ecosystems and in knowledge systems that integrate ecological, cultural, and spiritual dimensions of health (Kuhnlein et al., 2009; Settee & Shukla, 2020). These systems encompass biodiversity, sustainability, and resilience, reflecting both the material and cultural foundations of Indigenous wellbeing.

Indigenous food systems include both traditional and market foods, but traditional foods remain central to cultural continuity, nutrition, and identity (da Rosa et al., 2025; Domingo et al., 2021; Kenny, Hu, et al., 2018; Pressler et al., 2022). Traditional foods originate from local ecosystems and are obtained through culturally grounded practices such as harvesting, hunting, and fishing, as well as through sharing, barter, and exchange networks that sustain community food systems (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021a). They may be accessed through direct procurement, sharing networks, barter, exchange, or purchase, and are embedded within traditional knowledge systems and community food practices (Batal et al., 2021). Traditional foods allow for Indigenous People to exercise their connection to the land (Domingo et al., 2021). Food is a vital part of Indigenous Peoples' lives. It maintains their connections with their traditional knowledge, culture, and their mental, physical and spiritual well-being (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b). Thus, being a vital component of overall physical and mental well-being (Shafiee et al., 2022). Traditional food systems are central to the diets of First Nation coastal communities in BC (Chan et al., 2021). Traditional foods, particularly

seafood among FN coastal communities are essential to providing key nutrients such as omega-3 and omega-6 fatty acids (Chan et al., 2021).

Market foods are those obtained through retail outlets such as grocery stores, convenience stores, and local co-operatives (Kenny et al., 2020). Due to the remoteness of some FN coastal communities, access to market foods is shaped by transportation constraints, and reliance on supply chains that are vulnerable to disruptions (Shafiee et al., 2022). As a result, MFs are often substantially more expensive than in urban centres, and the selection of fresh, nutrient-dense items (e.g., fruits, vegetables, dairy, and lean proteins) can be inconsistent and lower quality due to long transport times and reduced shelf life (Shafiee et al., 2022). In many cases, households require access to a vehicle to reach the primary retail locations, creating additional barriers for Elders, low-income households, and those with limited mobility (Kenny et al., 2020). These dynamics have coincided with dietary shifts toward lower-cost, readily available foods, including many ultra-processed products that are often high in sodium, added sugars and saturated fats (Kenny, Hu, et al., 2018; Pressler et al., 2022). Over time, greater dependence on MF, particularly ultra-processed options, can contribute to inadequate intakes of essential nutrients and increase the risk of diet-related chronic diseases (Pressler et al., 2022).

Colonial policies and the legacy of residential schools disrupted Indigenous Peoples' control over land, food systems, and knowledge transmission, contributing to the imposed westernization of lifestyles and diets (Malli et al., 2023). This has led to a decrease in consumption in TF and a transition to an increase in consumption of MF (Malli et al., 2023). This dietary change is often referred to as a nutritional transition (Malli et al., 2023). This transition is disproportionately affecting Indigenous Peoples with negative health effects (Settee & Shukla, 2020). The reduced consumption of TF has led to a loss of traditional knowledge

(Settee & Shukla, 2020). Due to the remoteness of these communities, market food prices are high which has resulted in low-quality produce being sold for high prices pushing people to ultra-processed, canned, and calorie-dense foods (da Rosa et al., 2025). As a result, diets for these communities lack essential nutrients, causing nutrition-related chronic diseases (ex. obesity, cardiovascular disease, type 1 diabetes), a defining trait of food insecurity (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b).

Indigenous Peoples' food systems are closely tied to local ecosystems, making them particularly sensitive to climate change–driven environmental disruption (Settee & Shukla, 2020). As a result, they are particularly vulnerable to climate change, which can disrupt food availability, access, and safety through multiple, interconnective pathways (Zimmermann et al., 2023). In coastal FN communities, climate-driven changes in ocean temperature, acidification, extreme weather, and shifting species distributions can alter the abundance, timing, and location of culturally important seafood species (Ainsworth et al., 2011). These ecological shifts may reduce harvesting abundance, increase time and fuel costs required to access new fish migration patterns, and place additional pressure on community sharing networks that support food sovereignty and collective wellbeing (Ainsworth et al., 2011). At the same time, climate-driven change may introduce new species or increase the abundance of species not previously common or accessible in the region. For instance, the increase presence of albacore tuna in Skidegate waters leading to reshaping of local harvesting practices, food availability and dietary pathways (Yovanovich et al., n.d.). Climate change can also affect the nutritional quality and contaminant profiles of traditional foods, including potential changes in methylmercury exposure risk, further complicating decisions about which foods are safe and feasible to prioritize (Weatherdon et al., 2016).

At the same time, climate impacts often compound existing structural barriers created by colonial policies and ongoing inequities (Malli et al., 2023). When traditional foods become less available or harder to harvest, households may rely more heavily on market foods (da Rosa et al., 2025). Yet in remote communities, market foods are frequently expensive, low quality, and limited in variety, reinforcing dependence on ultra-processed options (da Rosa et al., 2025; Kenny, Hu, et al., 2018). This feedback loop can intensify dietary inadequacy and increase nutrition-related chronic disease risk while accelerating the erosion of land-based practices and Traditional Knowledge (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b). In this way, climate change does not act as a single stressor; it interacts with social and economic constraints to amplify food insecurity and threaten the cultural and health dimensions embedded within Indigenous food systems. (Shafiee et al., 2022)

1.1.2 Food Security

Figure 1 Food security framework

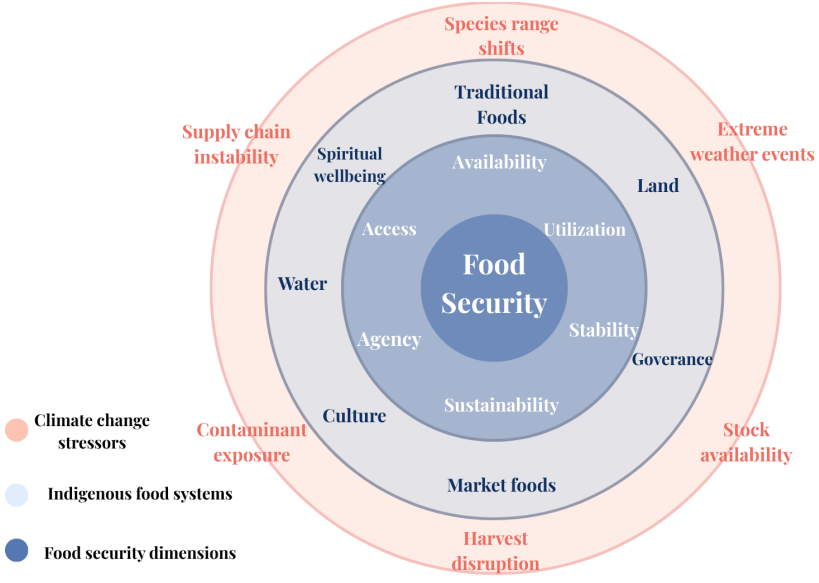


Figure 1. 6-dimensional framework of food security taken from Clapp and colleagues, 2022.

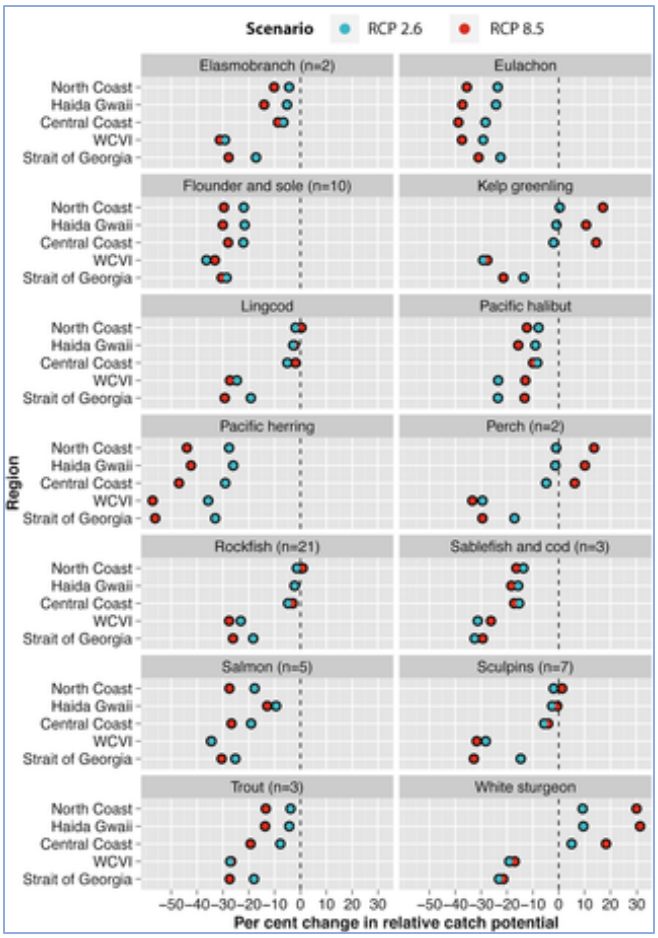
For individuals to be food secure, they and their households must have access to nutritious, acceptable-quality foods and reliable access to them (FAO, 1999). Food security is a multidimensional concept hinged on four pillars, availability, access, utilization and stability and in more recent work the addition of agency and sustainability (Clapp et al., 2022). Where agency refers to the power of the people and communities to shape their food systems and food choice, and sustainability refers to the capacity of food systems to support food security over time without undermining ecological and social foundations (Clapp et al., 2022). The FAO defined food security as "exists when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1999). The pillars serve as instruments in assessing and characterizing where security is falling short (Clapp et al., 2022). Food security among First Nation communities is characterized by access to both traditional and market foods (Shafiee et al., 2022). Therefore, food insecurity is associated with compromised diet quality, poor general and mental health and a weak sense of community belonging (Shafiee et al., 2022). Coastal First nation communities uniquely experience instability of all four pillars (Shafiee et al., 2022). For instance, the availability of food fluctuates due to remoteness, impact on fish migration and stock availability and lack of control over land and resources (Marushka et al., 2019a). Governance changes, commercial fisheries and other stressors such as climate change, and loss of coastal habitats, have resulted in First Nation fisheries being in serious decline compared to their historical abundance and catch (Marushka et al., 2019a). For example, First Nation fishers are increasingly targeting Chinook and Coho rather than Chum, Pink and Sockeye, reflecting both a cultural shift and a response to drastic decreases in their abundance in recent decades (Marushka et al., 2019a). Furthermore, food safety concerns arise when considering environmental

contaminants in traditional foods such as heavy metals and persistent organic pollutants (POPs) in seafood (Marushka et al., 2021). Traditional food, specifically seafood contributes to a nutritious diet, promotes mental, social and cultural well-being by fostering harmonious intergenerational relationships, intimate connections to the land, and the transfer of intergenerational knowledge (Marushka et al., 2021). Thus, the benefits of seafood on overall well-being outweigh food safety concerns (Marushka et al., 2021). An additional challenge to resolving the food security crisis in the observed and projected decline in fish stock availability in the Northeastern Pacific due to climate change (Weatherdon et al., 2016).

As a result, this has created a number of food security challenges for First Nation communities in British Columbia including for Tla'amin and Skidegate Nations, with 48.6% experiencing food insecurity (Batal et al., 2021). Accessibility is restricted by the lack of direct access to traditional food and changing migration patterns of fish (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b; Shafiee et al., 2022). Furthermore, limited knowledge of market foods threatens the food security of First Nations by constraining their ability to make informed food choices and limiting their prospects of healthy eating (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b; Kenny, Hu, et al., 2018; Shafiee et al., 2022). As well, the quality of market foods available to purchase at stores is limited in diversity, and often nutrient costly (Kenny, Fillion, et al., 2018). The compromised availability and accessibility pillars have caused a dietary transition to increasing consumption of processed market food considered nutrient-poor (Kenny, Fillion, et al., 2018; Shafiee et al., 2022). Consequently, leading to an increase in nutrition-related chronic diseases, with a prevalence of 50% obesity, and 19% type 2 diabetes, both double the rates seen in other Canadians (Batal, Chan, Fediuk, Ing, Berti, Mercille, et al., 2021).

1.1.3 Impact of Climate Change on Food and Nutrition Security

Figure 2 Fish stock availability for traditional seafood



Source : (Weatherdon et al., 2016)

Climate change impacts the entire food security framework, with coastal First Nations communities being even more particularly vulnerable (Marushka et al., 2019a). Climate change influences availability by changing the migration patterns of species and the local availability of food (Weatherdon et al., 2016). Under a low mitigation climate change scenario (RCP 8.5), species that are nutritionally and culturally important for First Nation communities such as salmon and; Pacific herring are projected to decrease by up to 50% (Figure 2.) (Weatherdon et al., 2016). As a result, accessibility and availability of traditional foods are directly impacted by

climate change (Marushka et al., 2019a). Furthermore, as climate change reduces biodiversity and modifies the nutrient content in fish and size, the utilization of essential nutrients that come from traditional foods is hindered (Weatherdon, et al., 2016). Further, MeHg bioaccumulation exacerbated through climate change can result in an increase in MeHg exposure through traditional food (Alava et al., 2018).

Furthermore, the retail food environment significantly influences nutrient availability, forming a critical link between the food system and dietary habits (N. D. Willows et al., 2024). Challenges such as the lack of a nearby grocery store are associated with inadequate diets and a higher prevalence of nutrition-related chronic diseases (Batal, Chan, Fediuk, Ing, Berti, Mercille, et al., 2021; Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b; N. D. Willows et al., 2024). As well, poor retail food environments play a key factor in food insecurity (Batal, Chan, Fediuk, Ing, Berti, Mercille, et al., 2021). Low-income households must meet energy requirements within budgetary constraints; often, this leads to a dietary transition of less nutritionally dense, non-perishable food items. (Kenny, Fillion, et al., 2018) As a result, this has led to an environment that offers adequate access to calories but is deficient in vital micronutrients (Kenny, Fillion, et al., 2018). This creates food environments in which calorie access is comparatively more achievable than micronutrient adequacy, with implications for population health and for the feasibility of nutritionally adequate diets (Kenny, Fillion, et al., 2018).

1.1.4 Food system resilience

Food system resilience is widely discussed as the capacity of a food system to absorb disturbances, adapt to changing conditions and continue to deliver adequate, safe, and culturally appropriate foods over time (Zurek et al., 2022). Resilience is shaped by exposure to hazards (e.g. climate variability and extremes), sensitivity of production and access pathways, and adaptive capacity, including governance, infrastructure, knowledge systems, and the diversity of

food sources and supply option (Tendall et al., 2015). From this perspective, climate change can affect resilience through both acute shocks (e.g., storms, heat waves, flooding) and longer-term ecological change that alters the reliability of food production and access (Béné et al., 2023; Tendall et al., 2015; Zurek et al., 2022).

Despite growing recognition that climate change is reshaping Indigenous food systems, the evidence base remains uneven in both coverage and depth. Existing research consistently shows that warming waters, shifting species distributions, extreme events, and ecosystem change can disrupt the availability, timing, and safety of key traditional foods, particularly seafood in coastal regions, while increasing the time, fuel, and costs required to harvest and access culturally important species (Marushka et al., 2019b). However, fewer studies translate these ecological changes into food-system analyses that quantify how climate-driven shocks interact with governance, access rights, market dependence, and household constraints to determine what diets remain feasible in practice. As a result, Indigenous food-system resilience is often described conceptually but is less often evaluated as a set of measurable trade-offs (e.g., nutrition, affordability, cultural acceptability, and food safety) under specific climate scenarios. This gap limits adaptation planning, because it remains unclear which constraints are the most constraining in different communities and which interventions most effectively expand feasible, culturally grounded dietary pathways under climate stress.

Food system vulnerability can be understood as the susceptibility of a food system to food insecurity resulting from climate variability, extremes, and long-term change (Zurek et al., 2022). In this context, greater vulnerability increases the likelihood that households experience compromised diet quality, reduced nutrient adequacy, and heightened exposure to diet-related health risks (Tendall et al., 2015). Susceptibility to food insecurity is therefore often reflected not

only in reduced access to sufficient food, but also in elevated prevalence of nutrition-related chronic diseases linked to shifts toward lower-quality, energy-dense market foods and reduced availability of nutrient-rich traditional foods (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b).

Although food security is influenced by the resilience of the food system, the two concepts are not synonymous (Zurek et al., 2022). Food system resilience refers to the capacity to absorb disturbances, adapt, and continue to provide adequate, culturally appropriate, and safe foods over time (Zurek et al., 2022). Food security, by contrast, describes an outcome where people have consistent access to sufficient, safe, and nutritious food (Shafiee et al., 2022). A community may experience short-term food security through external supports (e.g., income transfers or food shipments) even if the underlying food system remains fragile and highly exposed to shocks (Zurek et al., 2022). As such, evaluating vulnerability and adaptation requires examining not only food security outcomes, but also the structural and ecological conditions that determine whether the food system can withstand and respond to climatic stressors (Clapp et al., 2022).

1.1.5 Quantitative scenario-modelling

Scenario approaches are widely used in climate adaptation and food systems research to support planning under deep uncertainty, where future conditions cannot be credibly represented using a single best estimates (Scarborough et al., 2012). Scenarios are structured descriptions of plausible future conditions that specify how important drivers might change and interact over time (Candy et al., 2015). They can be developed and used with or without quantitative models (Candy et al., 2015). For example, participatory scenario work with Indigenous communities often focuses on co-developing plausible futures, risks, and response options through qualitative processes, without translating those narratives into simulation or optimization models (Walz et

al., 2007). In contrast, modelling is a separate methodological step that uses formal equations to represent relationships and generate quantitative outputs (Candy et al., 2015).

Within this thesis, scenarios are used as inputs to a quantitative modelling framework rather than as predictions. Quantitative scenario modelling refers to the process of translating scenario assumptions into parameter values that can be evaluated in a formal model. (Symstad et al., 2017) This is analytically distinct from forecasting: the objective is not to predict a most likely future or assign probabilities, but to systematically explore "what-if" conditions, sensitivities, and trade-offs that are relevant for decision-making (Johnson-Down et al., 2019b).

In food systems contexts, scenarios commonly represent changes in interacting drivers that influence food security dimensions (Candy et al., 2015). When operationalized quantitatively, scenario parameters may include food availability (including climate-sensitive traditional foods), price levels and affordability constraints, retail access conditions, dietary patterns and preferences, contaminant exposure limits, and environmental constraints affecting harvesting (Candy et al., 2015). Comparing model outputs across scenarios helps identify which drivers most strongly shape outcomes and which trade-offs are persistent when objectives such as nutritional adequacy, affordability, cultural relevance, and safety are pursued simultaneously (Johnson-Down et al., 2019b).

Scenario-based approaches are particularly appropriate in Indigenous food system contexts because key determinants of food access and availability are often non-linear and influenced by interacting ecological and socioeconomic processes (Johnson-Down et al., 2019b). Under these conditions, scenario thinking supports planning by evaluating multiple plausible futures rather than relying on point estimates (Johnson-Down et al., 2019b). In this thesis, scenario narratives, co-developed and informed by community knowledge, are translated into

quantitative assumptions and used to parameterize a shared dietary optimization framework. This enables consistent comparison of diet feasibility under current conditions and alternative plausible futures, while maintaining a clear conceptual separation between the scenario descriptions and the model used to evaluate their implications.

1.2 Problem Statement

Although Skidegate and Tla'amin are both remote coastal First Nations in British Columbia, their food environments, retail access conditions, and climate-related exposure to changes in seafood availability are shaped by distinct ecological, economic, and governance contexts. As a result, applying regionally averaged climate or fisheries projections risks obscuring the community-specific constraints that determine whether nutritionally adequate and culturally meaningful diets are actually feasible. This thesis therefore adopts a community-specific, scenario-based quantitative modelling approach, in which a shared analytical framework is parameterized separately for each Nation. Doing so enables climate change impacts on diets to be evaluated in ways that reflect locally grounded food environments, cultural priorities, and structural conditions, rather than relying on generalized regional assumptions.

Environmental and socioeconomic change has occurred alongside dietary shifts toward greater reliance on market foods, including many ultra-processed products, and reduced consumption of some traditional foods in many First Nations contexts (Kenny, Fillion, et al., 2018). These shifts reflect interacting drivers, including colonial policies and disruptions to land- and marine-based food practices, changing retail and transportation systems, affordability constraints, and climate-related ecological change (Zimmermann et al., 2023). Importantly, these drivers do not operate in isolation: climate change functions as an ecological shock (e.g., altering

fish availability, seasonality, and contaminant dynamics), while the food environment mediates how that shock is experienced at the household level (Ratelle et al., 2023). As a result, the same ecological change can produce different dietary and health implications depending on the local food environment and adaptive capacity.

Planning interventions to support food sovereignty and nutrition therefore requires approaches that can represent both ecological change and the structural conditions that shape dietary feasibility (Candy et al., 2015). A central challenge is that the impacts of climate change on food security are not captured solely by ecological indicators (e.g., fish stock projections), but by how changes in availability and exposure risk translate into feasible dietary choices under real constraints (Marushka et al., 2021). This motivates the need for quantitative tools that can represent trade-offs among nutritional adequacy, affordability, cultural relevance, and contaminant exposure, while remaining grounded in community context (N. Willows et al., 2019a).

Mixed-method, scenario-based approaches are well suited to this problem because they allow multiple plausible futures to be explored without relying on point predictions, and they can incorporate both quantitative data and community-informed evidence (N. Willows et al., 2019a). In this thesis, scenarios representing climate-driven changes are evaluated through a dietary optimization framework. Quantitative diet models therefore serve as a decision-support tool for examining how climate-related ecological changes propagate through structurally constrained food environments, and for identifying which constraints and trade-offs most strongly shape feasible diets under different pathways (Walz et al., 2007).

To our knowledge, few studies have applied quantitative diet optimization in a way that explicitly combines scenario-based climate stressors with community-informed cultural and

socioeconomic constraints for coastal First Nations communities. This thesis addresses that gap through comparative application in Skidegate and Tla'amin. Although both are remote coastal First Nations communities in British Columbia, they differ in retail access conditions, local food environments, and projected climate-related impacts on seafood availability. Using a shared modelling framework that is parameterized separately for each community enables comparison of how similar ecological shocks can produce different dietary implications when mediated by distinct food environments. This comparison also demonstrates why regionally averaged modelling assumptions may be insufficient for adaptation planning, and why community-specific parameterization is necessary for decision-relevant scenario analysis.

1.3 Research Objectives

The objective of this project is to develop a quantitative model of the population-level diet of First Nation coastal communities in B.C. (specifically Tla'amin and Skidegate Nations). The goals are to provide quantitative insight into the food system dynamics under climate change. More specifically, to provide food group dietary guidelines that are mindful of nutrient, cost restrictions and cultural significance under different scenarios. Scenarios developed through this project will support the development of climate change adaptation strategies in participating First Nations. Table 1 below outlines the research objectives with their corresponding methodology and data sources.

Table 1 Research objectives, methodology and data sources

OBJECTIVES	METHODOLOGY	DATA SOURCES
I. To examine the current availability of a nutritionally adequate and low MeHg intake diet in the current food environment	- Goal Programming - Baseline diet - Identify key nutrients lacking in the diet - Understand and identify key socioeconomic, health, and environmental factors	- CNF (Canadian Nutrient File, 2015) - 24 hr dietary recall - Food frequency questionnaire - 2009 FNFNES contaminant data - Retail market food survey - Traditional food costing from community leaders (Skidegate Band Council, Land and resources in Tla'amin) - Expert Interviews
II. To simulate and explore potential dietary and nutritional consequences of climate change under low mitigation scenarios on the fish availability stocks	GP - Future fish availability stocks	- CNF (Canadian Nutrient File, 2015) - 24 hr dietary recall - Food frequency questionnaire - 2009 FNFNES contaminant data - Retail market food survey - Traditional food costing from community leaders (Skidegate Band Council, Land and resources in Tla'amin) - Fish Projections from (Justrabo, n.d.; Weatherdon et al., 2016)
III. To simulate and explore potential dietary and nutritional consequences of climate change under high mitigation scenarios on the fish availability stocks	GP- Future fish availability stocks	- CNF (Canadian Nutrient File, 2015) - 24 hr dietary recall - Food frequency questionnaire - 2009 FNFNES contaminant data - Retail market food survey - Traditional food costing from community leaders (Skidegate Band Council, Land and Resources in Tla'amin) - Fish Projections from (Justrabo, n.d.; Weatherdon et al., 2016)

1.4 Research Design

This thesis project is part of a larger, collaborative project, Climate Change Adaptation and Food Security for First Nations (CCFS4N) with funding from the Canadian Institutes of Health Research (CIHR). CCFS4N partners with First Nations from the Tla'amin Nation, the Skidegate

Band Council, the Nuxalk Nation and the 'Namgis First Nation. This multidisciplinary project draws on expertise spanning nutrition to marine ecology and climate change modelling. The primary knowledge user is the First Nations Health Authority. The objectives of the larger project, CCFS4N, revolve around the concerns raised by the Steering Committee about the effects of climate change on the food environment for coastal First Nations communities and consequently, an increased risk of food insecurity and nutrition-related chronic diseases. The objectives of this master's project directly align with the concerns outlined by the Steering Committee and in turn the objectives of CCFS4N.

Scenario-based quantitative modelling enables the investigation of multiple trajectories of change without assigning probabilities (Candy et al., 2015). As well, quantitative modelling allows for consideration of budgetary, cultural significance, and nutrient constraints when developing nutrient-sufficient diets for a population where socioeconomic factors are essential to consider (Kenny et al., 2018). Furthermore, as food products are converted into numerical information, they can be effectively integrated into other subsystems to provide a broader perspective on the driving forces of dietary patterns and intervention targets to promote food security or healthier and more sustainable diets for communities (Kenny et al., 2018). As a result, we can identify robust foods-based dietary guidelines for multiple future scenarios (Willows et al., 2019).

Co-developing scenarios with community partners, allows for the models to be culturally adapted and significant while exploring diets under different stressors (Candy et al., 2015) . This process also facilitates knowledge co-evolution, whereby community knowledge informs how scenarios are defined and interpreted, and model outputs provide structured evidence that can be used to refine assumptions, clarify trade-offs, and identify decision-relevant priorities (Chapman

& Schott, 2020). In this way, scenarios function not only as technical inputs, but as a collaborative planning tool that links local priorities with quantitative analysis (Johnson-Down et al., 2019b). Hence, scenario-based quantitative modelling fits well within an Indigenous food system framework because it allows for the integration of fundamental factors such as environmental, cultural, and socioeconomic (Johnson-Down et al., 2019b).

1.5 Data sources

The diet models draw on complementary datasets to capture dietary patterns, nutrition, contaminants, and affordability in Skidegate and Tla'amin across the three scenarios. Population-level intake data came from 24-hour dietary recalls (Skidegate n=70; Tla'amin n=72; collected summer 2023 by trained community coordinators) and Food Frequency Questionnaires (FFQs) (Skidegate n=70; Tla'amin n=72) that documented weekly traditional food consumption and key socioeconomic and household context. Nutrient composition for reported foods was primarily obtained from the Canadian Nutrient File (CNF) 2015 (Health Canada), supplemented with other food composition sources where traditional foods were missing. Methylmercury (MeHg) exposure in traditional foods was informed by the First Nations Food, Nutrition and Environment Study (FNFNES, 2008–2018)**.** Food affordability was parameterized using community-administered retail food price surveys (Tla'amin: Dec 2023; Skidegate: Apr 2025), with additional Skidegate traditional food costing drawn from Nation distribution program information.

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Chapter 2: Co-development of optimal diet models

2.1 Introduction

Food systems are dynamic socio-ecological systems, which make them well suited for scenario-based dietary modelling approaches (Candy et al., 2015). However, it is important to note the distinction between food system modelling and diet modelling, as they operate at different levels of analysis. Food systems models examine upstream processes such as production, supply chains, prices, and governance (Reilly & Willenbockel, 2010). In contrast, dietary models operate closer to the individual or population level and focus on dietary consumption given constraints such as nutrient requirements, cost, cultural preferences and contaminant exposure (Johnson-Down et al., 2019a). Accordingly, the purpose of dietary modelling is not to simulate the entire food system, but to assess which dietary patters are within the current food system conditions and constraints (Johnson-Down et al., 2019a).

Scenario-based modelling is well suited for dietary modelling as it allows the investigation of multiple change trajectories without assigning probabilities (Candy et al., 2015). Thus, scenario-based diet modelling enables systematic identification of the parameters and constraints that most strongly influence food system resilience under different scenario conditions, for instance, climate change (Candy et al., 2015). Baseline scenarios describe the current state of the system (Candy et al., 2015). Future scenarios pose "what-if" questions and then evaluate how feasible diets may shift under specified conditions (Candy et al., 2015). Translating qualitative scenario narratives into quantitative model inputs enables explicit evaluation of trade-offs among cost, nutrient adequacy, cultural acceptability, and exposure constraints (Candy et al., 2015). In dietary optimization, foods are parameterized in terms of nutrients and costs and are grouped into food categories to facilitate interpretation (N. Willows et

al., 2019a). By holding selected parameters constant while varying others, models can identify which constraints most strongly shape feasible diets and which intervention levers improve diet feasibility under projected conditions, such as ecological change (Candy et al., 2015; Moraes et al., 2015). This is relevant to Indigenous' food systems where harvesting conditions are highly sensitive to climate change (Johnson-Down et al., 2019b).

To allow for relevant and complete scenario-based quantitative modelling especially in the utilization of climate change adaptation planning, there is a need for a high-level understanding of the community's food environment and priorities (Davis et al., 2021). This community-informed foundation is also critical during the optimization process, where feasibility often requires adjusting constraints or weights (Yue, 2011). These adjustments have been frequently made in an arbitrary manner; however, modelling in a regional and community context, small modelling decisions can meaningfully alter outputs and can have widespread effects within the system outputs, therefore skewing the projections. Embedding co-developed, community-informed decision processes into optimization therefore strengthens the interpretability and appropriateness of scenario results (Davis et al., 2021).

This thesis applies scenario-based dietary modelling to examine: (i) the feasibility of diets that are nutritionally adequate, cost- and contaminant-constrained, and culturally significant within the current food system; and (ii) how climate-related changes effect the feasibility of nutritionally adequate and culturally relevant diets in First Nation community contexts.

A distinctive contribution of this thesis is the quantitative diet models and scenarios are co-developed with community partners, rather than being specified exclusively by modeller-driven assumptions. Scenario-based dietary optimization requires modelling choices, such as the representation of cultural preferences, feasible substitutions, constraint prioritization, and

constraint recalibration to avoid infeasible solutions, that can materially affect results. In community applications, these choices can influence projected dietary patterns and downstream interpretation for planning. For this reason, this thesis frames dietary optimization as a decision-support tool that benefits from participatory-engaged modelling, where community priorities, contextual knowledge, and feasibility judgments inform model structure, constraints, and scenario design (Davis et al., 2021).

2.2 Data sources

To effectively promote healthful diets and support food security, there is a need for a more comprehensive understanding of the variables that shape dietary trends among First Nations. Hence, the diet models developed exploring the three scenarios will integrate meta-datasets in environmental, socioeconomic and health. A detailed description of each data source is outlined below along with a summary found in Table 2.

Table 2 Detailed description of data sources

DATA SOURCE	DESCRIPTION	USE IN MODEL
24-HR DIETARY RECALLS	- Detailed description of all food and beverages consumed within 24 hours, – midnight to midnight	- Develop food groups and sub-food groups used within the diet model framework - Ability to use taste preferences as a constraint
FOOD FREQUENCY QUESTIONNAIRE (FFQ)	- The consumption of traditional foods within the week - Socioeconomic questions	- Quantify the consumption of traditional foods - Dictated semi-structured interview questions that reinforce the scenarios
CANADIAN NUTRIENT FILE (CNF) 2015	- A comprehensive nutrient database managed by Health Canada	- Quantify the nutrient contents
FIRST NATIONS FOOD, NUTRITION AND ENVIRONMENT STUDY (FNFNES)	- A decade-long collaborative research project with 92 First Nations across Canada. - The aim was to collect regionally representative data on diet quality, food-related exposure to environmental contaminants, food security and health status of First Nation people living on reserves.	- MeHg concentration intake for traditional foods
FOOD RETAIL SURVEY	- Prices collected from grocery stores frequented by community members of items found in a typical food basket and commonly found in the 24-hr recall surveys.	- Capture the cost of foods found in the 24-hr recall surveys

To capture taste preferences and dietary patterns from a population perspective 24-hr recall surveys were utilized for both Skidegate (n =70) and Tla'amin (n=72). The surveys were administered by trained community coordinators and completed in the summer of 2023. Participants were asked to detail their food and beverage consumption over the previous full 24 hours (midnight to midnight of the previous day). The 24-hr dietary surveys allow for the simulations to grasp the full complexity of food choice at the population level. Quantifying the nutrient content of food items poses a significant challenge due to the diversity of cultivation and harvesting conditions. The nutritional profile of plants and animals can vary based on the resources available in their environment or along their migratory paths, impacting the nutritional value of the foods humans consume (Shafiee et al., 2022). To accurately evaluate and model the nutritional adequacy across different scenarios, each item reported in the 24-hour dietary recall is matched with the corresponding entry in the Canadian Nutrient File (CNF), 2015. The CNF is a comprehensive food and nutrient database managed by the Nutrition Research Division of Health Canada. The nutrient content detailed in the CNF represents an average from different brands or composites, derived from various sources including Health Canada's analyses, industry data, and scientific literature. While the CNF encompasses a range of traditional foods, it is not exhaustive. For traditional foods not covered by the CNF, additional databases were utilized to provide nutritional data. such as, the USDA, Native Foods and Nutrition and the First Nations Food, Nutrition and Environment Study (FNFNES) project.

FNFNES was a decade-long (2008-2018) collaborative research project with 92 First Nations across Canada. The aim of the project was to collect regionally representative data on diet quality, food-related exposure to environmental contaminants, food security and the health status of First Nations (Chan et al., 2021). Traditional food samples were collected in 2009 and

analyzed for contaminants and toxic metals including MeHg (Chan et al., 2021). Traditional food samples collected and tested include food items such as shellfish (mussels, oysters, seafood), and fish (salmon, tuna) which have all been frequently reported in both the FFQ and 24-hr dietary recall surveys.

The Food Frequency Questionnaire (FFQ) included questions on demographics, grocery store perception, food security, traditional food weekly consumption, nutrition-related chronic diseases, household structure, and the use of community food programs. The FFQ were completed by 72 individuals in Tla'amin and 70 individuals in Skidegate. They were administered by trained community coordinators. The FFQ aids in understanding the circumstances that promote or detract from the ability to consume traditional foods (i.e. environmental and socioeconomic factors). Understanding of these variables were used in aiding in structuring the semi-structured interviews questions. As a result, the use of the FFQ assists not only in quantifying the consumption of traditional foods but also in reinforcing the scenario building and the development of the modelling framework. The sampling demographics from both the 24-hour recall dietary survey and FFQ were cross-referenced using the 2021 census from StatsCan and weighted accordingly when formulating the input tables.

Market food prices were collected as part of the CCFS4N research program, under the leadership of [2]RC, TK, LHMC and KF, to characterize the local food environments in Skidegate and Tla'amin. Methodology was adapted based on previous work conducted by Kenny and colleagues (Kenny et al., 2017). These community-administered retail food surveys provide direct measures of food affordability and availability as experienced by community members, including the economic constraints associated with low income and high food costs in remote

[2] RC = Ramneek Cheema, TK = Dr. Tiff-Annie Kenny, LHMC= Dr. Laurie Chan, KF = Karen Fediuk

settings. The retail market survey was administered by a trained community coordinator at a grocery store frequented by Tla'amin community members completed in December 2023. For the Skidegate Band Council, the retail market survey was completed in April of 2025 at the Co-op store. Prices were collected for items found in the Revised Northern Food Basket and cross-referenced to ensure common foods found in the 24-hr recall surveys were included. Traditional food expenses were estimated using the Nation distributed costs for key fish species from the Skidegate Nation distribution programs. This was obtained through Missy (a Skidegate community leader), and the costing for Tla'amin was not obtained due to lack of traditional food within the diet.

Nutrient Composition for Skidegate Nation

Table 3 Community diet from the 24 hr recall survey and food-groups and sub-food groups for women

Nutrients		Dietary reference intake		Observed (n = 36)
	Unit/day	Weighted requirement		Population mean intake
		RDA	Max	
Protein	g	46	1000	78
Total Fat	g	45	1000	68
Carbohydrates	g	130	130	180
Dietary Fibre	g	25	70	15
Calcium	mg	1000	2500	629
Iron	mg	18	45	12
Magnesium	mg	320	350	239
Phosphorus	mg	700	4000	1031
Potassium	mg	2600	1000	2120
Sodium	mg	1500	2300	2626
Zinc	mg	8	40	8.3
Copper	ug	900	10000	1.1
Vitamin A	ug	700	3000	2857
Vitamin D	ug	15	100	5
Vitamin C	mg	75	2000	63
Riboflavin	mg	1.1	1.3	1.3
Niacin	mg	14	35	28
Folate	ug	400	1000	256
Toal saturated fat	g	16	20	23.5
Linoleic acid (omega-6)	g	12	20	7.14
Alpha-Linolenic acid (omega-3)	g	1.1	3	1.5
Monosaturated fatty acids	g	33	1000	22
Polyunsaturated fatty acids	g	11	1000	13
Total sugars	g	25	1000	52
Cholesterol	mg	200	300	303
Thiamin	mg	1.1	5	1.05

Vitamin B6	mg	1.3	100	1.4
Vitamin B12	ug	2.4	1000	3.55

Table 4 Community diet from the 24 hr recall survey and food-groups and sub-food groups for Skidegate men

Nutrients		Dietary reference intake		Observed (n =13)
	Unit/day	Weighted requirement		Population mean intake
		RDA	Max	
Protein	g	56	1000	55
Total Fat	g	45	1000	53
Carbohydrates	g	100	130	113
Dietary Fibre	g	38	1000	8.8
Calcium	mg	1000	2500	452
Iron	mg	8	45	7
Magnesium	mg	420	1000	180
Phosphorus	mg	700	4000	876
Potassium	mg	3400	10000	1377
Sodium	mg	1500	2300	1956
Zinc	mg	11	40	5.6
Copper	ug	900	10000	0.8
Vitamin A	ug	900	3000	1109
Vitamin D	ug	15	100	7.6
Vitamin C	mg	90	2000	33
Riboflavin	mg	1.3	1000	1
Niacin	mg	16	35	21
Folate	ug	400	1000	150
Toal saturated fat	g	0.1	1000	19
Linoleic acid (omega-6)	g	17	1000	5.6
Alpha-Linolenic acid (omega-3)	g	1.6	1000	1.3
Monosaturated fatty acids	g	0.1	1000	16
Polyunsaturated fatty acids	g	0.1	1000	13
Total sugars	g	0.1	1000	32
Cholesterol	mg	300	1000	214
Thiamin	mg	1.2	100	0.72

Vitamin B6	mg	1.3	100	0.9
Vitamin B12	ug	2.4	100	4.6

Overall, observed patterns indicate multiple micronutrient shortfalls, several of which align with nutrient inadequacies previously reported in FNFNES. Consistent with broader evidence on nutrition transitions, the nutrient gaps observed here likely reflect the combined effects of high food costs, limited access to fresh market foods, and reduced intake of nutrient-dense traditional foods.

Among women, macronutrient intake was generally adequate for protein and carbohydrate (Protein: 78 g vs 46 g; Carbohydrates: 180 g vs 130 g). However, several nutrients of concern were identified. Fibre intake was low (15 g vs 25 g), suggesting limited intake of high-fibre foods such as whole grains, legumes, and fruits/vegetables. Multiple micronutrients also fell below recommended levels, including calcium (629 mg vs 1000 mg), iron (12 mg vs 18 mg), magnesium (239 mg vs 320 mg), and potassium (2120 mg vs 2600 mg). Vitamin D intake was notably low (5 µg vs 15 µg), and folate was also below target (256 vs 400), indicating a baseline dietary pattern that may not consistently meet key micronutrient requirements. Several nutrients were elevated in women's diets. Sodium intake exceeded the recommended benchmark (2626 mg vs 2300 mg), indicating substantial contribution from ultra-processed foods. In addition, saturated fat exceeded the table threshold (23.5 g vs 20 g) and cholesterol slightly exceeded the threshold (303 mg vs 300 mg). Total sugars were also high relative to the threshold used (52 g vs 25 g). Together, these results suggest a baseline diet with insufficient intake of protective nutrients (fibre, calcium, vitamin D, folate, potassium) and elevated intake of nutrients such as sodium suggest for nutrient-related chronic disease risk which is associated with food insecurity.

For men, several inadequacies were more pronounced. Protein intake was close to the reference level (55 g vs 56 g), and carbohydrate intake exceeded the reference level used in the table (113 g vs 100 g), though it remains below 130 g if that is the chosen RDA threshold. The most notable concern is very low fibre intake (8.8 g vs 38 g), indicating particularly low consumption of fibre-rich foods. Men also showed substantial shortfalls for calcium (452 mg vs 1000 mg), iron (7 mg vs 8 mg), magnesium (180 mg vs 420 mg), potassium (1377 mg vs 3400 mg), and zinc (5.6 mg vs 11 mg). Several vitamins were also below recommended levels, including vitamin D (7.6 µg vs 15 µg), vitamin C (33 vs 90), folate (150 vs 400), thiamin (0.72 vs 1.2), and vitamin B6 (0.9 vs 1.3). Essential fatty acids were low, particularly linoleic acid (5.6 g vs 17 g) with linolenic acid slightly below target (1.3 g vs 1.6 g). Although men's sodium intake (1956 mg) was lower than women's, it remains above the Upper Limit value listed in the table (1500 mg). Taken together, the men's nutrient profile suggests broader micronutrient inadequacy relative to women, which may reflect both dietary patterns and structural factors influencing food access and affordability.

Nutrient Composition for Tla'amin Nation

Table 5 Community diet from the 24 hr recall survey and food-groups and sub food-groups for Tla'amin women

Nutrients		Dietary reference intake		Observed (n = 49)
	Unit/day	Weighted requirement		Population mean intake
		RDA	Max	
Protein	g	46	1000	78
Total Fat	g	45	1000	77
Carbohydrates	g	130	130	232
Dietary Fibre	g	25	70	15
Calcium	mg	1000	2500	713
Iron	mg	18	45	15
Magnesium	mg	320	350	289
Phosphorus	mg	700	4000	1077
Potassium	mg	2600	1000	2373
Sodium	mg	1500	2300	3120
Zinc	mg	8	40	9
Copper	ug	900	10000	1.4
Vitamin A	ug	700	3000	1292
Vitamin D	ug	15	100	4.4
Vitamin C	mg	75	2000	103
Riboflavin	mg	1.1	1.3	68
Niacin	mg	14	35	31
Folate	ug	400	1000	288
Toal saturated fat	g	16	20	25
Linoleic acid (omega-6)	g	12	20	9.8
Alpha-Linolenic acid (omega-3)	g	1.1	3	1.1
Monosaturated fatty acids	g	33	1000	28
Polyunsaturated fatty acids	g	11	1000	15
Total sugars	g	25	1000	84

Cholesterol	mg	200	300	307
Thiamin	mg	1.1	5	1.2
Vitamin B6	mg	1.3	100	1.4
Vitamin B12	ug	2.4	1000	3.7

Table 6 Community diet from the 24 hr recall survey and food-groups and sub food-groups for Tla'amin men

Nutrients		Dietary reference intake		Observed (n =22)
	Unit/day	Weighted requirement		Population mean intake
		RDA	Max	
Protein	g	56	1000	242
Total Fat	g	45	1000	88
Carbohydrates	g	100	130	92
Dietary Fibre	g	38	1000	15
Calcium	mg	1000	2500	833
Iron	mg	8	45	15
Magnesium	mg	420	1000	302
Phosphorus	mg	700	4000	1303
Potassium	mg	3400	10000	2596
Sodium	mg	1500	2300	4147
Zinc	mg	11	40	12
Copper	ug	900	10000	1.5
Vitamin A	ug	900	3000	397
Vitamin D	ug	15	100	6.2
Vitamin C	mg	90	2000	64
Riboflavin	mg	1.3	1000	1.8
Niacin	mg	16	35	39
Folate	ug	400	1000	268
Toal saturated fat	g	0.1	1000	30
Linoleic acid (omega-6)	g	17	1000	10
Alpha-Linolenic acid (omega-3)	g	1.6	1000	1.4
Monosaturated fatty acids	g	0.1	1000	33
Polyunsaturated fatty acids	g	0.1	1000	18
Total sugars	g	0.1	1000	91

Cholesterol	mg	300	1000	478
Thiamin	mg	1.2	100	1.2
Vitamin B6	mg	1.3	100	1.7
Vitamin B12	ug	2.4	100	5

Table 5 and 6 (women, n=49; men, n=22) summarize mean daily nutrient intakes from the 24-hour recall survey for Tla'amin Nation and compare these with weighted RDA values. The bolded values identify nutrients below recommended intake targets (potential inadequacy) and components above recommended limits (potential excess), and therefore represent the main areas of concern for diet quality when modelling for optimal versions.

For women, the most consistent shortfalls occur in fibre, calcium, iron, magnesium, potassium, vitamin D, and folate. Fibre intake (15 g/day vs 25 g/day) suggests low consumption of whole grains, fruits/vegetables, legumes, and other high-fibre foods. Calcium (713 mg vs 1000 mg) and vitamin D (4.4 µg vs 15 µg) are notably low, indicating challenges in meeting bone- and muscle-health–related requirements through current dietary patterns, especially when access to nutrient-dense market foods is constrained. Folate intake (288 vs 400) and iron intake (15 vs 18) also fall below recommended values.

In addition to shortfalls, several "limit" nutrients are elevated. Women's sodium intake (3120 mg vs 1500 mg; exceeds 2300 mg benchmark) is high, consistent with greater intake of ultra-processed foods. Saturated fat (25 g vs a 20 g limit), total sugars (84 g vs 25 g), and cholesterol (307 mg vs 300 mg) are also elevated, reinforcing a pattern of diets that may be energy-dense but relatively micronutrient-poor. Together, these findings point to a baseline diet characterized by insufficient intake of several protective nutrients (fibre, potassium, calcium, vitamin D, folate) alongside excess sodium can contribute to nutrition-related chronic disease risk which is associated to food insecurity.

For men, the tables indicate even more pronounced diet-quality challenges. The most notable inadequacies are fibre, carbohydrate, calcium, magnesium, potassium, vitamin A, vitamin D, vitamin C, folate, and linoleic acid. Fibre is substantially low (15 g/day vs 38 g/day), suggesting very low intake of fibre-rich foods. Potassium (2596 vs 3400) and magnesium (302 vs 420) are also below recommended levels, which may reflect limited intake of fruits/vegetables, legumes, and whole grains. Vitamin D remains low (6.2 vs 15), and men additionally show low vitamin A (397 vs 900) and vitamin C (64 vs 90), indicating shortfalls in micronutrients typically supported by fruits/vegetables and certain traditional foods.

2.3 Formulation of input tables

Three input tables were formulated for both females and males for both communities. Prior to the formulation of the input tables, the food items from the 24-hr dietary recall surveys were aggregated into larger food groups and then aggregated further into sub-food groups (Batal et al., 2022). A table detailing this is found in the Appendix 6.3. Each food item was measured as a unit of g/person/day. Food items were then split into market foods or traditional foods. Market foods were then categorized into 10 groups including dairy, added fats, animal protein, plant protein, fruit, vegetables, grains, sweets, salty snacks, mixed foods, and beverages (Batal et al., 2022). Traditional foods were split into three groups, game meat, fish and shellfish, and berries (Batal et al., 2022). The aggregated food items are placed in a table, formatted as an array.

Consumption data

Consumption data derived from the 24-hr dietary recalls with similar food items grouped into food groups and sub-food groups. The mean, min, and max CI 95% is calculated for each sub-food group on a population level, including both consumers and non-consumers, ensuring the estimates represent the population not a subset (N. Willows et al., 2019a). This is completed to capture the dietary patterns of the entire population, whereas the food choice picture would be

incomplete if only consumers were included in the calculations. Furthermore, the consumption data includes the cost for each sub-food group. From the retail market survey each food item is converted to cost/gram (Kenny et al., 2020). For each sub-food group a weighted cost is calculated based on the consumption patterns within the 24-hr dietary recalls. This is completed for both men and women due to different consumption patterns.

Nutritional profile

The nutritional profile for each sub-food group is taken from the Canadian Nutrient File (2015) and calculated based on a weighted average. Furthermore, the MeHg content for each sub-food group item was based on the FNFNES reporting completed for the British Columbia region (Chan et al., 2021). The MeHg threshold limit was calculated based on the average weight of both females and males within the surveys (Chan et al., 2021). The recommended daily allowance was derived from the CNF and calculated using a weighted approach. This was completed for both men and women due to different dietary patterns and nutrient requirements.

2.4 Model formulation

A set of diet optimization models was developed to evaluate present-day and climate-adaptation scenarios and to estimate the minimum dietary changes required to achieve nutrient adequacy while respecting feasibility constraints at the population level. Models were run separately for women and men, using sex-specific mean intakes derived from 24-hour dietary recalls. Each model was designed to meet nutrient targets while remaining as close as possible to observed consumption patterns, because diets that require fewer departures from typical intake are more likely to be feasible and acceptable, particularly in remote settings where affordability and access constrain food choice (N. Willows et al., 2019a).

Optimization models consist of an objective function subject to a set of constraints (Abejón et al., 2020). The solver identifies values for the decision variables, here, the grams/day

of each food subgroup. Consistent with the literature, the primary objective was defined as Total Departure from Mean Intake (TDMI), representing the sum of absolute deviations between optimized food quantities and the observed mean diet (N. Willows et al., 2019a). Deviations were standardized across food items to ensure comparability. Minimizing TDMI operationalizes the goal of identifying nutritionally adequate diets that require the fewest changes from baseline intake (N. Willows et al., 2019a).

Since, the models were also intended to generate diets that are affordable and lower in MeHg exposure, the optimization was formulated as a weighted multi-objective problem. Affordability was explicitly prioritized to reflect the reality that cost is often the binding constraint shaping feasible diets in remote communities and aligns with community priorities.

Let $\mathbf{x_i}$ represent the grams/day of food item *i*. Total diet cost and total MeHg exposure are defined as:

Equation 1 Total cost and MeHg exposure

$$\text{Cost}(x) = \Sigma_i \, (c_i \, x_i)$$

$$\text{MeHg}(x) = \Sigma_i \, (m_i \, x_i)$$

where c_i is the cost per gram and m_i is the MeHg concentration (or MeHg intake per gram) for food item *i*.

To combine objectives on a comparable scale, each term was normalized (e.g., by a baseline/reference value):

Equation 2 Normalised total cost and MeHg exposure

$$\text{Cost}\sim(x) = \text{Cost}(x) \,/\, \text{Cost_ref}$$

$$\text{MeHg}\sim(x) = \text{MeHg}(x) \,/\, \text{MeHg_ref}$$

The weighted objective function was then defined as:

Equation 3 Weighted objective function

$$\min F(x) = w_C \cdot \text{Cost}\sim(x) + w_M \cdot \text{MeHg}\sim(x)$$

subject to all nutrient, food-group, and feasibility constraints described above. Weights were selected such that w_C > w_M (and w_C + w_M = 1), ensuring the model prioritizes affordability. For example, w_C = 0.6 and w_M = 0.4 places 1.5 times more emphasis on minimizing cost than minimizing MeHg. In practice, this structure yields diets that remain cost-minimizing while still shifting away from high-MeHg foods when doing so does not substantially increase total diet cost (Abejón et al., 2020; Hassna et al., 2024; Moraes et al., 2015).

All models were isoenergetic meaning, total dietary energy was held constant so that nutrient requirements were assessed within a realistic energy envelope. Total energy intake was constrained to the mean observed energy intake for women and men, respectively.

Nutrient constraints were informed by Health Canada Dietary Reference Intakes (DRIs). To balance adequacy with feasibility and community relevance, nutrients were classified as hard or soft constraints. Hard constraints required meeting 100% of the weighted RDA (or AI where no RDA exists). Soft constraints required meeting a less stringent threshold (e.g., ≥80% of the weighted RDA/AI) for nutrients that were difficult to achieve without unrealistic departures from observed diets, excessive cost, or trade-offs that conflicted with community priorities. Where available, Tolerable Upper Intake Levels (ULs) were included as upper bounds. Because Health Canada does not specify ULs for saturated fat or cholesterol, recommending instead that they be kept “as low as possible while consuming a nutritionally adequate diet,” upper limits for saturated fat, dietary cholesterol, and total sugars were informed by World Health Organization guidance, and set as constraints within the model parameterization.

Food composition data were available for the nutrients modelled in the intake tables, comprising nine vitamins, vitamin A (as RAE), vitamins B6, B12, C, and D, niacin (as NE), riboflavin, thiamin, and folate, and eight minerals, calcium, copper, iron, magnesium, phosphorus, potassium, sodium, and zinc. Sex-specific population-weighted requirements were calculated using the community/region age structure from the 2021 Census (Statistics Canada, 2021).

To ensure model outputs remained aligned with community priorities and ecological feasibility, additional food-system constraints were used to represent the relationship between traditional foods (TF) and market foods (MF). First, a minimum contribution of TF in optimized diets was maintained or increased relative to baseline to ensure solutions retained culturally significant foods.

Second, projected fish stock availability under climate change was incorporated directly into the optimization as an availability constraint on seafood quantities in adaptation scenarios (e.g., year 2050 under a high-emissions pathway). Specifically, projected percent changes in relative abundance or catch potential were converted into an availability multiplier for each seafood type:

For each seafood item *s*, an availability multiplier was calculated from the projected percent change in availability:

Equation 4 Fish availability multiplier

$$\text{AvailMult}_s = \max(0,\ 1+\Delta s/100)$$

where Δ_s is the projected percent change (%) for seafood item *s*.

These multipliers were then used to scale the feasible upper bounds for seafood subgroups. This constrains the solver so that foods projected to decline cannot be selected above

a reduced maximum, while foods projected to increase can be selected up to a higher maximum (subject to any realism caps already imposed in the model).

Operationally, for each seafood item *s*, the model applied:

$$x_s \leq x_s^{max} \cdot \text{AvailMult}_s$$

where x_s^{max} is the baseline feasibility bound (e.g., the 95th-percentile consumption limit or another palatability maximum) (Hassna et al., 2024).

This approach incorporates climate impacts as supply-side limits (rather than forcing minimum increases). As a result, projected changes in seafood availability modify the feasible diet space in a transparent, scenario-specific way.

For aggregated categories where projections were not species-specific or where multiple species map to a single dietary item, availability multipliers were constructed using biological proxies and weighted means. Groundfish availability was represented as a weighted mean across halibut, lingcod, sablefish/black cod, and rockfish, and applied to all groundfish items. Herring roe availability was parameterized using Pacific herring as the biological proxy. These mapping decisions were made to retain interpretability while aligning diet categories with the available ecological projections.

In combination, the nutrient, cost, contaminant, food-group, and stock-availability constraints ensured that optimized diets were not only nutritionally adequate, but also economically feasible, culturally grounded, and consistent with anticipated climate-driven limits on traditional seafood availability.

2.5 Co-development

Knowledge co-development between Western science and Indigenous knowledge has been shown to be useful when creating adaptation pathways specifically for climate change (Davis et al., 2021). Adaptation pathways in this context are defined as a series of robust

decisions in response to the climate stressors (Davis et al., 2021). This concept aligns directly with quantitative scenario-based modelling since, which similarly evaluates alternative futures by requiring explicit specification of assumptions to assess how these choice influence outcomes across scenarios.

2.5.1 Semi-Structured interviews

Table 7 Thematic analysis for semi-structured interviews

Interviewee / Role	Expertise	Purpose	Key themes
Clinical dietitian	Community nutrition assessment; nutrient adequacy and deficiency patterns; diet quality considerations; guideline-based planning	Identify priority nutrient gaps and population-specific nutrition considerations to inform model targets (e.g., nutrient constraints, food group emphasis) and interpret scenario outputs.	nutrient adequacy; nutrient deficiencies; dietary guidelines; diet quality; life-stage needs; culturally relevant nutrition
Harm reduction coordinator	Harm reduction food supports; food baskets; community garden kits; program delivery constraints; participant needs	Document how harm reduction food supports operate (food baskets, gardens), including operational constraints and participant needs; identify feasible food items, access barriers, and substitution logic for realistic scenario modelling.	shelf-stable foods; kitchen constraints; impacts of vulnerable peoples; gardens & seasonality; climate disruptions; cultural relevance; access & equity
Health director	Community food program governance; budgeting and funding; procurement; program evaluation; operational decision-making	Incorporate community food initiatives; identify budget envelopes, procurement pathways, and evaluation metrics so modelling outputs align with operational planning needs.	program governance; budgeting; decision criteria; evaluation metrics; cultural priorities; scenario planning; climate adaptation; access & equity
Healthcare worker (Elders support)	Elders' grocery access and shopping logistics; barriers to purchasing and preparation; support needs; substitution practices	Capture real-world grocery access and shopping constraints for Elders; document common barriers, preferred foods, feasible substitutions, and access-related costs to ensure model outputs reflect lived feasibility.	Elders support; grocery access; transportation; affordability; cultural preferences; preparation/storage constraints; substitution; access & equity
Super-harvesters	Effort/catch patterns; access dynamics; regulatory context; observed impacts on local availability and prices	Characterize how climate change affect availability, timing, and access to key foods (e.g., seafood); identify mechanisms to parameterize scenarios (e.g., catch concentration, species migration, equipment costs, invasive species, processing capacity).	Super-harvesters; harvesting pressure; access & equity; species availability; seasonality; market channels; pricing dynamics; governance & regulation; scenario parameters; climate interactions

Semi-structured expert interviews were conducted to inform constraint selection, constraint calibration, and weight assignment for optimization objectives. Interviews were designed to capture information across the community's socioeconomic, health/nutrition, programmatic, and environmental contexts so that model assumptions reflected local feasibility conditions rather than mathematical defaults. Participants included a clinical dietitian, harm reduction coordinator, health director, healthcare worker supporting Elders, community leaders, and super-harvesters. Participants were approached with support from community coordinators, and interviews were scheduled via email. All interviews were conducted remotely via Zoom.

A structured question guide was prepared in advance to ensure coverage of key domains; however, interviews were semi-structured, using the guide to direct the conversation rather than enforce a fixed sequence of questions. Domains reflected the key thematic areas required to parameterize and interpret the models, including: i) nutrient adequacy and deficiency patterns; ii) food access and affordability constraints (cost); iii) program operations and decision criteria (food baskets, community kitchens, procurement pathways, budgeting, evaluation metrics); and iv) harvesting access and ecological dynamics affecting seafood and other culturally important foods (seasonality, species availability, and regulatory context).

Interview findings were used to parameterize dietary feasibility in several ways. First, interviews with community leaders and harvesters informed which fish and emerging species aligned with dietary preferences and could be represented as realistic substitutions under scenario conditions. These discussions also clarified practical requirements for adoption, such as whether harvesting methods and preparation knowledge existed locally and whether this knowledge could be shared within the community, supporting defensible assumptions about food availability and use. Second, interviews with the clinical dietitian contributed to identifying priority nutrient gaps

and contextual factors that may explain them, which informed nutrient constraint targets and, where needed, justified adjustments to constraints to avoid unrealistic solutions. Third, interviews with health director and harm reduction coordinator clarified operational objectives and constraints, allowing model weights and scenario inputs to align with real program decision-making rather than abstract optimization preferences. For example, planned community initiatives, such as the community garden were incorporated into weight distribution and scenario design. Finally, interviews highlighted the local availability and equity of access of traditional foods, which informed scenario parameterization (e.g., availability limits, seasonal constraints, and potential price or access impacts).

With participants' explicit permission, interviews were transcribed using Zoom's built-in transcription function. Notes were also taken during interviews, and transcripts were used to verify details and capture any information not recorded in real time.

2.6 Modelling Framework

Figure 3 Community-informed modelling framework for scenario-based dietary optimization

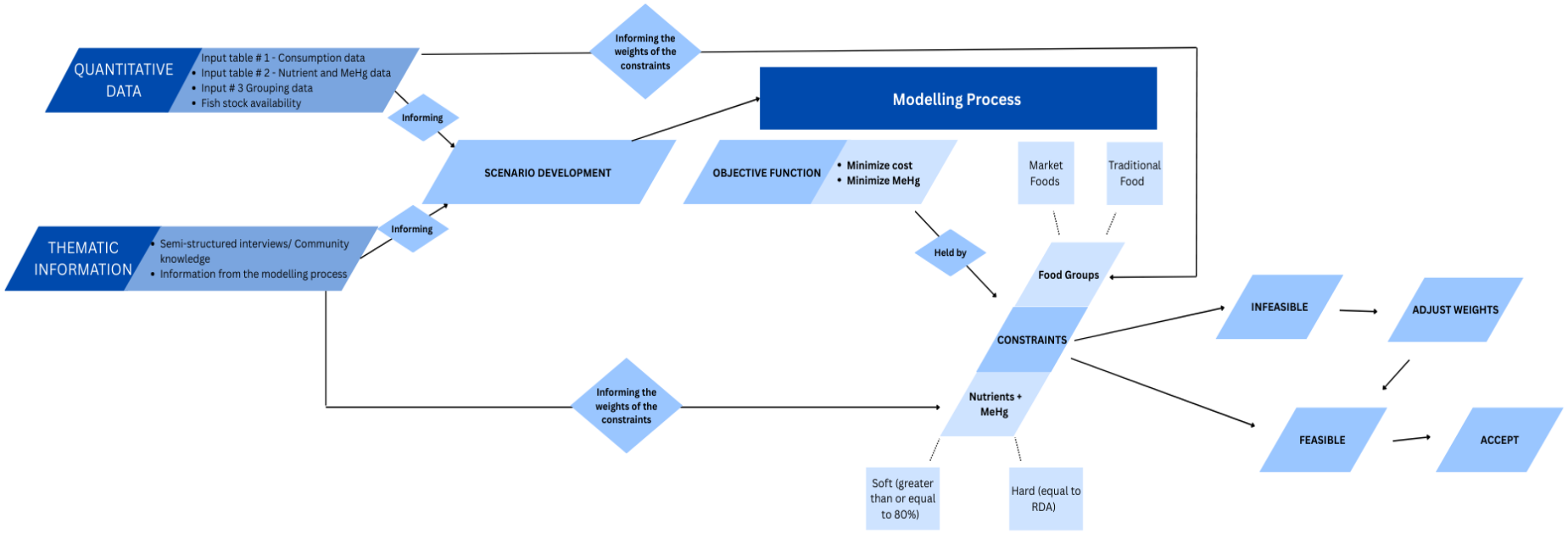


Figure 3 Quantitative inputs (consumption data, nutrient and MeHg composition data, food-grouping tables, and fish-stock availability projections) and thematic inputs (semi-structured interviews/community knowledge and insights from model iteration) jointly inform scenario development and the weighting/parameterization of constraints. The optimization minimizes cost and MeHg across market and traditional foods aggregated into food groups, subject to food-group bounds and nutrient/MeHg constraints (soft targets ≥80% RDA and hard constraints = RDA). Rectangles denote core modelling components or modules (inputs, scenario development, objective function, constraints, and the modelling process), whereas diamonds denote decision/feedback nodes where information is used to parameterize the model or outputs are evaluated (e.g., informing constraint weights, feasibility checks, and decisions to adjust weights or accept solutions). Solutions are evaluated for feasibility; infeasible runs trigger constraint-weight adjustment and re-optimization, while feasible solutions are accepted for the given scenario.

A single dietary optimization framework was applied with two distinct, community-specific parameter sets. The generic model structure, including the objective function, constraint set, and hard/soft constraint logic, is specified in Chapter 2. Chapters 3 and 4 then describe how this shared framework is parameterized differently, using community-specific inputs, bounds, weights, and availability assumptions. Framing the work in this way clarifies that observed differences in model outputs are driven by community-specific parameterization within a single shared modelling framework. Thus, reflecting distinct food environments, priorities, and availability constraints, rather than from separate model formulations.

Diet optimization requires iterative decisions about the specification and calibration of constraints, including nutrient adequacy targets, food-group bounds, MeHg exposure limits, and consumption preference constraints (N. Willows et al., 2019a). In many applications, these decisions are made primarily through mathematical feasibility. However, feasibility-driven adjustments can embed assumptions that are not aligned with community priorities or traditional ecological knowledge. To address this, a modelling framework was developed to guide constraint and weight revisions in a manner that is transparent, repeatable, and explicitly justified using community-informed evidence (Figure 3).

The framework is informed by two complementary streams of evidence: quantitative model inputs and thematic evidence. Quantitative model inputs include the three model input tables described earlier as well as fish stock availability projections. These inputs define the baseline food environment and are used to parameterize food-group bounds and the relative weighting of market foods versus traditional foods within the optimization structure. Fish stock projections, for example, are used to adjust the feasible bounds or weights applied to seafood

food groups under climate scenarios so that model outputs remain consistent with plausible future ecological constraints.

Thematic evidence consists of findings from semi-structured expert interviews and diagnostic information generated during model runs. Interview evidence provides context on cultural food significance, feasibility constraints, affordability and access barriers, and harvesting dynamics relevant to seafood availability and equity of access. Model diagnostics indicate which constraints are binding, which nutrient requirements are repeatedly unmet under the current consumption preference structure, and what trade-offs emerge when objectives are pursued. Together, these forms of thematic evidence are used to interpret infeasibility and guide revisions without defaulting to relaxations that conflict with community-defined priorities.

A central feature of the shared framework is the classification of nutrient constraints as either hard or soft. Hard nutrient constraints require meeting 100% of RDA targets and represent full adequacy thresholds for requirements that are treated as non-negotiable given community priorities and health considerations. Soft nutrient constraints require meeting at least 80% of RDA targets and are applied when enforcing full adequacy produces persistent infeasibility or requires trade-offs that undermine community acceptability in practice, such as substantial deviation from community consumption patterns, displacement of traditional foods, or cost increases beyond realistic affordability. This hard/soft structure provides an explicit mechanism for addressing a common optimization challenge: simultaneously meeting full nutrient adequacy, cost objectives, MeHg exposure limits, and preference/acceptability constraints may be mathematically infeasible or produce outputs that are not plausible within the local food environment.

Within this framework, decisions to reclassify nutrient constraints, adjust food-group bounds, or modify weights are made through an iterative workflow. As shown in Figure 3, the process begins with scenario development and specification of the objective function. Food-group bounds and nutrient/MeHg constraints are then applied and the model is solved. If the solution is infeasible or produces outputs inconsistent with community priorities, the framework cycles through predefined revision steps, such as adjusting weights, revising food-group bounds, or selectively reclassifying specific nutrients from hard to soft constraints. Each iteration requires documentation of the constraint or weight changes, the evidence used to justify them (interview evidence and/or model diagnostics), and the resulting trade-offs (e.g., diet cost, traditional food share, nutrient shortfalls, or changes in MeHg exposure).

A solution is accepted only when it is mathematically feasible and consistent with community priorities as represented in the parameterization and thematic evidence. By specifying one generic optimization model and applying structured, evidence-based parameter adjustments across communities, this approach maintains a consistent modelling structure while ensuring that outputs remain grounded in locally defined feasibility conditions and decision-making needs.

2.7 Conclusion

In conclusion, effective scenario-based modelling requires rigorous representation of the local food environment, coupled with a community-led co-development process that is respectful, and non-extractive. Community leaders and TK holders are often operating at or beyond capacity; co-development processes must therefore be designed to respect their time, priorities and preferred modes of engagement. If, collaboration becomes overly demanding, it can reproduce power imbalances, where TK holders provide deeply rooted, knowledge without

receiving commensurate benefits, creating a parasitic dynamic that undermines trust and equity (Chapman & Schott, 2020).

Concurrently, co-developing community-specific, scenario-based models facilitates the generation of knowledge that is directly aligned with community priorities and decision contexts. Since, modelling is inherently iterative, this approach supports ongoing recalibration as empirical evidence accumulates and as local conditions and objectives evolve. Over time, such iterative refinement enhances the validity and decision relevance of model outputs for climate adaptation planning, strengthening their utility for grounded and actionable community decision-making.

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Chapter 3- Skidegate (Xaayda • Xaadée) Model Formulation and Results

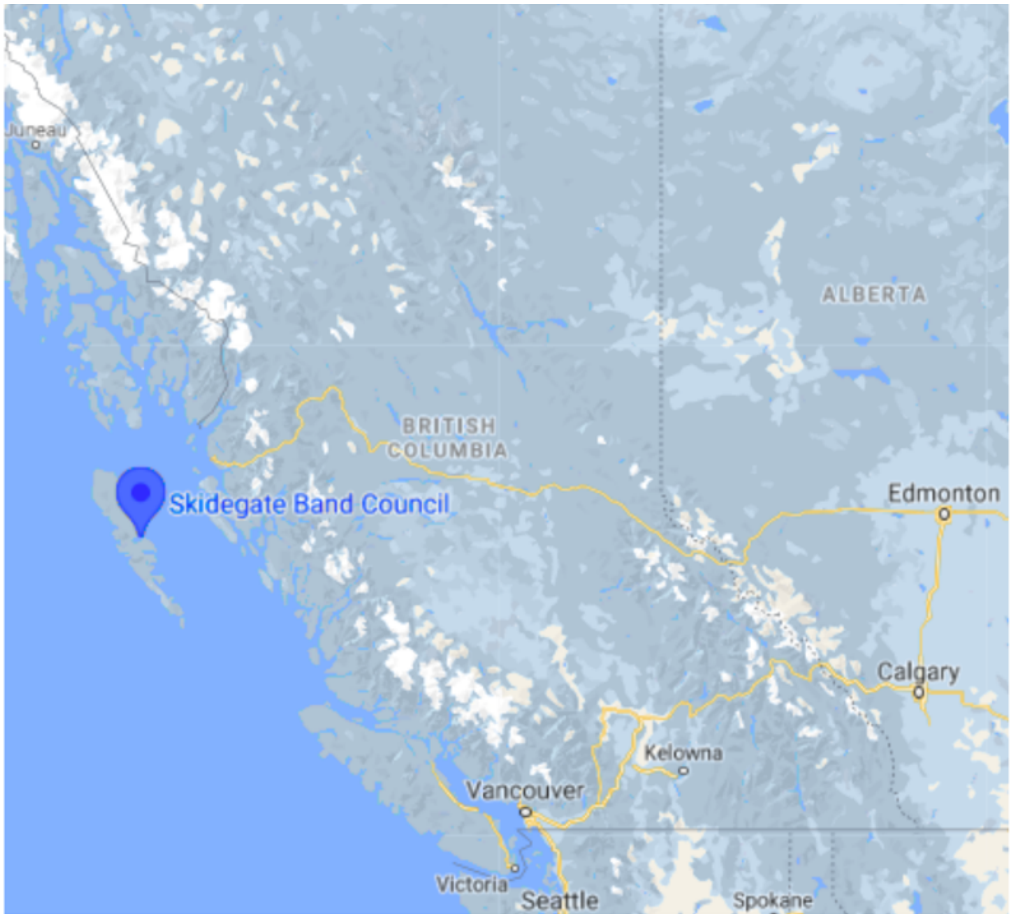
3.1 Introduction

A robust understanding of community context is essential both for interpreting model outputs and for developing defensible scenarios. Indigenous' food environments especially for remote FN communities are shaped by interactions among retail market food availability and quality, access to traditional food, household economic resources, and dietary patterns (Shafiee et al., 2022). As a result, characterizing the local food environment requires integrating multiple empirical inputs, including food basket costing, and socioeconomic conditions (Tarasuk et al., 2019).

Food basket costing provides an indicator of affordability and helps quantify how costs shape feasible dietary choices (Power et al., 2019). Demographic information (e.g., population size, age structure, and household composition) contextualizes differences in dietary requirements and potential vulnerability across groups. Socioeconomic indicators (e.g., income, and employment) further inform constraints on market food access and on the capacity to engage in harvesting or procurement activities (Tarasuk et al., 2019).

Together, these contextual dimensions ensure that model assumptions, scenario parameters, and interpretations of results remain aligned with community conditions and support meaningful application to climate change adaptation planning and decision-making.

Figure 4 Map of Skidegate



Adapted from Google maps

Skidegate Band Council is a part of the Haida Nation and is located on Haida Gwaii (Figure 4). Skidegate Band Council functions as a central governance body supporting local programs, services and community priorities. As a remote coastal community, Skidegate's food environment reflects a close interdependence between traditional foods, particularly seafood and other locally harvested foods, and the retail market. This setting makes Skidegate an important context for examining how climate change, market access, and cultural food practices interact to shape food security and dietary resilience.

Demographic Data

Table 8 Demographic Information for Skidegate

	Statistic Canada			**Survey**		
	(Government of Canada, 2022a)					
Characteristic	Total	Men	Women	Total	Men	Women
Total- Distribution (%) of the population by board age groups	100	100	100	100	100	100
0 -14 years	15.7	15.4	16.0	N/A	N/A	N/A
15- 64 years	65.0	66.2	64.0	70.0	63.6	72.3
65 years and over	17.9	16.9	18.7	30.0	36.4	27.7
85 years and over	2.1	1.5	2.7	4.3	4.5	4.3
Average age of the population	41.2	41.1	41.4	55.2	59.5	54.0
Median age of the population	40.0	41.2	39.2	53.0	60.0	52.0

Table 8. compares key demographic characteristics for the study community using Statistics Canada survey results alongside participant characteristics from the community survey. Statistics Canada data provide a population-level profile, including age distribution and summary age measures, which are useful for situating the community within a broader regional context. In contrast, the survey results reflect the composition of respondents and should be interpreted as descriptive of the sample rather than representative of the full community population.

Based on Statistics Canada, the community has a relatively balanced age structure, with 15.7% of the population aged 0–14 years, 65.0% aged 15–64 years, and 17.9% aged 65 years and over. Older adults aged 85 years and over comprise 2.1% of the population. The average age is 41.2 years (men: 41.1, women: 41.4), while the median age is 40.0 years (men: 41.2, women: 39.2), indicating a community age profile that is broadly centred around middle adulthood.

Survey results indicate an older respondent profile compared to the population-level Statistics Canada estimates. Among survey participants, 70.0% were aged 15–64 years and 30.0% were aged 65 years and over (men: 36.4%; women: 27.7%), while data for ages 0–14 years were not applicable. Adults aged 85 years and over-represented 4.3% of the survey sample. The mean age of respondents was 55.2 years overall (men: 59.5, women: 54.0), and the median age was 53.0 years (men: 60.0, women: 52.0).

Since the community survey was designed to capture adult dietary patterns, food access, and household decision-making, it did not include children (0–14 years). As a result, age categories and summary statistics from the survey are not directly comparable to Statistics Canada's full population distribution, which includes children.

Specifically, participants were adults (18+ years), so the 0–14 age group is not applicable (N/A) in the survey table. Consequently, the survey age distribution is expected shift toward older age groups, and the higher proportions of respondents aged 65+, and the higher mean and median ages, reflect the sampling frame rather than a true difference in community demographics.

Table 9 Demographic data from survey for Skidegate

Characteristic	Mean	
	Women	Men
Age	50	60
Post secondary education (%)	70	29
Social Assistance (%)	67	33
Homeownership (%)	62	36
Full time employment (%)	76	24

Table 9. shows the results from the health survey administered.

Marked gender differences were observed across several socioeconomic measures reported in Table 9. A larger proportion of women reported completing post-secondary education (70%), owning their home (62%), and working full-time (76%) compared with men (29%, 36%, and 24%, respectively). At the same time, reliance on social assistance was common among respondents, with 67% of women and 33% of men receiving some form of income support. Together, these patterns highlight a participant group in which economic circumstances may vary substantially by gender, with implications for purchasing power, retail food access, and the affordability constraints incorporated in subsequent modelling.

Community Wellbeing Index

Table 10 Community Wellbeing index and its 4 components for Skidegate

Nation	Income	Education	Housing	Labour force	Overall CWB
Skidegate	71	50	84	83	72

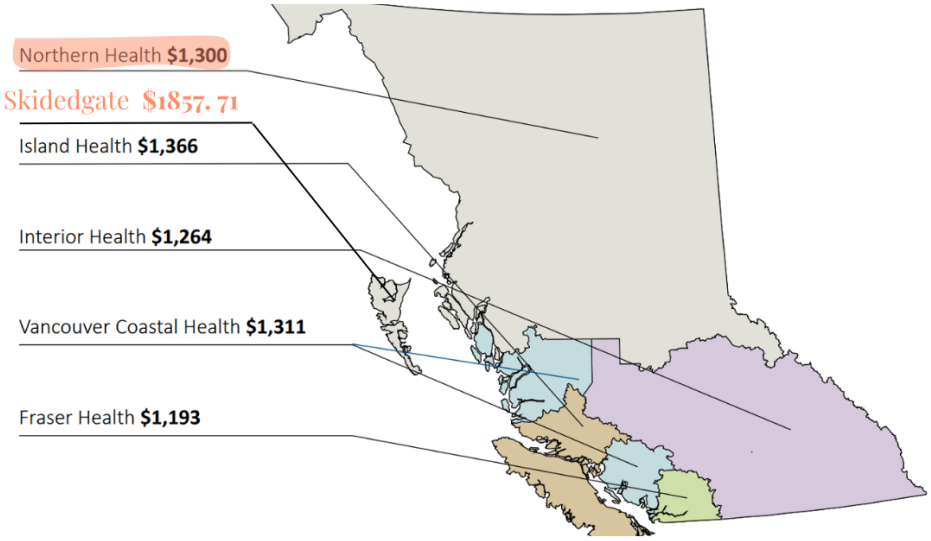
Adapted from: (*Community Well-Being (CWB) Index - Table View*, n.d.)

Community-level indicators from the Community Wellbeing (CWB) Index provide additional context for these survey findings. Skidegate's overall CWB score was 72, with component scores of 71 (income), 50 (education), 84 (housing), and 83 (labour force) (Table 10). While this overall score has improved over the last decade, it remains lower than the non-Indigenous population, reflecting persistent structural inequities. The CWB profile suggests

relatively strong housing and labour force conditions at the community level, which can support food security by strengthening household income stability, improving access to transportation and storage infrastructure, and increasing the capacity to consistently obtain sufficient, nutritious foods. However, comparatively lower education outcomes may reflect structural constraints on employment mobility and long-term earning potential, which can increase vulnerability to food insecurity for some households despite favourable community-level conditions. This pattern also aligns with the gendered differences observed in the survey, insofar as education and labour-market opportunities can shape differential exposure to affordability constraints and access barriers. Taken together, these findings underscore the importance of incorporating socioeconomic context when interpreting diet-related constraints and when evaluating the feasibility and equity implications of adaptation options.

Food Basket Costing

Figure 5 Food basket costing for a family of four for Skidegate



Adapted from: (*BC Centre for Disease Control, 2022*)

Food affordability in Skidegate is further illustrated through food basket costing. The estimated monthly cost of a standard food basket for a family of four in Skidegate is $1857.71, which is

substantially higher than the Northern Health average of approximately $1300 (*Food_Costing_in_BC_2022_Report_FINAL.Pdf*, n.d.).

In practical terms, elevated food basket costs can constrain household food choices, increase reliance on lower-cost, shelf-stable and ultra-processed foods, and heighten vulnerability to food insecurity, particularly for households with fixed or limited incomes.

When considered alongside the survey findings on grocery travel (most women reported using their own car as their primary grocery travel option at 72%, whereas men reported substantially lower reliance on driving themselves at 25%), these cost pressures are likely compounded by transportation barriers. For individuals who do not regularly drive their own vehicle and instead rely on rides, walking, or biking, the frequency and volume of grocery trips may be limited, further restricting access to affordable options and reinforcing dependence on what is locally available at higher prices. Together, the food basket costing, and transportation patterns highlight how structural barriers such as cost and mobility, shape market food access in Skidegate and should be treated as key contextual determinants in interpreting dietary patterns and modelling constraints.

3.2 Scenario and Model Parameterization

Two scenario pairs are examined: i) baseline versus present optimal and ii) predicted versus adaptation (2050 scenario). The baseline diet represents observed intake patterns for Skidegate (sex-stratified). The optimal diet represents the model-generated solution that satisfies the nutrient and feasibility constraints under current conditions while optimizing the objective function (i.e., achieving requirements efficiently within the constrained diet space). The predicted diet represents the future diet implied by the scenario assumptions without an adaptive optimization response. The adaptation optimal diet represents the optimized solution under the

future constraint set, including traditional food availability adjustments consistent with projected ecological change. These paired comparisons allow the analysis to separate (i) improvements that are possible now within current constraints from (ii) shifts that become necessary or newly feasible under future conditions.

Each scenario was constructed by integrating three categories of inputs: nutrient requirements, diet feasibility bounds, and cost/risk attributes. First, nutritional constraints were parameterized using dietary reference values (RDA/AI and upper limits where relevant), with nutrients designated as either hard or soft constraints. This distinction is important because, even with the broader Canadian food system certain nutrients, such as vitamin D or specific fatty acids, are often difficult to meet through food-only intake, and these challenges can be amplified in constrained food environments (Batal, Chan, Fediuk, Ing, Berti, Sadik, et al., 2021b). Treating selected nutrient requirements as soft constraints therefore allows the model to generate plausible compromise solutions. Second, feasibility constraints were imposed to preserve diet realism. These bounds restrict the maximum contribution of specific foods and/or food groups and are intended to reflect local accessibility, cultural acceptability, and observed dietary patterns. They prevent the optimizer from meeting nutrient targets through implausible "single-food" solutions and ensure that optimized diets remain interpretable in relation to the baseline. Third, economic and risk attributes were included to support the evaluation of affordability and contaminant trade-offs. Diet cost were represented by food prices and aggregated into a daily total diet cost. Methylmercury (MeHg) exposure was calculated as an outcome, enabling direct assessment of whether shifts toward seafood and other traditional foods increase contaminant burden.

In the future scenario, projected ecological change was incorporated explicitly through traditional food availability constraints. In particular., fish stock projections were translated into

scenario-specific multipliers that scale the allowable upper bounds for seafood items or seafood groupings. Species projected to decline were constrained to lower maximums, while species projected to remain stable or increase could contribute more to the adapted diet. This approach links climate-driven ecosystem change to dietary feasibility and prevents the model from recommending future diets that rely on unrealistic increases in declining stocks.

All models were run separately for females and males because nutrient requirements and energy targets differ by sex for several key constraints (e.g., iron, fibre, and total energy). Baseline diets were sex-stratified to create appropriate reference patterns, and each scenario pair was evaluated within the same sex-specific constraint structure to ensure comparability.

Results are presented in two main sections for each sex: i) nutrients and food-group composition and ii) Diet cost analysis. The first section interprets changes in total energy, diet weight, diet cost, and the balance between market foods and traditional foods. It identifies the "high-leverage" food groups that the optimizer increases or decreases to satisfy nutrient constraints, and it highlights persistent nutrient gaps that remain difficult to close within the feasible diet space. The analysis explicitly considers the role of traditional foods, especially seafood, in meeting protein and micronutrient needs while managing MeHg exposure. The second section evaluates affordability at the nutrient level by estimating the cost required to achieve 100% for each nutrient requirement in each model. This metric distinguishes nutrients that become more economically achievable under optimization from those that remain structurally expensive, providing insight into where targeted interventions may be needed (e.g., improved access to specific foods, fortification options, or supplementation scenarios).

Collectively, these analyses provide an integrated characterization of dietary feasibility in Skidegate by quantifying (i) the extent of attainable nutritional improvement under observed

constraints, (ii) the sensitivity of feasible dietary pathways to climate-driven reductions in traditional food availability, and (iii) the resulting implications for affordability, food sovereignty–relevant dietary composition, and contaminant exposure risk.

Fish stock availability and model parameterization

Table 11 Household consumption and costs for Skidegate

Seafood	HH ideal qty mean (lbs)	SD (lbs)	HH ideal qty median (lbs)	Cost used ($/lb)	HH cost mean ($)	SD ($)	HH cost median ($)	Community total cost ($)
Salmon	131	167	100	20	2 631.10	3 357.10	2 000	147 340
Groundfish (Halibut and Black cod)	105	123	50	4.32	457.2	532	216	26 059
Prawns	69	133	50	10	690.9	1 337	500	40 070
Herring roe on kelp	82	142	50	4	328.1	567	200	18 704

HH = Household
SD = Standard deviation

Table 12 Changes in seafood abundance within 100km of Skidegate

English name	Xaayda Kil name	Abundance change under RCP -8.5 (within 100 km of Skidegate)	Source
Pacific salmon (aggregate)	—	-23.80%	(Justrabo, n.d.)
Chinook (spring) salmon	taaG̲uun	43.90%	(Justrabo, n.d.)
Chum salmon	sk’aagii	-10.20%	(Justrabo, n.d.)
Coho salmon	táay.yii	-13.30%	(Justrabo, n.d.)
Sockeye salmon	taax̲id	-42.50%	(Justrabo, n.d.)
Groundfish (aggregate)	—	10%	(Justrabo, n.d.)
Pacific littleneck clam	k’aaga	-78.90%	(Justrabo, n.d.)
Pink salmon	ts’iit’an	-37.70%	(Weatherdon et al., 2016)
Black cod (sablefish)	sk̲il	-9.20%	(Weatherdon et al., 2016)
Pacific halibut	X̲aagu	-13.20%	(Weatherdon et al., 2016)
Lingcod	skaynang	-6.60%	(Weatherdon et al., 2016)
Rockfish	k’alts’ida	3.80%	(Weatherdon et al., 2016)
Pacific herring (proxy for herring roe)	linang	-49.20%	(Weatherdon et al., 2016)
Prawn	G̲uuda gii G̲ayd	353.4%	(Justrabo, n.d.)
Albacore tuna	—	106.80%	(Justrabo, n.d.)

To ensure that optimization outputs were both nutritionally meaningful and grounded in the lived realities of Skidegate's food system, two complementary evidence inputs were used to parameterize scenario conditions: (1) household (HH) "ideal" harvest quantities and associated harvest costs derived from Nation distribution programs, and (2) projected changes in local seafood abundance under climate change. Together, these inputs operationalize the central premise of the scenario framework: that future dietary adequacy will be shaped not only by nutrient requirements and preferences, but also by the affordability of harvesting and the physical availability of culturally important seafood species.

The HH ideal harvest table provides a demand-relevant benchmark for the types and quantities of seafood that households identify as desirable and quantifies the economic implications of supplying these foods using per-pound cost estimates. These values serve two functions in the modelling framework. First, they anchor the economic realism of traditional foods by providing scenario-consistent unit costs that can be translated into the model's cost parameters (e.g., $/g) and carried through to total diet cost, traditional food (TF) cost shares, and community-level cost implications. Second, the HH ideal distributional statistics (mean, median, SD) inform how TF-related constraints are framed. The large standard deviations observed for several seafood categories indicate substantial heterogeneity across households' desired harvest quantities; accordingly, TF feasibility is best represented using bounded constraints rather than a single-point target. In practice, median and mean values provide complementary planning lenses, median quantities represent a "typical household" benchmark, whereas means reflect population-average demand that is more sensitive to high-demand households. This structure allows the model to remain culturally grounded while avoiding solutions driven by outliers or implying unrealistic uniform consumption across the population.

Projected changes in seafood abundance within 100 km of Skidegate under RCP 8.5 (year 2050) were used to translate climate change into explicit, scenario-specific supply constraints (Justrabo, n.d.; Weatherdon et al., 2016). The abundance change table provides percent changes for key species and subgroups relevant to the TF basket, including salmon species (e.g., sockeye, coho, chum, chinook), groundfish components (halibut, lingcod, sablefish/black cod, rockfish), Pacific herring (used as a biological proxy for herring roe on kelp and labelled as such), prawns, and tuna (Justrabo, n.d.; Weatherdon et al., 2016). Where consumption categories were aggregated (e.g., "groundfish") availability was represented using a transparent aggregation rule (e.g., weighted mean of constituent species for groundfish). This ensured that climate impacts were applied at the same functional resolution as the dietary intake tables while retaining biological interpretability.

Importantly, fish stock projections were implemented as supply-side limits, rather than minimum requirements. Rather than forcing increases or decreases in consumption, projected abundance changes were used to scale the feasible upper bounds of seafood subgroups. Foods projected to decline were constrained to a lower maximum selection level, while foods projected to increase could be selected up to a higher maximum. This approach directly embeds ecological change into the feasible diet space: the solver can only choose diets that are consistent with what is plausibly available under the scenario, while still being free to substitute among foods to meet nutrient targets and cost objectives.

These two inputs jointly structure the four-diet scenario framework used for Skidegate. In the present-day scenario pair (baseline vs. present optimal), current observed diets derived from 24-hour recalls define the baseline consumption pattern, and harvest costs are used to represent the current economic feasibility of traditional foods. Fish stock multipliers are not applied (or

equivalently are set to 1), such that seafood availability reflects present conditions. The present optimal diet therefore, asks: within today's food environment, what is the smallest departure from current consumption required to improve nutrient adequacy while maintaining feasibility and affordability?

In the future scenario pair (projected 2050 RCP 8.5 vs. adaptation), projected changes in seafood abundance are applied to the model as scaled upper bounds, creating a climate-constrained future baseline diet space. This produces a "projected" diet that reflects ecological pressures on traditional access to seafood, including heterogeneous changes within culturally important categories. The optimal adaptation model is then solved under the same climate-constrained availability conditions, allowing the model to identify the minimum dietary restructuring needed to achieve nutrient adequacy when key traditional foods are less (or differently) available. In this way, the harvest costing table ensures that optimized solutions remain economically interpretable, while the fish stock availability table ensures that future solutions remain ecologically plausible.

Embedding harvest costing and fish stock availability into scenario development strengthens the interpretability of results in three ways. First, it distinguishes nutrient shortfalls driven by modifiable dietary choice from shortfalls driven by structural constraints in affordability and supply. Second, it makes trade-offs explicit: reductions in the availability of nutrient-dense traditional foods can raise the economic "price" of meeting certain RDAs by forcing substitutions into more expensive or less nutrient-dense foods. Third, it allows the model to identify pressure points for adaptation, species or food groups where projected declines substantially narrow the feasible diet space and therefore drive the largest downstream impacts on cost, nutrient adequacy, or contaminant exposure.

Scenarios Explored

To examine how dietary adequacy, feasibility, and affordability shift across time and climate conditions, four diets were modelled as two paired scenario sets: (1) a present-day comparison between the observed baseline diet and an optimized version of the current diet, and (2) a future comparison between a projected 2050 diet under a high-emissions climate scenario (RCP 8.5) and an optimized 2050 adaptation diet that explicitly incorporates projected seafood stock availability for Skidegate.

The baseline diet represents the current observed dietary pattern derived from 24-hour dietary recall data and reflects the existing food environment, including food availability, pricing, and current consumption preferences. The present optimal diet represents an optimized version of the baseline diet under present-day conditions. This scenario was designed to identify the minimum dietary changes necessary to achieve nutrient adequacy while remaining feasible within current constraints (e.g., isoenergetic intake, food-group bounds, palatability limits, cost, and MeHg exposure constraints). In practice, the present optimal model tests what small, realistic shifts in food choices and quantities, within foods already observed in the diet, could improve nutrient adequacy without requiring transformative changes to the food system. This comparison therefore helps distinguish nutrient gaps that are primarily behaviourally modifiable from those that reflect structural limits of the current food environment.

To assess future vulnerability, a second scenario pair was developed for 2050 under RCP-8.5. The projected 2050 diet reflects anticipated climate-related impacts on the local food system for Skidegate, with a specific focus on changes in the availability of traditional seafoods. Seafood availability was operationalized using species and group-specific projected changes in relative abundance/catch potential for waters 100km near Skidegate. These projections were translated into availability multipliers that scale the feasible upper bounds of relevant traditional

seafood subgroups. As a result, seafood projected to decline could not be selected above a reduced maximum, while seafood projected to increase could be selected up to a higher maximum. This approach treats climate impacts as supply-side constraints that reshape the feasible diet space, rather than forcing minimum seafood consumption levels.

The 2050 adaptation optimal diet uses the same RCP 8.5 climate assumptions and the same availability-adjusted seafood bounds,but is optimized to meet nutrient targets while minimizing departure from the projected 2050 diet under the full constraint set. In other words, the adaptation model identifies the least-disruptive, nutritionally adequate diet that remains feasible given projected changes in Skidegate seafood availability. Together, the projected-versus-adaptation comparison quantifies how much of future nutritional risk arises from constrained traditional food supply and what dietary reallocations are required to maintain adequacy when seafood availability changes under climate pressure.

3.3 Female Results

This section summarizes optimal diet model outputs for women and interprets results across (i) nutrient adequacy, (ii) food-group composition, and (iii) affordability, with an emphasis on how model constraints shift diets relative to the observed baseline. Results are presented as baseline diet versus present optimal diet, and projected diet (2050) versus adaptation optimal diet, and these models are then compared. Male results are presented in Appendix 6.1.

3.3.1 Food group and nutrient analysis

3.3.1.1 Baseline and Optimal diet comparison

Table 13 Baseline and optimal model comparisons for Skidegate females

Metric	Baseline	Optimal	Change	Percent change
Total energy (kcal/day)	2699	2598	-101	-3.8
Total diet cost ($/day)	18	16	-1.4	-8.2
MeHg exposure (ng/day)	3304	1199	-2104	-64
TF intake (g/day)	74	358	284	386
TF energy (kcal/day)	87	282	195	225
TF share of total energy (%)	3.2	11	7.6	238
MF intake (g/day)	1706	1927	221	13
MF energy (kcal/day)	2612	2315	-297	-11
MF share of total energy (%)	97	89	-7.6	-7.9
Total diet weight (g/day)	1780	2285	505	28

Total energy decreased modestly from 2699 to 2597 kcal/day (−3.8%), indicating that the optimized solution remained broadly isoenergetic relative to baseline rather than relying on a major reduction in food intake. Total diet cost declined from $17.79 to $16.34/day (−8.2%), demonstrating that meeting nutritional targets did not require higher spending in this scenario. This matters for feasibility in remote food environments, where affordability commonly constrains dietary change; the model found a solution that improves diet quality while slightly reducing cost burden.

The most important outcome is the reduction in MeHg exposure from 3303.6 to 1199.7 ng/day (−63.7%). This means the baseline diet's contaminant burden was being driven by a relatively small subset of high-MeHg items, and that the solver was able to reallocate intake toward lower-MeHg TF options while preserving overall dietary feasibility. Importantly, this reduction occurred while TF intake increased dramatically, showing that contaminant mitigation did not depend on removing traditional foods from the diet.

The optimized diet reflects a clear shift toward increased TF as part of a broader expansion in diet mass. TF intake increased from 73.6 to 358.0 g/day (+386%), and TF energy

increased from 86.9 to 282.4 kcal/day (+225%). Consequently, TF's share of total energy rose from 3.2% to 10.9% (+7.65 percentage points; +238% relative change).

At the same time, MF intake also increased in grams (from 1706.6 to 1927.3 g/day, +12.9%), even though MF energy decreased (from 2612.4 to 2315.3 kcal/day, −11.4%). This combination implies that the optimized solution increased the volume of lower–energy-density foods (e.g., fruits/vegetables/beverages/other low-calorie items) while reallocating calories away from some higher-energy MF items and toward TF. The net effect is an increase in total diet weight from 1780.1 to 2285.3 g/day (+28.4%) alongside a small decline in total calories consistent with a shift toward more nutrient-dense foods.

Table 14 Changes in distribution of the food groups in grams for females in Skidegate

Food Group	Baseline (g/day)	Optimal (g/day)	Change (g/day)	Percent change
Dairy	110	140.0	29.6	26.8
Fats	9.86	2.39	-7.47	-75.8
Animal protein	129	195	66.2	51.2
Plant protein	51.5	80.9	29.4	57.2
Fruit	130.4	144	13.4	10.3
Vegetables	117	44.3	-73.2	-62.3
Grains	239	253	14.3	6.01
Sweets	49.4	68.2	18.8	38.1
Salty snacks	75.5	0.25	-75.2	-99.7
Mixed foods	177	95.5	-82.0	-46.2
Berries	16.4	17.2	0.79	4.80
Fish	55.1	305	251	454
Game meat	2.08	34.9	32.9	1580

Figure 6 Changes in distribution of the food groups in grams for females in Skidegate

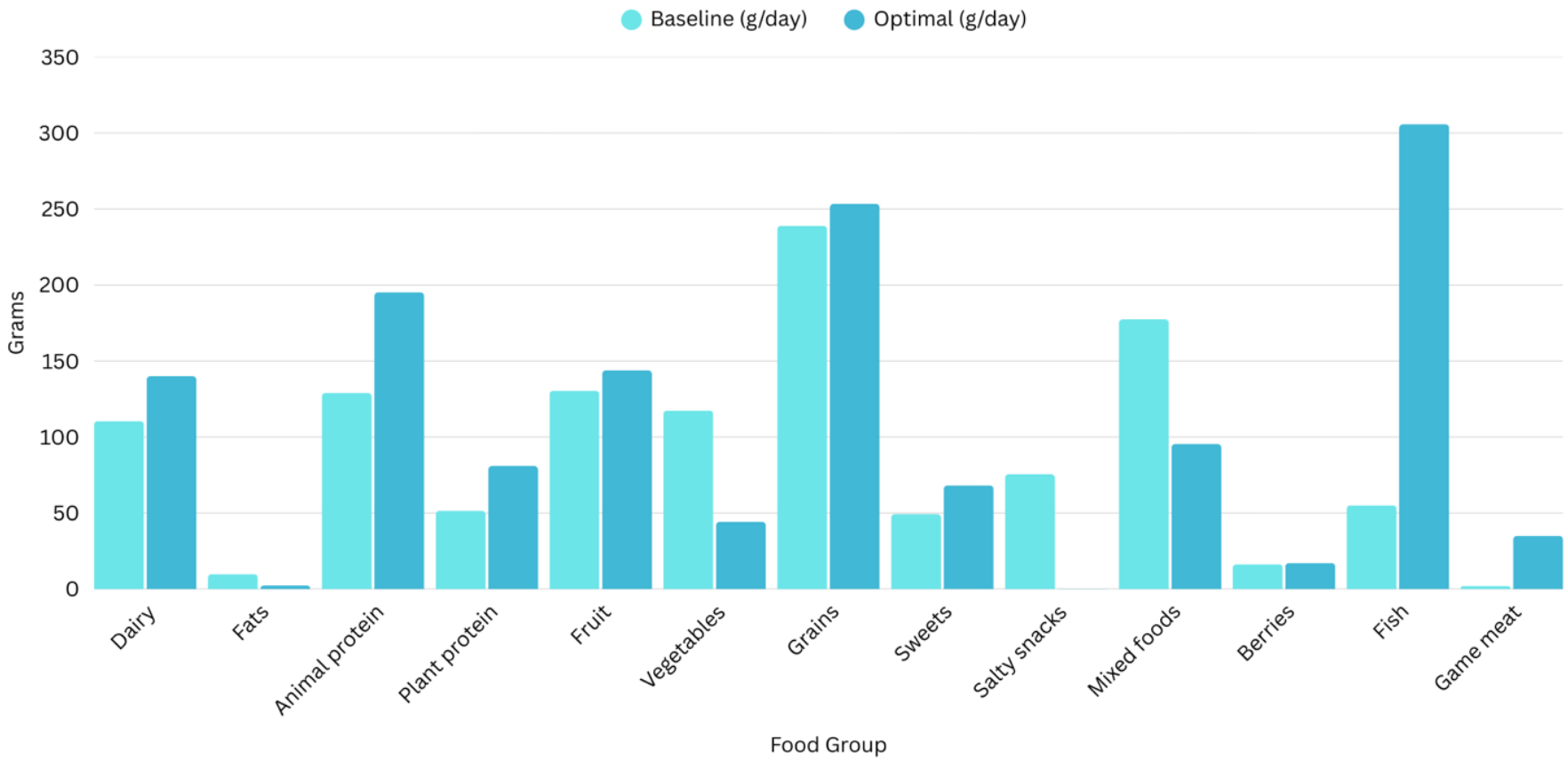


Figure 6 shows a comparison mean daily intake (grams per day) across food groups in the observed baseline diet versus the model-derived optimal diet. The optimized solution increases intake of several nutrient-dense groups (including fish, grains, fruit, dairy, and protein foods) while reducing intake of mixed foods, illustrating how the optimization reallocates consumption patterns to improve nutrient adequacy under feasibility constraints.

Table 15 Changes in distribution of the nutrients for females in Skidegate for the baseline and optimal models

Nutrient	Unit	Optimal amount	Baseline % of RDA	Optimal % of RDA	Change (%RDA)	Hard constraint	Soft constraint	Optimal below 100% RDA
PROTEIN	g/day	132	223	287	64.01	1	0	0
FAT	g/day	71.4	187	158	-28.07	1	0	0
CARB	g/day	203	170	156	-13.6	1	0	0
FIBRE	g/day	18.3	88.3	73.3	-15.06	1	0	1
CALCIUM	mg/day	999	71.4	100	28.6	1	0	0
IRON	mg/day	21.6	88.3	120	31.8	1	0	0
MAGNESIUM	mg/day	349	110.6	109	-1.32	1	0	0
PHOSPHOROUS	mg/day	1404	218	201	-17.8	1	0	0
POTASSIUM	mg/day	2971	117	114	-2.3	1	0	0
SODIUM	mg/day	1602	374	107	-266	1	0	0
ZINC	mg/day	22.4	229	279	50.7	1	0	0
COPPER	mg/day	1.102	119	122	3.09	1	0	0
VITAMIN A	ug RAE/day	700	181	100.01	-81.1	1	0	0
VITAMIN D	ug/day	5.61	38.7	37.4	-1.34	0	1	1
VITAMIN C	mg/day	60.4	77.4	80.6	3.13	1	0	1
RIBOFLAVIN	mg/day	1.97	163	179	16.3	1	0	0
NIACIN	mg/day	34.9	219	249	30.4	1	0	0
FOLATE	ug/day	342	58.3	85.5	27.2	1	0	1
TOTAL SATURATED FATS	g/day	27.1	143	135	-8.42	1	0	0
LINOLEIC	g/day	0.873	9.58	7.27	-2.3	0	1	1
LINOLENIC	g/day	1.92	398	174	-224	1	0	0
MUFA	g/day	23.2	137	105.4	-32.2	1	0	0
PUFA	g/day	8.39	242	139	-102	1	0	0
TOTAL SUGARS	g/day	69.01	260	276	15.8	1	0	0
CHOLESTEROL	mg/day	252	99.3	126	27.2	1	0	0
THIAMIN	mg/day	1.33	124	120	-3.67	1	0	0
VITAMIN B6	mg/day	2.16	161	166	4.88	1	0	0
VITAMIN B12	ug/day	7.04	261	293	32.5	1	0	0

Figure 7 Changes in distribution of the nutrients for females in Skidegate for the baseline and optimal models

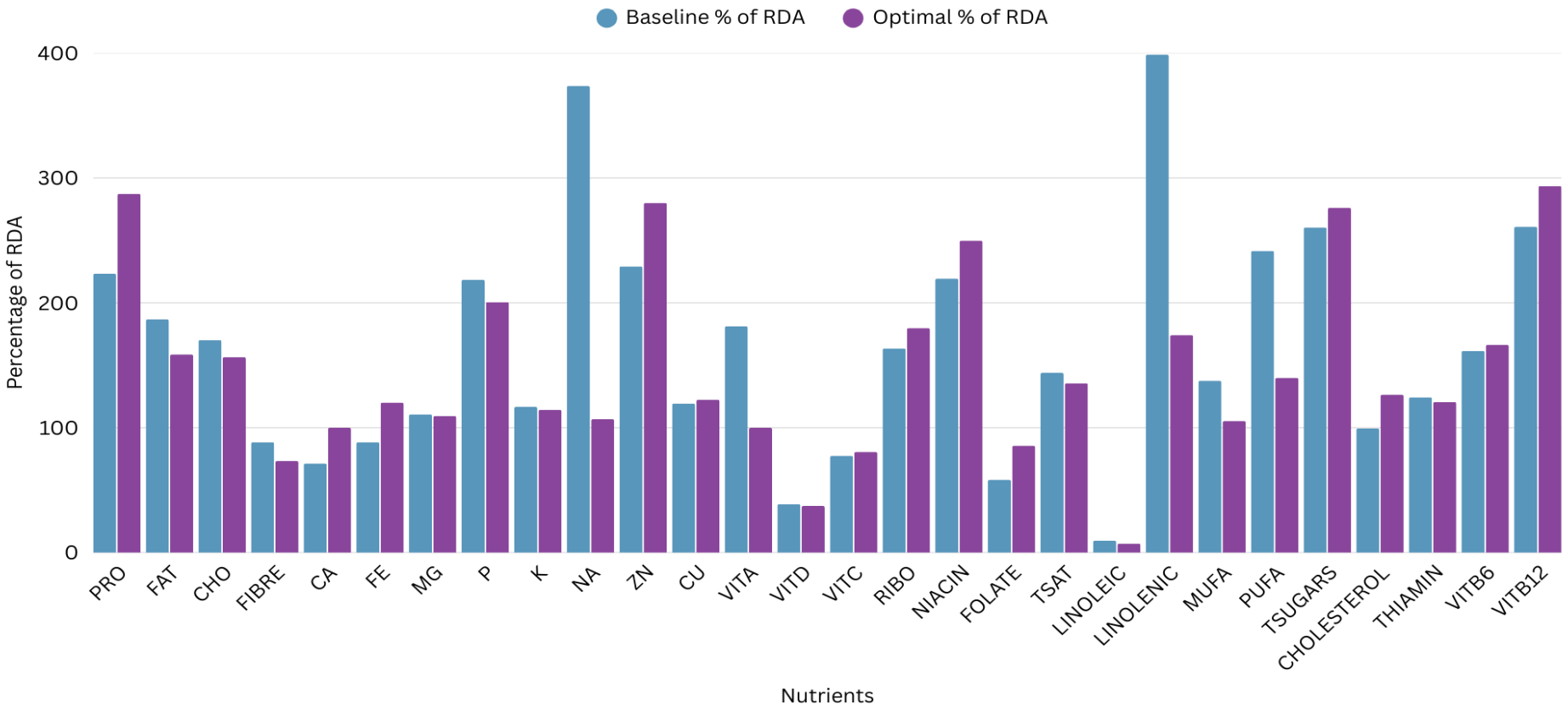


Figure 7 shows the percentage of the recommended dietary allowance (RDA) achieved for each nutrient in the observed baseline diet compared with the model-derived optimal diet. The optimized solution increases adequacy for several limiting micronutrients (including vitamin C, folate, and essential fatty acids) while maintaining or reducing excessive intakes for nutrients already above requirements (e.g., sodium), illustrating how the optimization reallocates intake to improve overall nutrient balance under feasibility constraints.

Note: Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.[3]

[3]

The optimization for Skidegate females produced a clear pattern where, nutrient adequacy improved primarily through a major increase in traditional proteins, especially fish, paired with a sharp reduction in processed market foods that drive sodium exposure. Rather than requiring broad, across-the-board changes across all food groups, the optimal model concentrated change in a few high-leverage categories, revealing where the current food environment makes nutritional improvement most feasible.

The most consequential shift was the large increase in fish, from 55.1 g/day to 305 g/day (+455%). Although several other groups changed, this shift stands out because it aligns with the biggest improvements in nutrient adequacy and reflects the model's reliance on nutrient-dense foods that deliver multiple micronutrients per serving. Game meat also increased substantially in relative terms (+1579%), though from a very small baseline, indicating that traditional land-based foods contributed but were not the primary driver compared with seafood. As a result, under present constraints, the model "solves" adequacy most efficiently by amplifying traditional food contributions, suggesting that maintaining or strengthening access to traditional harvesting is not just culturally important but nutritionally strategic.

A second major outcome is the dramatic reduction in sodium, baseline sodium was extremely elevated (373.7% of RDA/AI), but the optimal diet reduced sodium close to adequacy (106.8%). This improvement coincided with a large reduction in mixed foods (−46.2%), indicating that the model reduced sodium primarily by removing high-sodium processed categories rather than relying on small reductions spread across many foods. Thus, reducing processed-food intake is a high-impact pathway for improving sodium intake without compromising energy targets.

The optimal diet achieved several notable improvements in adequacy, most importantly calcium and iron. Calcium increased from 71.4% to 100%, and iron improved from 88.3% to 120.2%, indicating the model successfully corrected two nutrients that commonly constrain women's diets. These gains are consistent with increases in dairy (+26.8%) and protein sources (animal protein +51.3%; fish +455%), indicating that targeted changes in a small set of foods can correct specific limiting nutrients. The optimization demonstrates that, within current feasibility bounds, calcium and iron adequacy are achievable with relatively interpretable dietary substitutions (more dairy and traditional proteins), providing a concrete evidence base for nutrition programming that prioritizes these nutrients.

However, several nutrients remained limiting even after optimization. Fibre declined (88.4% → 73.3%) and remained below adequacy, and folate (85.5%), vitamin C (80.6%), vitamin D (37.4%), and linoleic acid (7.3%) remained below targets. These persistent shortfalls occurred alongside a large decrease in vegetable intake (−62.3%), suggesting that the model's pathway to meeting calcium/iron and lowering sodium did not simultaneously maximize plant-based nutrient density. However, this also reflects the constraints within Skidegate from obtaining quality produce.

3.3.1.2 Predicted and Adaptation model comparison

Table 16 Comparison of the predicted and adaptation models for Skidegate females

Metric	Predicted	Adaptation
Total energy (kcal/day)	2700	2880
Total diet cost ($/day)	17.8	10.5
MeHg exposure (ng/day)	3300	422
TF intake (g/day)	20.8	153
TF energy (kcal/day)	38.5	160
TF share of total energy (%)	1.34	5.56
MF intake (g/day)	1760	2130
MF energy (kcal/day)	2660	2720
MF share of total energy (%)	98.7	94.4
Total diet weight (g/day)	1780	2290

Across the scenario pair, the adaptation solution produced three dominant and policy-relevant outcomes. First, total diet cost declined substantially, decreasing from $17.79/day (predicted) to $10.51/day (adaptation). This indicates that the model was able to achieve future nutrient adequacy without requiring a higher-cost diet; instead, the optimized adaptation diet identified a more economically efficient combination of foods within the feasible set.

Second, the adaptation diet achieved a very large reduction in contaminant risk, with MeHg exposure decreasing from 3303.62 ng/day to 421.74 ng/day. This magnitude of change is noteworthy because MeHg risk is typically concentrated in a limited number of seafood pathways. The reduction implies that the adapted solution shifts away from higher-MeHg seafood items (or from patterns that indirectly drive higher MeHg intake) and toward lower-MeHg options and/or non-seafood protein sources that remain feasible under the constraints.

Third, the adaptation solution increased the contribution of culturally significant foods. Traditional food (TF) intake increased from 20.78 g/day to 153.50 g/day, and TF share of total energy increased from 1.34% to 5.56%. Importantly, this change demonstrates that improving

affordability and reducing MeHg exposure did not require reducing traditional food intake; rather, the adaptation pathway made it possible to raise TF intake while improving other objectives. This is relevant to both nutrition and food sovereignty outcomes, as TF inclusion is linked to cultural continuity, harvesting practices, and community wellbeing.

Table 17 Changes in food group distribution in predicted and adaptation models for Skidegate females

Food Group	Predicted (g/day)	Adaptation (g/day)	Change (g/day)	Percent change (%)
Salty snacks	75.5	0.230	-75.3	-99.7
Added fat	9.86	3.07	-6.79	-68.8
Mixed foods	177	102	-75.7	-42.6
Animal Protein	129	119	-9.68	-7.50
Fish	55.1	52.0	-3.08	-5.59
Sweets	49.4	46.7	-2.73	-5.53
Dairy	110	114	3.24	2.93
Grain	239	349	110	46.1
Fruit	130	200	69.7	53.5
Berries	16.4	29.1	12.7	77.7
Vegetables	117	223	105	89.6
Plant protein	51.5	102	50.2	97.4
Game	2.08	73.4	71.3	3.42e3

Figure 8 Changes in food group distribution in predicted and adaptation models for Skidegate females

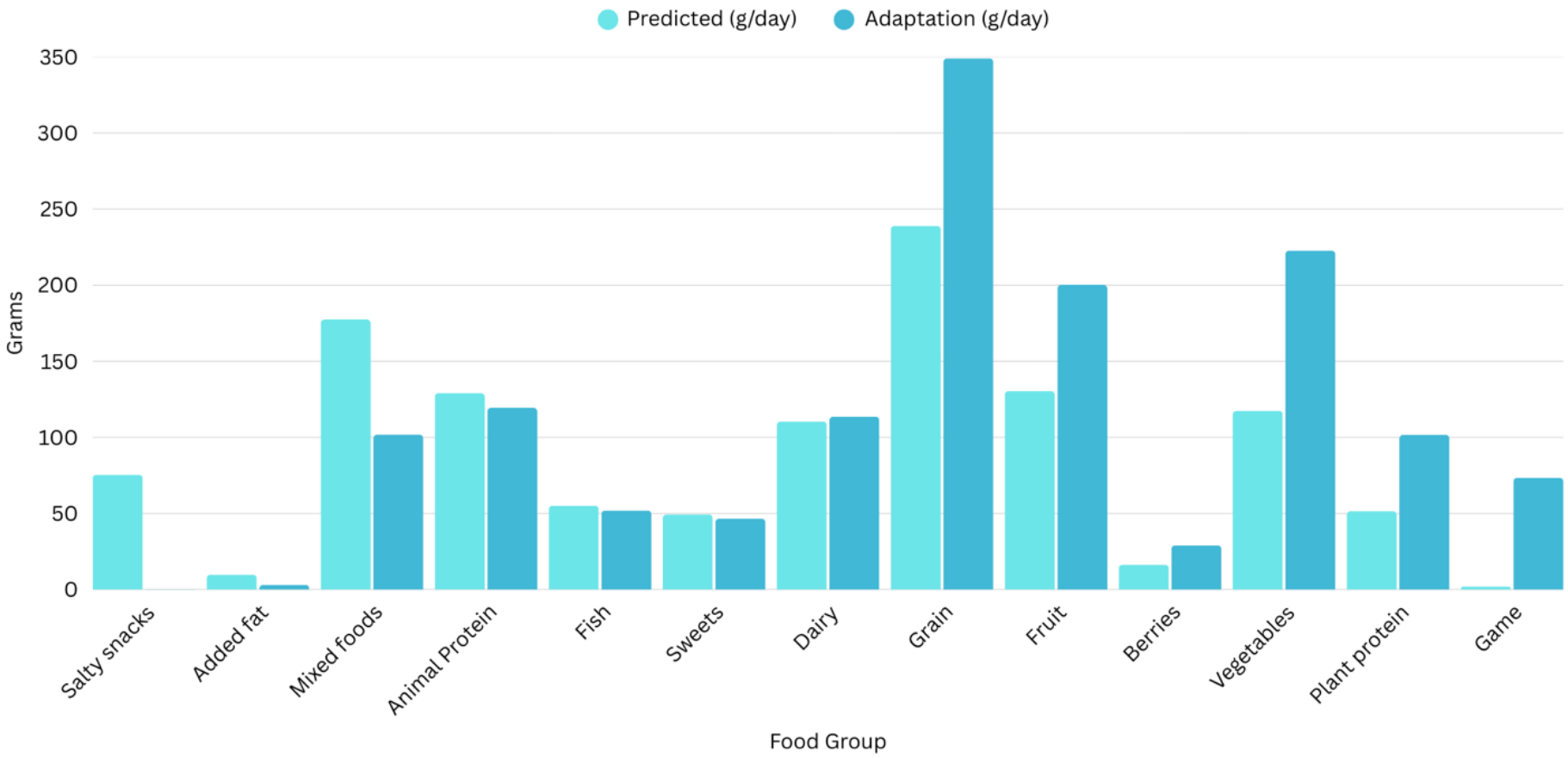


Figure 8 compares mean daily intake (grams per day) across food groups in the climate-driven predicted diet scenario versus the adaptation scenario. The adaptation model shifts intake toward nutrient-dense foods (notably grains, fruit, vegetables, and plant protein) while reducing reliance on mixed foods, illustrating how the adaptation constraints reconfigure feasible dietary patterns under projected food-system change.

Table 18 Nutrient distribution for predicted and adaptation models for Skidegate females

Nutrient	Adaptation amount	Predicted %RDA	Adaptation %RDA	Hard constraint	Soft constraint	Adaptation below 100% RDA
Calcium	773	71.4	77.3	0	1	1
Carbohydrate	281	170	216	1	0	0
Cholesterol	200	99.3	100	1	0	1
Copper	1.64	119	183	1	0	0
Total fat	97.0	187	216	1	0	0
Iron	19.5	88.3	109	1	0	0
Dietary fibre	31.8	88.3	127	1	0	0
Folate	320	58.3	80.0	0	1	1
Potassium	3.56e3	117	137	1	0	0
Linoleic acid (Omega-6 fatty acid)	0.818	9.58	6.82	0	1	1
Alpha-linolenic acid (Omega-3 fatty acid)	3.41	399	310	1	0	0
Magnesium	497	111	155	1	0	0
Monounsaturated fat	36.2	138	165	1	0	0
Niacin (Vitamin B3)	36.8	219	263	1	0	0
Phosphorus	1.68e3	218	240	1	0	0
Protein	121	223	262	1	0	0
Polyunsaturated fat	18.5	242	308	1	0	0
Riboflavin (Vitamin B2)	2.25	163	204	1	0	0
Thiamin (Vitamin B1)	1.76	124	160	1	0	0
Total saturated fat	30.0	144	150	1	0	0
Total sugars	82.7	260	331	1	0	0
Vitamin A	2.42e3	181	346	1	0	0
Vitamin B12	3.78	261	157	1	0	0
Vitamin B6	2.35	161	181	1	0	0
Vitamin C	93.6	77.4	125	1	0	0
Vitamin D	3.17	38.7	21.1	0	1	1
Zinc	39.5	229	494	1	0	0
Sodium	2.30e3	374	153	1	0	0

Figure 9 Nutrient distribution for predicted and adaptation models for Skidegate females

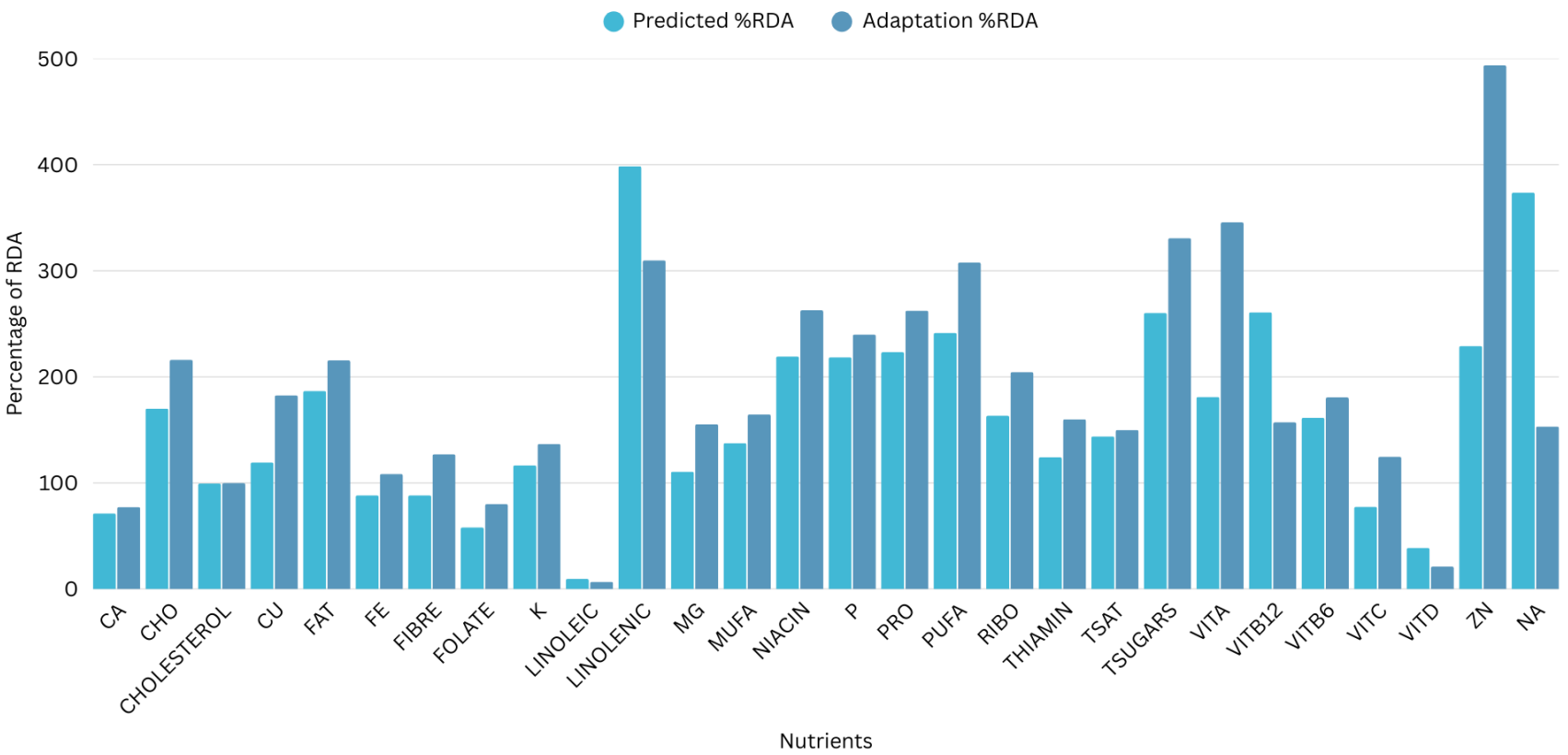


Figure 9 compares the percentage of recommended dietary allowance (RDA) achieved for each nutrient in the climate-driven predicted scenario versus the adaptation scenario. The adaptation model improves adequacy for several limiting nutrients while moderating nutrients that are excessive under the predicted diet (e.g., sodium), demonstrating how adaptation constraints reshape feasible diets to better balance nutrient targets under projected food-system change.[4]

[4] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The nutrient analyses (Table 18) indicate that the adaptation diet improved the feasibility of meeting nutrient targets under future constraints, but the direction and magnitude of changes differed across nutrients. In general, the adaptation diet's improved affordability suggests that adequacy was achieved through more cost-efficient nutrient sourcing. However, as observed in diet optimization studies more broadly, certain nutrients remain structurally difficult to achieve in food-based models, particularly where the feasible food list is limited, fortification is constrained, and key traditional seafoods become less available. For Skidegate, nutrients tightly tied to specific food pathways (e.g., certain fatty acids and vitamin D in many contexts) are expected to remain sensitive to the availability and selection of seafood and dairy/fortified foods. Therefore, interpretation should emphasize not only whether nutrients meet 100% of the RDA (or soft thresholds), but also which nutrients are easier or harder to meet economically, as shown in the cost-per-100% RDA results in section 3.3.2.

Fish stock availability influenced the adaptation outcomes by altering the feasible space seafood consumption in a transparent, scenario-specific manner. Rather than forcing seafood intake upward or downward, projected abundance changes were translated into multipliers that scale the upper bounds for aggregated seafood sub-groups. In effect, seafood projected to decline could not be selected above a reduced maximum, while seafood projected to increase could be selected up to higher maxima. This matters because optimization models will otherwise "solve" nutrient targets by concentrating consumption in a small number of nutritionally dense foods, often seafood, if those foods are not supply-limited. By introducing availability-scaled caps, the adaptation model prevents solutions that rely on unrealistic future increases in declining stocks and instead requires the solver to diversify across feasible seafood options or substitute toward market foods.

For Skidegate, the compiled availability table indicates heterogeneous changes under RCP 8.5: several salmon species are projected to decline (with exceptions such as Chinook), Pacific herring shows substantial decline, and components of the groundfish complex (e.g., halibut and sablefish/black cod) are projected to decline while others (e.g., rockfish) may be stable or increasing. Conversely, prawns and, tuna show strong projected increases. This asymmetric pattern creates a clear mechanism linking stock projections to dietary outcomes: the adaptation diet can increase TF intake and reduce MeHg only by reallocating traditional seafood intake toward the subset of seafood pathways that remain feasible under projected availability and/or toward lower-risk options that satisfy constraints. The large drop in MeHg exposure is consistent with the solver being constrained away from pathways that drive higher MeHg and toward combinations of foods that preserve nutrient adequacy at lower contaminant levels.

These findings have two direct implications. First, seafood should not be treated as a single homogeneous category in adaptation planning; species-specific projections materially change feasible diets and the resulting nutrient-cost risk trade-offs. Second, integrating fish stock availability as a supply-side constraint strengthens the credibility of the adaptation scenario as a realistic representation of climate impacts on the food system, because it prevents the model from relying on future increases in foods that are ecologically unlikely to be available.

3.3.2 Cost Analysis

3.3.2.1 Baseline and optimal diet cost comparison

Table 19 Cost per 100% of nutrient RDA for the Baseline and optimal models for Skidegate females

Nutrient	Unit	Baseline cost per 100% RDA ($)	Optimal cost per 100% RDA ($)	Change cost per 100% RDA ($)
Calcium	mg/day	15.8	15.7	-0.161
Total carbohydrate	g/day	5.17	5.80	0.626
Cholesterol	mg/day	10.2	12.5	2.29
Copper	mg/day	8.66	7.22	-1.44
Total fat	g/day	4.65	5.81	1.16
Iron	mg/day	12.7	12.2	-0.477
Dietary fibre	g/day	12.1	8.86	-3.23
Folate (Vitamin B9)	µg/day	20.5	14.1	-6.39
Potassium	mg/day	8.89	7.38	-1.52
Linoleic acid (Omega-6 fatty acid)	g/day	113	108	-5.42
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	1.72	1.38	-0.339
Magnesium	mg/day	10.1	8.26	-1.83
Monounsaturated fat	g/day	6.11	8.01	1.90
Niacin (Vitamin B3)	mg/day	5.10	5.86	0.764
Phosphorus	mg/day	5.24	5.28	0.0348
Protein	g/day	5.16	5.31	0.145
Polyunsaturated fat	g/day	3.55	3.24	-0.310
Riboflavin (Vitamin B2)	mg/day	5.47	6.14	0.662
Thiamin (Vitamin B1)	mg/day	8.20	8.47	0.260
Total saturated fat	g/day	5.92	8.89	2.98
Total sugars	g/day	2.36	4.41	2.05
Vitamin A	µg RAE/day	5.19	2.13	-3.07
Vitamin B12	µg/day	4.84	8.28	3.44
Vitamin B6	mg/day	7.43	6.61	-0.821
Vitamin C	mg/day	12.7	8.19	-4.55
Vitamin D	µg/day	48.1	59.3	11.3
Zinc	mg/day	1.93	2.64	0.702
Sodium	mg/day	4.66	4.16	-0.502

Figure 10 Cost per 100% of nutrient RDA for the Baseline and optimal models for Skidegate females

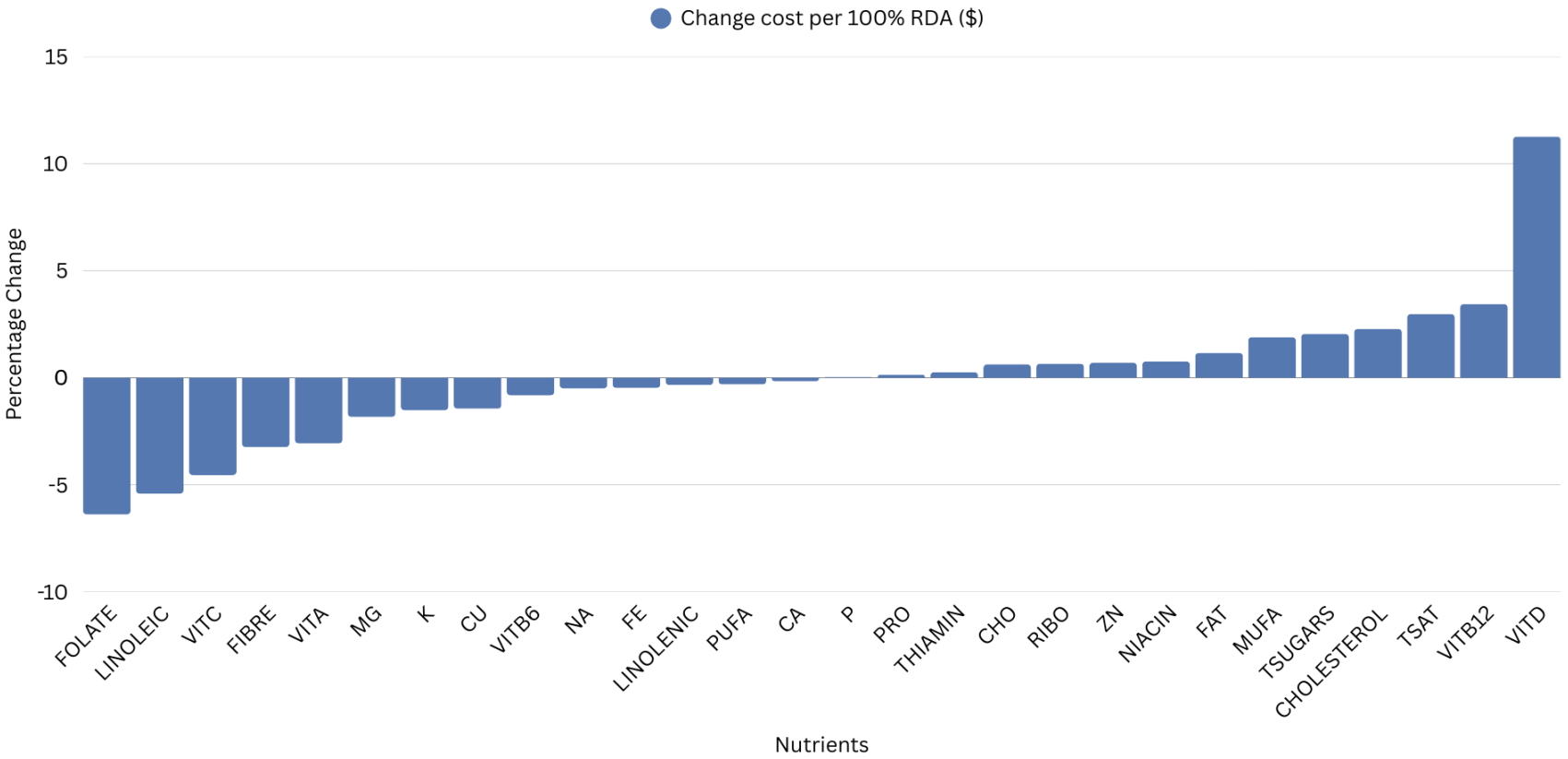


Figure 10 shows the difference in cost required to achieve 100% of the recommended dietary allowance (RDA) for each nutrient when comparing the baseline diet to the model-derived optimal diet. Negative values indicate nutrients that become less costly to meet under the optimized solution (improved cost-efficiency), while positive values indicate nutrients that become more costly to achieve, highlighting which nutrient targets drive the greatest affordability pressures in optimized diets.[5]

[5] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Cost-per-100% RDA outcomes show that the optimal diet made it cheaper to achieve adequacy for several nutrients that are typically difficult to meet. The largest improvements were for folate (−$6.39), vitamin C (−$4.55), fibre (−$3.23), and vitamin A (−$3.07), indicating that the optimized basket increased the "nutrient return per dollar" for multiple micronutrients at once. This matters because it suggests that, even when adequacy was not fully achieved (e.g., folate, fibre, vitamin C), the optimized pattern moved the diet toward more cost-effective sources of those nutrients.

In contrast, vitamin D became substantially more costly (+$11.27 per 100% RDA), and it remained far below adequacy. Vitamin D is revealed as a "hard-to-reach" nutrient in current food options, underscoring the need for explicit strategies (fortified foods, supplementation scenarios, or expanded feasible seafood/fortified dairy options).

Taken together, the Skidegate female results show that nutritional improvement is achievable through concentrated, interpretable shifts: (1) increasing traditional seafood and other protein sources, (2) increasing dairy to close calcium gaps, and (3) displacing sodium-dense processed foods. At the same time, persistent inadequacy in fibre, folate, vitamin C, vitamin D, and linoleic acid indicates that full nutritional adequacy is not guaranteed by optimizing within the current diet space, and that future scenario development should explicitly test interventions that expand feasible access to high-fibre and folate/vitamin C–rich foods (and vitamin D solutions). In practical terms, the optimization results do not just describe a better diet, they identify which parts of the food system currently make change easiest (traditional proteins and processed-food reduction) and which nutrients will require targeted structural solutions (vitamin D and plant-associated micronutrients).

3.3.2.2 Predicted and adaptation diet model cost comparison

Table 20 Cost per 100% nutrient RDA analysis for predicted and adaptation models for Skidegate females

Nutrient	Predicted cost per 100% RDA ($)	Adaptation cost per 100% RDA ($)	Change cost per 100% RDA ($)
Linoleic acid (Omega-6 fatty acid)	186	154	-31.6
Folate (Vitamin B9)	30.5	13.1	-17.4
Vitamin C	23.0	8.42	-14.6
Dietary fibre	20.1	8.27	-11.9
Calcium	24.9	13.6	-11.3
Iron	20.2	9.68	-10.5
Magnesium	16.1	6.77	-9.31
Copper	14.9	5.75	-9.16
Thiamin (Vitamin B1)	14.3	6.57	-7.75
Potassium	15.3	7.68	-7.57
Cholesterol	17.9	10.5	-7.40
Vitamin A	9.82	3.04	-6.78
Monounsaturated fat	12.9	6.39	-6.54
Riboflavin (Vitamin B2)	10.9	5.14	-5.75
Zinc	7.76	2.13	-5.63
Total carbohydrate	10.5	4.86	-5.60
Total saturated fat	12.4	7.01	-5.35
Vitamin B6	11.0	5.82	-5.21
Total fat	9.53	4.88	-4.65
Niacin (Vitamin B3)	8.11	4.00	-4.11
Protein	7.97	4.01	-3.96
Polyunsaturated fat	7.37	3.42	-3.95
Phosphorus	8.15	4.38	-3.77
Total sugars	6.84	3.18	-3.66
Alpha-linolenic acid (Omega-3 fatty acid)	4.46	3.39	-1.07
Vitamin B12	6.82	6.68	-0.139
Sodium	4.76	6.85	2.09
Vitamin D	45.9	49.8	3.84

Figure 11 Cost per 100% nutrient RDA analysis for predicted and adaptation models for Skidegate females

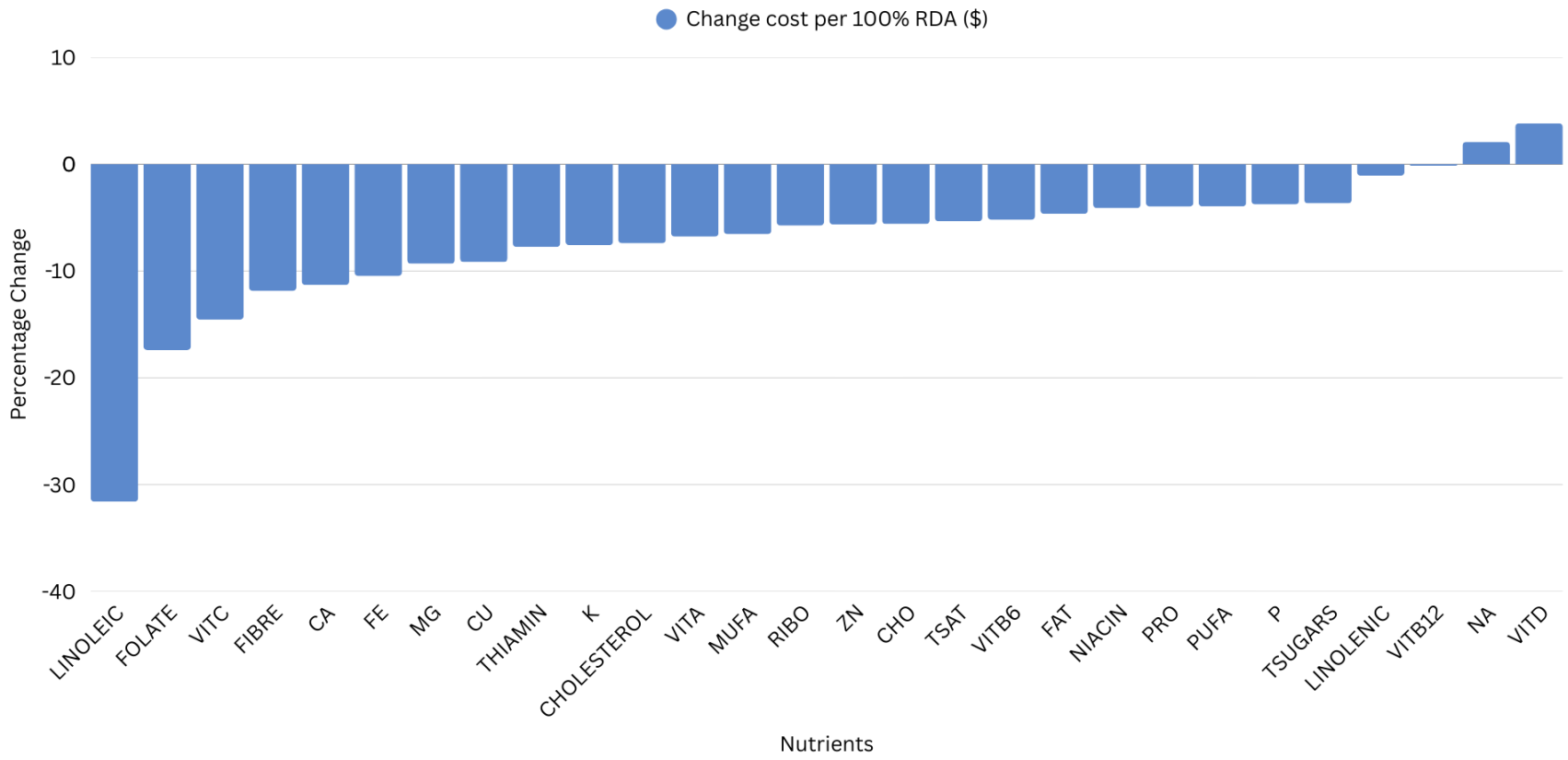


Figure 11 shows the difference in cost required to achieve 100% of the recommended dietary allowance (RDA) for each nutrient when comparing the climate-driven predicted scenario to the adaptation scenario. Negative values indicate nutrients that become less costly to meet under the adaptation model (greater cost-efficiency), whereas positive values indicate nutrients that become more costly, highlighting which nutrient targets drive affordability pressures under projected food-system change.[6]

[6] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The cost-per-100% RDA comparison (Table 20) is particularly valuable because it shows how the adaptation diet changes the economic burden of meeting adequacy, beyond whether adequacy is achieved. Reductions in cost per 100% RDA indicate nutrients that became more economically achievable under the adaptation solution, often reflecting dietary shifts toward foods that deliver multiple nutrients efficiently. Conversely, increases highlight nutrients that become more "expensive to satisfy" under future feasibility constraints, often indicating dependence on restricted foods (including seafood items constrained by availability projections). In the context of Skidegate, these results help distinguish (i) nutrients that can be supported through plausible substitution within the available food system, from (ii) nutrients that may require targeted intervention (e.g., improved access to specific low-risk seafood, fortified foods, or supplementation strategies).

3.3.3 Conclusion

Overall, the Skidegate results show that diet optimization can improve nutritional adequacy and, in some scenarios, reduce contaminant exposure, but that these improvements are achieved through explicit trade-offs among nutrient sufficiency, total diet cost, MeHg exposure, energy intake, and reliance on traditional foods (TF). Across both scenario pairs (Baseline vs. Optimal; Predicted 2050 vs. Adaptation), the model concentrates change in a small number of high-leverage categories, particularly traditional proteins (especially fish), dairy, and high-sodium processed market foods, because these categories most efficiently resolve binding constraints. Interpreting the outputs therefore requires emphasizing what the solver is "balancing": improvements in one dimension can increase pressure on another, revealing where the local food system is flexible versus structurally constrained.

For women, the optimization indicates that substantial gains are possible without requiring a major reduction in intake or increased spending. In the present-day comparison (Baseline vs. Optimal), energy remains broadly stable, while diet cost declines modestly and MeHg exposure decreases sharply. These outcomes indicate that, under current feasibility, the model can improve adequacy while simultaneously reducing contaminant risk by reallocating intake away from a small subset of higher-risk seafood and toward lower-risk TF options, alongside reductions in sodium-dense processed foods. At the same time, the results identify persistent structural constraints: several nutrients remain below adequacy (notably vitamin D, essential fatty acids, and plant-associated micronutrients such as folate and vitamin C), reflecting limits in the feasible food set on accessing quality produce and fortified foods. In other words, the model finds a feasible compromise that improves many objectives at once, but it cannot fully resolve nutrients that depend on constrained pathways.

In the future scenario pair (Predicted vs. Adaptation), the adapted solution further illustrates the model's trade-off structure: it achieves a large reduction in MeHg exposure and lowers total diet cost while increasing TF intake. This pattern suggests that, under the scenario parameterization used, the solver can identify a diet that is both more affordable and lower-risk while still increasing culturally significant foods. The integration of fish stock projections as availability-scaled caps, which prevents the model from meeting nutrient targets by unrealistically scaling up species expected to decline. Under RCP 8.5, heterogeneous species trajectories (declines in several salmon and herring species, mixed changes in types of groundfish, and increases others) reshape the feasible solution space: declining stocks cannot dominate the solution, and nutrient gaps must be closed through a reallocation among available seafood options and complementary market foods. The large MeHg reductions observed under

adaptation are consistent with this mechanism because availability limits and scenario bounds encourage substitution away from higher-risk pathways and toward combinations that satisfy constraints at lower contaminant intensity.

For men, nutritional adequacy is also achievable within the modelled diet space, but the pathway differs in both direction and magnitude of trade-offs. In the present-day comparison (Baseline vs. Optimal), the baseline diet is energy-deficient relative to the model target, so the optimized solution expands total intake substantially. This expansion is achieved primarily through large increases in TF (especially fish), which improves adequacy for multiple limiting micronutrients but increases total diet cost and, MeHg exposure (however, keeping MeHg exposure within the safe threshold for daily consumption). This highlights a key trade-off revealed by the model: when TF, particularly seafood, is the most nutrient-efficient lever, and adequacy targets can be met, but affordability may become a binding constraint, further underscoring of sustained investment in harvesting supports.

In the future scenario pair (Predicted vs. Adaptation), MeHg exposure remains approximately stable for men despite a large increase in TF intake and total energy. Relative to females, the male results therefore show a stronger dependence on TF expansion to meet energy and micronutrient requirements, and a clearer tension between achieving adequacy and controlling cost and exposure. By contrast, the female solutions more consistently demonstrate simultaneous improvements in affordability and contaminant reduction, with smaller changes in energy intake and a more moderate increase in TF contribution.

Taken together, the sex-disaggregated findings clarify three overarching points about Skidegate's dietary feasibility under current and climate-constrained conditions. First, the model repeatedly identifies TF, especially nutrient-dense seafood, as a high-leverage pathway for

meeting nutrient requirements, reinforcing the nutritional importance of maintaining access to culturally significant foods. Second, the outputs make clear that the feasibility of TF-led solutions depends on how ecological constraints are represented; incorporating fish stock availability as a supply-side constraint improves interpretability by preventing solutions that rely on ecologically implausible increases in declining species. Third, several nutrients remain persistently difficult to achieve through food-only optimization within the existing feasible set (notably vitamin D and essential fatty acids), indicating that these gaps are unlikely to be resolved without structural changes to the food environment. As a result, the optimization outputs do not only identify "better diets"; they specify which objectives can be improved concurrently, where trade-offs emerge (cost, MeHg, energy, TF reliance), and which constraints reflect underlying food system limits that adaptation planning and policy interventions would need to address.

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Chapter 4- Tla'amin (ʔəms noʔomɪxw) Model Formulation and Results

4.1 Introduction

A robust understanding of community context is required to both parameterize scenarios and interpret optimization outputs (Tarasuk et al., 2019). In remote First Nations communities, food environments are shaped by the interaction of access to retail market foods and traditional foods, household economic resources, and prevailing dietary patterns (Tarasuk et al., 2019). This context represents through a set of empirical inputs, including food basket costing, demographic profiles, socioeconomic conditions, and baseline nutrient intakes (N. Willows et al., 2019b).

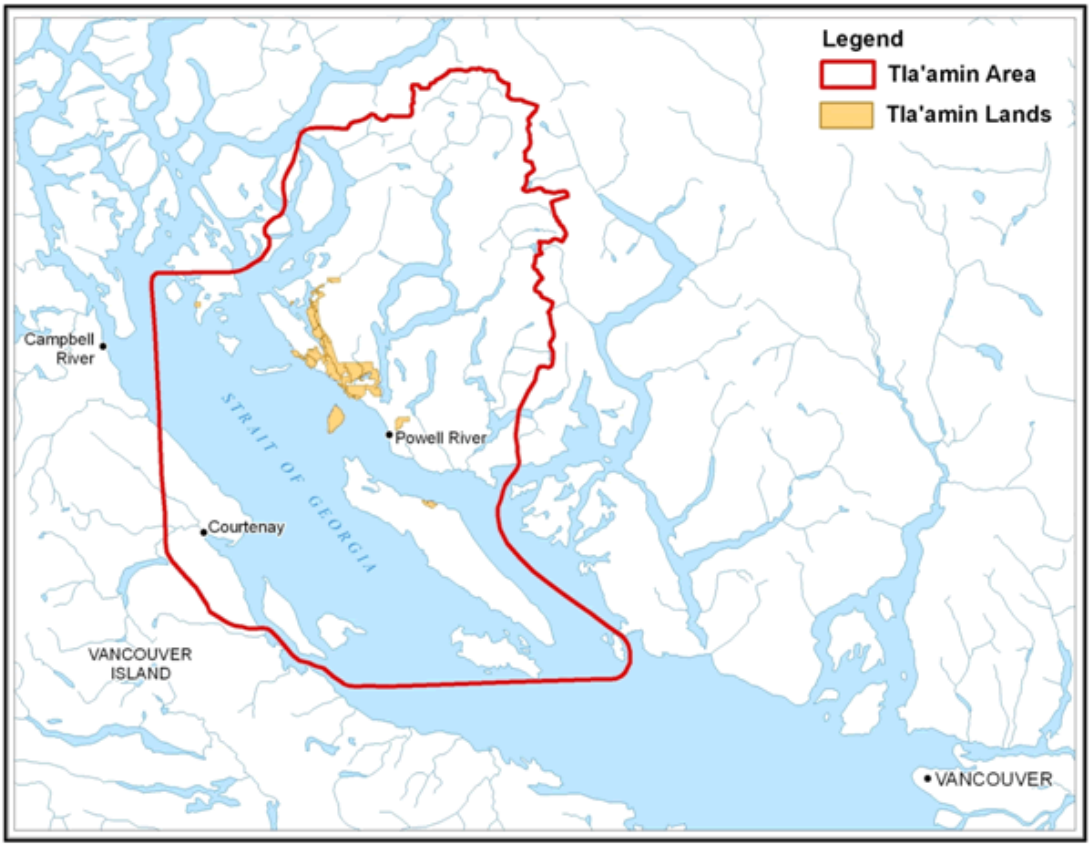
Food basket costing provides an indicator of affordability and quantifies how prices constrain feasible dietary choices (Power et al., 2019). Demographic characteristics (e.g., population size, age structure, household composition) inform variation in dietary requirements and potential differences in exposure or risk across subgroups (Tarasuk et al., 2019). Socioeconomic indicators (e.g., income and employment) further characterize constraints on market food access and on the capacity to participate in harvesting, sharing networks, or procurement activities (Tarasuk et al., 2019).

Taken together, these contextual dimensions support transparent specification of model assumptions and scenario parameters, and they strengthen the relevance of results for climate change adaptation planning and decision-making.

Tla'amin Nation is located on the Sunshine Coast shown below in Figure 12. Tla'amin Nation has also been actively engaged in governance and community planning processes that support self-determination, including approaches that strengthen local decision-making and community-led priorities. In the context of this study, situating modelling inputs and scenario assumptions within Tla'amin's social, economic, and ecological context is critical for ensuring that dietary

optimization and scenario outputs are interpretable, culturally relevant, and aligned with community-defined needs, particularly under climate-related changes that may affect access to key traditional foods and the affordability of market foods.

Figure 12 Map of Tla'amin lands and waters



Source: (*Native-Land.ca | Our Home on Native Land*, n.d.)

Demographic Data for Tla'amin Nation

Table 21 Demographic Data for Tla'amin Nation

	Statistics Canada (Government of Canada, 2022b)			Survey		
Characteristic	Total	Men	Women	Total	Men	Women
Total- Distribution (%) of the population by board age groups	100	100	100	100	100	100
0 -14 years	17.0	18.8	15.0	N/A	N/A	N/A
15- 64 years	61.0	58.8	62.5	80.6	83.3	78.7
65 years and over	22.0	22.5	21.3	19.4	16.7	21.3
85 years and over	1.3	1.3	0.0	0.0	0.0	0.0
Average age of the population	43.8	43.8	43.8	48.7	49.2	49.0
Median age of the population	46.4	46.4	36.4	48.0	49.5	47.0

Table 21 compares population-level demographic indicators from Statistics Canada (2021) with respondent characteristics from the community survey (2023), disaggregated by sex. Statistics Canada values describe the overall community age structure, while the survey results reflect the composition of respondents and should be interpreted as sample characteristics rather than representative population estimates.

Based on Statistics Canada, the community has a relatively mature age profile, with 17.0% of the population aged 0–14 years, 61.0% aged 15–64 years, and 22.0% aged 65 years and over. Adults aged 85 years and over comprise 1.3% of the population. The average age is 43.8 years for the total population (and is identical for men and women in this dataset), and the median age is 46.4 years overall (men: 46.4; women: 36.4), indicating a population distribution centred around mid-to-late adulthood.

Survey respondents were predominantly adults, with 80.6% aged 15–64 years and 19.4% aged 65 years and over (men: 16.7%; women: 21.3%). The 0–14 age group is not applicable (N/A) because the survey was designed to capture adult dietary intake and food procurement behaviours (e.g., 24-hour recall, purchasing, and access), and children were not included in the sampling frame. As a result, the direct comparison of the full age distribution between Statistics Canada and the survey should be made with caution because the denominators differ (population vs adult respondents).

Consistent with an adult-only sample, the survey shows a higher central tendency of age than would be expected if children were included: the mean age of survey participants was 48.7 years overall (men: 49.2; women: 49.0), and the median age was 48.0 years (men: 49.5; women: 47.0). These values suggest that respondents are somewhat older than the overall population distribution reported in Statistics Canada, which is expected in a survey focused on adult household decision-makers and may also reflect participation patterns (e.g., greater participation among older adults). These demographic differences are important to consider when interpreting subsequent survey-based results, particularly those linked to food access, affordability, and dietary adequacy.

Community Wellbeing Index

Table 22 Community Wellbeing Index and its 4 components for Tla'amin

Nation	Income	Education	Housing	Labour force	Overall CWB
Tla'amin	73	58	83	76	72

Adapted from: (*Community Well-Being (CWB) Index - Table View*, n.d.)

Table 22 presents the Community Wellbeing (CWB) Index for Tla'amin and its four component dimensions: income, education, housing, and labour force. The CWB is a composite indicator that contextualizes community-level socioeconomic conditions that can influence food access, affordability, and overall vulnerability to food insecurity.

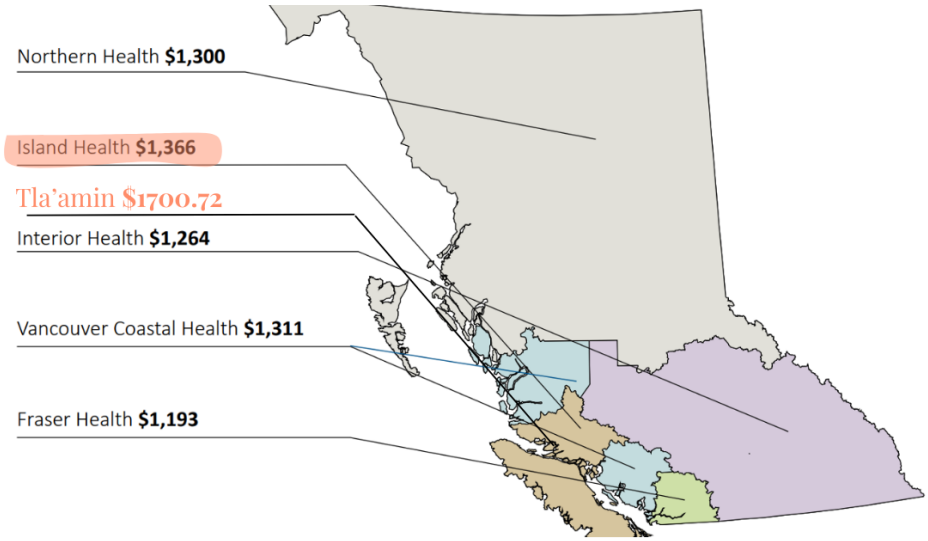
Tla'amin's overall CWB score is 72, with component scores of 73 for income, 58 for education, 83 for housing, and 76 for labour force. The strongest scores are observed in housing (83) and income (73), suggesting relatively favourable conditions related to housing quality and income compared to the other components. The labour force score (76) indicates moderate-to-strong labour market participation and employment-related outcomes. In contrast, education (58) is the lowest component score, highlighting education as a potential area of relative disadvantage within the index profile.

These CWB results provide critical context for interpreting diet and food access patterns in Tla'amin. Indicators related to income and employment are directly linked to purchasing power and therefore to the affordability of nutrient-dense market foods, particularly in settings where food prices are high. Housing and infrastructure conditions also inform practical dimensions of food access, such as reliable transportation, adequate refrigeration and storage, and the capacity to buy in bulk or maintain perishable foods, factors that can meaningfully influence diet quality

and consistency. Moreover, educational attainment can affect food security indirectly through its association with employment opportunities, income stability, and access to information and services, potentially contributing to uneven vulnerability to food insecurity across households.

Food Basket Costing

Figure 13 Food basket costing for a family of four for Tla'amin Nation



Adapted from: (*BC Centre for Disease Control, 2022*)

Figure 13. contextualizes food affordability for Tla'amin using monthly food basket costing (family of four) across BC health authority regions. Tla'amin is estimated at $1700.72/month, which is notably higher than Island Health at $1366. The elevated basket cost reflects the broader structural challenge of achieving nutritionally adequate diets in coastal and rural areas, where food prices are shaped by transportation costs, supply chain constraints, and reduced retail competition.

From a food systems perspective, higher food basket costs have direct implications for diet quality and food security. When a standard nutritious basket is substantially more expensive, households may be pushed toward cheaper, shelf-stable, and ultra-processed foods that are more

affordable per calorie but less nutrient-dense. This affordability pressure can reinforce nutrient shortfalls identified in dietary intake data and can constrain the feasibility of meeting nutrient targets without significant increases in diet cost. In the context of optimal diet modelling, the food basket costing therefore serves as a key indicator of the economic boundary conditions within which "optimal" solutions must operate, and highlights why affordability-sensitive scenarios (e.g., subsidies, improved access, or increased traditional food availability) are critical for adaptation planning.

4.2 Scenario and Model formulation

Scenarios Explored

To examine how dietary adequacy, feasibility, and affordability shift across time and climate conditions, four diets were modelled as two paired scenario sets: (1) a present-day comparison between the observed baseline diet and an optimized version of the current diet, and (2) a future comparison between a projected 2050 diet under a worst-case climate scenario (RCP 8.5) and an optimized adaptation diet that incorporates community-led initiatives.

The baseline diet represents the current observed dietary pattern derived from 24-hour dietary recall data and reflects the existing food environment, including food availability, pricing, and current consumption preferences (N. Willows et al., 2019b). The present optimal diet represents an optimized version of the baseline diet under present-day conditions. This scenario was designed to identify the minimum dietary changes necessary to achieve nutrient adequacy while remaining feasible within current constraints. In practice, the present optimal model tests what small, realistic shifts in food choices and quantities, within the foods already accessible to households, could improve nutrient intake outcomes without requiring transformative changes to the food system. This comparison therefore isolates the extent to

which nutrient shortfalls are attributable to modifiable dietary patterns versus structural limitations in the current food environment.

To assess future vulnerability, a second scenario pair was developed using 2050 projections under RCP 8.5, representing a worst-case climate change scenario. The projected 2050 diet reflects anticipated climate-related impacts on the local food system, including reduced availability of key traditional foods, particularly seafood, where fish stock projections indicate substantial declines in Tla'amin waters (Weatherdon et al., 2016). These risks are further compounded by governance constraints that limit community control over local waters, thereby increasing uncertainty and reducing adaptive capacity in relation to traditional seafoods (Marushka et al., 2021). The projected 2050 diet therefore represents a plausible future baseline under ecological and governance stressors.

The adaptation optimal diet builds on the same 2050 RCP 8.5 assumptions but integrates community-driven adaptation pathways directly into the model structure. Specifically, foods supported through local initiatives, such as vegetables, fruits, and bread distributed or made more accessible through night markets, partnerships with local farmers, and community gardens, were weighted more heavily in the food-group constraints. This reflects practical opportunities for adaptation that are actionable at the community level, particularly in a context where reliance on seafood may be less viable. The adaptation diet was then optimized to meet nutrient targets as effectively as possible under 2050 constraints, allowing assessment of how community initiatives may buffer nutrient inadequacy, reduce vulnerability, and improve feasibility in a climate-constrained future.

Model Parameterization

For Tla'amin, projected reductions in fish stock availability and the additional challenge of the limited control over their waters, necessitated greater emphasis on locally actionable food-system adaptations. Accordingly, market foods supported through existing community initiatives, including vegetables, fruits, and bread, were assigned higher weights in the food-group constraints. These weights reflected practical opportunities to strengthen food access through initiatives such as the night market, collaboration with local farmers, and community gardens, which can increase the availability of nutrient-dense foods and buffer reliance on seafood as ecological conditions change. Together, these constraints and weighting decisions ensured that model outputs were not only nutritionally adequate but also grounded in the community's current capacity for action and the anticipated constraints on traditional seafood access under future climate conditions.

4.3 Female Results

This section summarizes optimal diet model outputs for women and interprets results across (i) nutrient adequacy, (ii) food-group composition, and (iii) affordability, with an emphasis on how model constraints shift diets relative to the observed baseline. Results are presented as baseline diet versus present optimal diet, and projected diet (2050) versus adaptation optimal diet and then these models are compared. Males results are presented in Appendix 6.2.

4.3.1 Nutrients and the Food Group Shifts

4.3.1.1 Baseline diet versus Present Optimal diet for Females in Tla'amin Nation

Table 23 Overall Comparison for the Baseline and Optimal Models for Females in Tla'amin Nation

Metric	Baseline	Optimal	Absolute change	Percentage change
Total energy (kcal/day)	2880	2880	−2.60	−0.0900%
Total diet cost ($/day)	9.97	12.5	2.57	25.8%
MeHg exposure (ng/day)	387	418	31.3	8.09%
TF intake (g/day)	20.8	154	133	639%
TF energy (kcal/day)	38.5	160	121	316%
TF share of total energy (%)	1.34%	5.56%	+4.22 pp	+316%
MF energy (kcal/day)	2840	2720	−124	−4.37%
MF share of total energy (%)	98.7%	94.4%	−4.22 pp	−4.28%
Total diet weight (g/day)	2.07e3	2.29e3	219	10.6%
MF intake (g/day)	2.05e3	2.13e3	86.6	4.24%

pp = percentage points

Total energy remains virtually unchanged (2879.6 vs. 2877.0 kcal/day; −0.09%), indicating that the model improves diet quality primarily through substitutions within the same caloric envelope rather than through changes in overall intake (Table 23). In contrast, total diet cost increases substantially from $9.97 to $12.53 per day (+25.8%), underscoring that meeting nutrient targets under current food costs and feasibility constraints requires a higher-cost food basket. This cost increase also reinforces the potential value of the proposed community initiatives such as the Night Market, community gardens, local farmer collaboration and elk distribution, which would reduce this cost substantially for community members.

A defining feature of the optimal model is the increased contribution of traditional foods (TF). TF intake rises from 20.8 to 153.5 g/day (+638.8%), with TF energy increasing from 38.5 to 160.0 kcal/day (+315.7%). This shifts TF from 1.34% to 5.56% of total energy (+4.22 percentage points). Although TF still contributes a minority of calories, the change is meaningful because it reflects a rebalancing toward culturally relevant, nutrient-dense foods within the optimization structure. Correspondingly, market foods (MF) remain dominant but decline in

energetic contribution: MF energy decreases by 4.37% and MF share of energy drops from 98.66% to 94.44% (−4.22 percentage points). Importantly, MF grams increase slightly (+4.24%) even as MF calories decline, and total diet weight increases by 10.6%. Together, these patterns indicate a shift toward less energy-dense, higher-volume foods meaning a greater inclusion of fruits, vegetables, and other lower-calorie, nutrient-dense items replacing ultra-processed foods. More importantly, the modelled shift toward TF also underscores a broader structural implication: for rural coastal communities in BC to achieve nutritionally adequate diets in a feasible way, there must be improved access to TF. In practice, this requires strengthened community-led stewardship and decision-making over local lands and waters, alongside the governance and resource supports needed to sustain harvesting, distribution, and intergenerational food practices.

The optimal diet also highlights a MeHg exposure–nutrition trade-off. Estimated MeHg intake increases from 387.1 to 418.5 ng/day (+8.1%), consistent with the greater contribution of traditional foods, particularly seafood, within the optimal diet. Importantly, this level of exposure remains below the daily “low exposure” reference threshold. In this context, the modest increase in MeHg is accompanied by clear nutritional benefits associated with higher traditional food intake (e.g., improved access to high-quality protein and key micronutrients), suggesting that the nutrient gains and benefits of incorporating more traditional foods outweigh the incremental increase in MeHg.

Table 24 Changes in distribution of the food groups in grams for females in Tla'amin Nation

Group	Baseline (grams)	Optimal Model (grams)	Change (grams)	Percentage change
Dairy	114.9	111	-3.57	-3.10
Fats	24.3	40.05	15.8	65.1
Fruit	125	200.2	74.5	59.2
Grains	204	314	110.0	53.9
Mixed foods	159	112	-46.6	-29.4
Animal protein	143	114	-28.2	-19.79
Plant protein	34.76	72.4	37.6	108
Salty snacks	37.9	62.3	24.4	64.5
Sweets	62.9	62.5	-0.453	-0.72
Berries	0	29.1	29.1	0
Fish	12.4	52.04	39.6	319
Game meat	5.10	72.3	67.2	1317
Vegetables	115	351	236	205

Figure 14 Changes in distribution of the food groups in grams for females in Tla'amin Nation

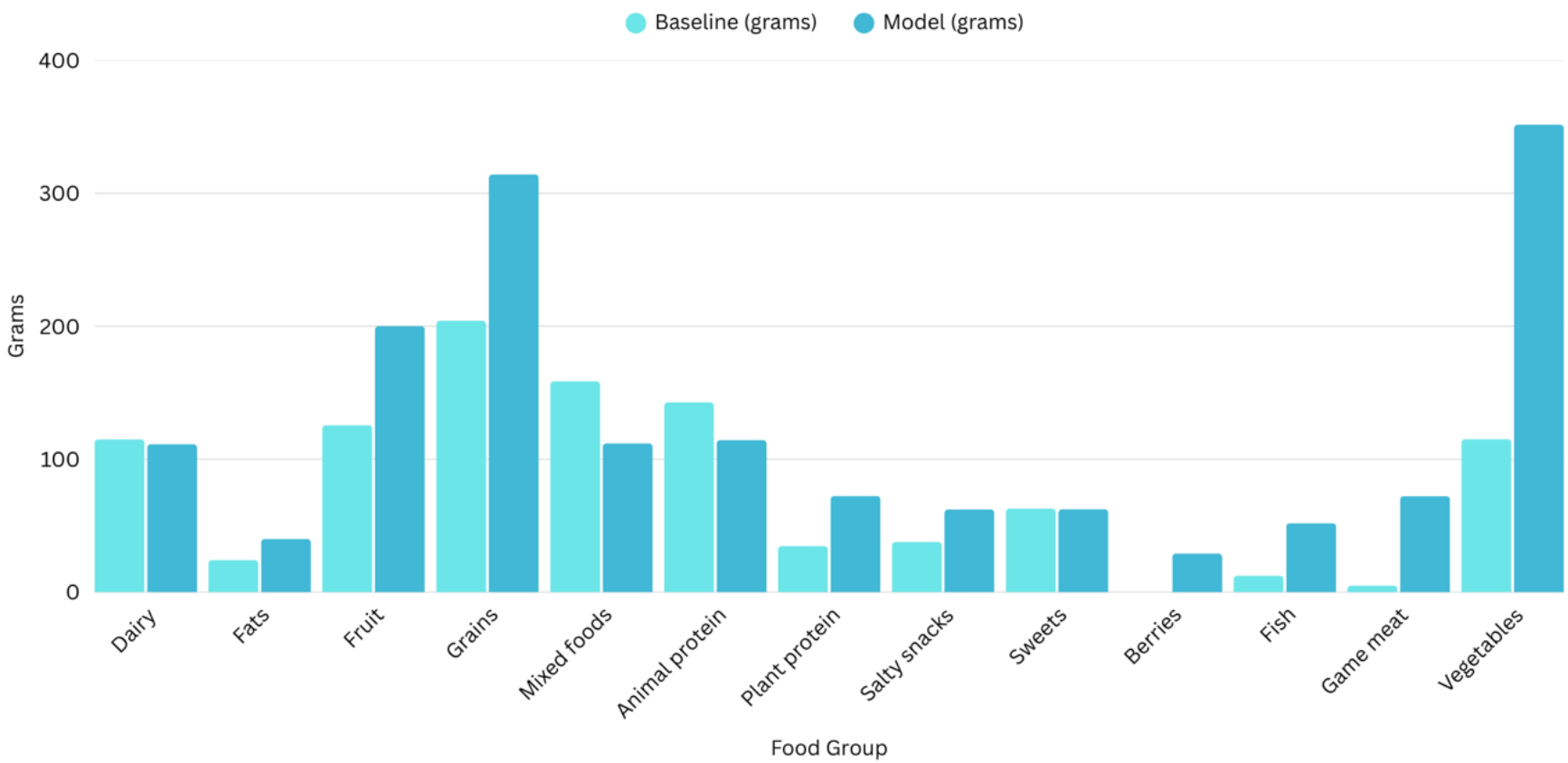


Figure 14 compares mean daily intake (grams per day) across food groups in the observed baseline diet versus the model-derived diet. The modelled solution increases consumption of nutrient-dense groups (notably vegetables, grains, and fruit) while reducing intake from mixed foods and some animal protein categories, illustrating how the optimization reallocates food-group composition to improve nutrient adequacy within feasibility constraints.

In summary, the optimal solution reallocated daily intake toward higher-volume, nutrient-dense plant foods and culturally significant traditional foods, while reducing reliance on several market-based mixed foods (Table 24; Figure 14). Since, the total energy remained essentially constant across scenarios, these gram-level shifts reflect changes in dietary composition rather than increased caloric intake, meaning the model achieved improved nutrient performance primarily through substitution.

The dominant structural change was a large increase in vegetables (+236.36 g/day; +205.16%), indicating that vegetables functioned as a key "lever" to raise diet quality by increasing fibre and a broad suite of micronutrients at relatively low energy cost. As well, there was a higher grain intake (+110.00 g/day; +53.87%) and fruit (+74.48 g/day; +59.24%), alongside a doubling of plant protein (+37.64 g/day; +108.29%). Together, these changes suggest the model relied heavily on affordable, nutrient-dense market foods to close nutrient gaps while staying within feasibility constraints, producing a higher-volume dietary pattern consistent with the observed increase in overall diet weight.

Traditional foods increased sharply, but the pattern was concentrated in traditional protein sources. Game meat rose from 5.10 to 72.33 g/day (+67.23 g/day; +1317.75%) and fish increased from 12.43 to 52.04 g/day (+39.61 g/day; +318.72%). Berries were also introduced (0 to 29.12 g/day), although the percentage change is not interpretable because baseline intake was zero. These results have clear implications: when allowed within constraints, the model preferentially uses traditional foods, especially fish and game meat, as efficient pathways to meet nutrient targets, while also aligning more closely with culturally relevant dietary patterns. Practically, this reinforces that sustaining nutrient-adequate diets in coastal First Nation communities is closely tied to increasing access in traditional harvesting and distribution

systems, and that adaptation strategies which protect and support land and marine-based foods can directly translate into food system resilience.

Several market-based categories declined, notably mixed foods (−46.60 g/day; −29.38%) and animal protein (−28.25 g/day; −19.79%). Dairy remained stable (−3.10%), implying it played a consistent but not dominant role in achieving feasibility in the optimized pattern. Sweets were essentially unchanged (−0.72%), indicating that swaying far away from current consumption patterns was not necessary to meet the model's objective.

Finally, the model increased fats (+15.80 g/day; +65.13%) and salty snacks (+24.41 g/day; +64.47%), which signals an important trade-off. Importantly, this does not imply that higher salty snack intake is nutritionally desirable, rather, it identifies where the constraint set and the food environment interact to produce a compromise solution. The result suggests that further tightening of "discretionary" pathways, such as shifting sodium constraints from minimum-only to a tighter upper bound, adding limits on high-sodium snack items, or creating separate bounds that favour healthier fat preserve the nutrient and traditional-food gains while reducing reliance on ultra-processed foods.

Table 25 Changes in distribution of the nutrients for females in Tla'amin Nation for the baseline and optimal models

Nutrient	Unit	Optimal	Baseline % of RDA	Optimal % of RDA	Hard constraint	Soft constraint	Below 100% RDA
Protein	g/day	109	193	236	1	0	0
Total fat	g/day	97.0	214	216	1	0	0
Total carbohydrate	g/day	281	193	216	1	0	0
Dietary fibre	g/day	35.3	82.4	141	1	0	0
Calcium	mg/day	800	63.0	80.0	0	1	1
Iron	mg/day	18.4	78.4	102	1	0	0
Magnesium	mg/day	485	98.8	152	1	0	0
Phosphorus	mg/day	1.66e3	190	237	1	0	0
Potassium	mg/day	4.42e3	112	170	1	0	0
Zinc	mg/day	38.0	515	475	1	0	0
Copper	µg/day	1.56	115	174	1	0	0
Vitamin A	µg RAE/day	4.12e3	192	589	1	0	0
Vitamin D	µg/day	3.17	20.7	21.1	0	1	1
Vitamin C	mg/day	115	78.3	153	1	0	0
Riboflavin (Vitamin B2)	mg/day	2.25	182	204	1	0	0
Niacin (Vitamin B3)	mg/day	29.9	195	214	1	0	0
Folate (Vitamin B9)	µg/day	356	48.7	89.0	0	1	1
Total saturated fat	g/day	28.2	168	141	1	0	0
Linoleic acid (Omega-6 fatty acid)	g/day	1.40	8.81	11.6	0	1	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	10.0	580	909	1	0	0
Monounsaturated fat	g/day	34.4	163	156	1	0	0
Polyunsaturated fat	g/day	23.2	281	387	1	0	0
Total sugars	g/day	71.0	422	284	1	0	0
Cholesterol	mg/day	200	97.2	100	1	0	1
Thiamin (Vitamin B1)	mg/day	1.63	121	148	1	0	0
Vitamin B6	mg/day	2.46	134	190	1	0	0
Vitamin B12	µg/day	3.63	206	151	1	0	0
Sodium	mg/day	2.70e3	214	180	1	0	0

Figure 15 Changes in distribution of the nutrients for females in Tla'amin Nation for the baseline and optimal models

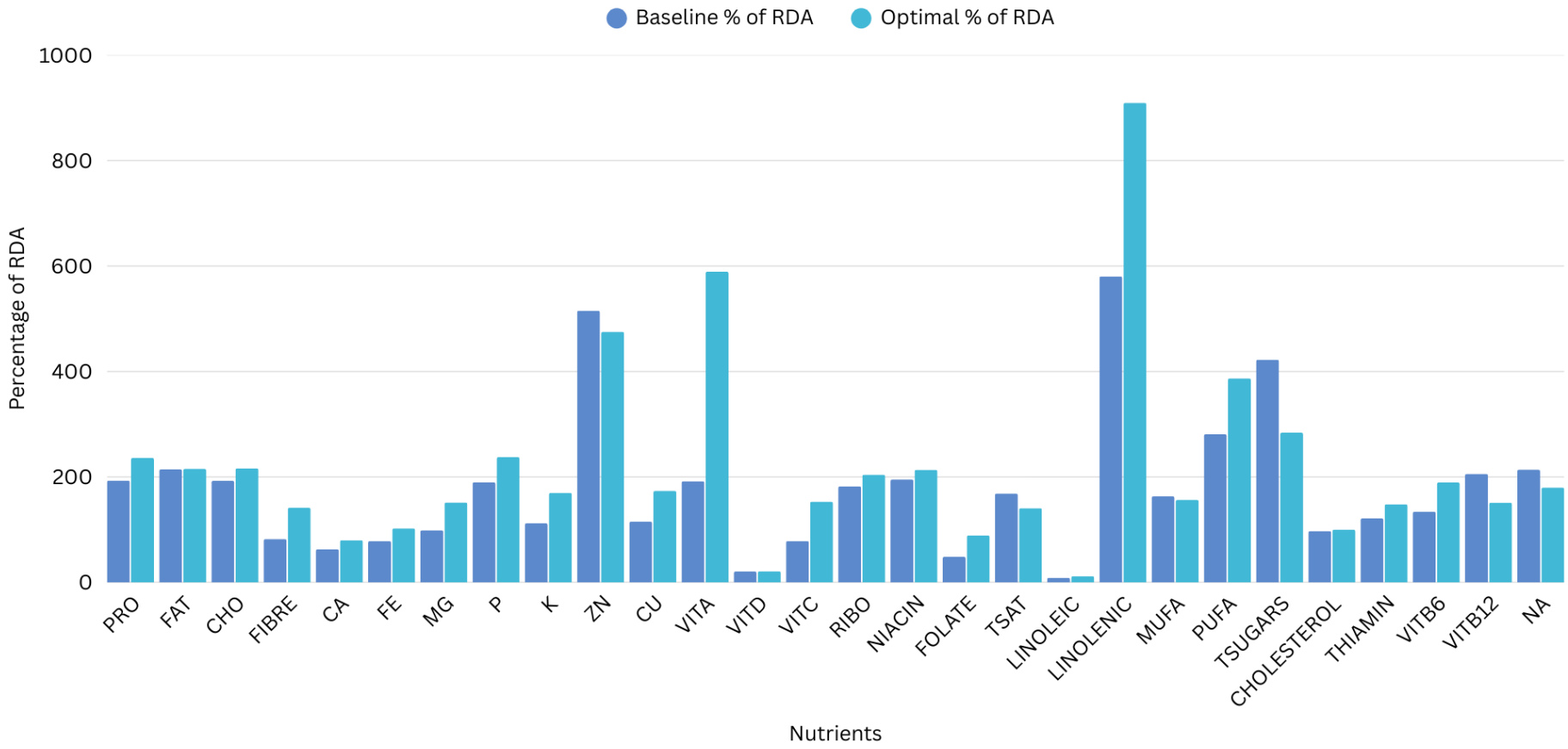


Figure 15 shows the percentage of recommended dietary allowance (RDA) achieved for each nutrient in the observed baseline diet compared with the model-derived optimal diet. The optimized solution improves adequacy for several limiting nutrients while moderating excessive intakes for nutrients already above requirements, illustrating how the model reallocates intake to achieve a more balanced nutrient profile under feasibility constraints. [7]

[7] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

There were several improvements for nutrients that fell short of the RDA in predicted model that were met within the adaptation model. Fibre increased from 82.4% to 141.4% of the RDA, vitamin C rose from 78.3% to 153.1%, and iron improved from 78.4% to 102.5%, crossing the adequacy threshold. Magnesium also increased meaningfully (98.8% to 151.7%), alongside higher potassium (112.1% to 169.9%) and vitamin A (191.9% to 589.3%). These improvements reflect a clear shift in diet composition toward higher-volume, lower–energy-density foods, consistent with the large gram increases observed in vegetables (+205%), fruit (+59%), grains (+54%), and plant protein (+108%). Together, these food-group shifts concentrate the diet's micronutrient and fibre supply in foods that deliver high nutrient returns per calorie, explaining the strong improvements in fibre, vitamin C, magnesium, and potassium.

At the same time, the optimal model maintained adequacy for most macronutrients and several micronutrients that were already above target at baseline. Protein increased further (193% to 236% of recommended intake), and carbohydrates rose (193% to 216%), indicating that meeting micronutrient requirements did not require sacrificing macronutrient sufficiency. Multiple B-vitamins remained well above adequacy (riboflavin, thiamin, niacin, vitamin B6, and vitamin B12), consistent with the combined contribution of increased grains and plant proteins alongside continued animal and traditional protein intake. Importantly, the model achieved the iron improvement in a way that is meaningful across the entirety of the diet; the gram reallocation away from market animal protein (−20%) and mixed foods (−29%) was offset by sharp increases in traditional proteins, seafood (+319%) and game meat (+1318%) and higher plant protein (+108%). This means that iron and several B-vitamin outcomes are being supported through a diversification of protein sources, including culturally significant foods, rather than through increased reliance on market-based meats.

However, Table 25 also highlights persistent constraints and trade-offs that remained even after substantial redistribution. Four nutrients remained below 100% of recommended intake and were treated as soft constraints, indicating that full adequacy would have required infeasible or costly changes under the model's bounds. Calcium improved from 63.0% to 80.0% but remained below target, which aligns with dairy grams changing minimally (−3%) and limited feasible non-dairy calcium options in the food set. Folate increased substantially (48.7% to 89.0%), consistent with the large increases in vegetables and plant protein, yet still did not reach adequacy, meaning that meeting folate needs fully would require either larger quantities of folate-rich foods that were constrained by affordability. Vitamin D remained very low (20.7% to 21.1%), reinforcing that, given the available foods and costs, vitamin D adequacy is structurally difficult. Linoleic acid also remained extremely low (8.8% to 11.6%), suggesting that the optimized pattern did not substantially increase the specific fat sources that would raise linoleic acid levels.

Finally, total sugars decreased markedly (422% to 284%), and saturated fat declined (168% to 141%), consistent with reduced consumption of mixed foods and a partial shift away from more processed market items. Sodium decreased (214% to 180%) but remained elevated, and cholesterol was effectively at the threshold (97.2% to 100.0% of the 200 mg reference). Notably, these nutrient patterns are consistent with the model's gram-level trade-offs: large increases in vegetables, fruit, grains, and traditional foods improved fibre and micronutrients, while remaining constraints in the food environment, particularly reliance on some processed items and limited access to specific nutrient-dense options. Overall, the results show that nutrient adequacy gains are achievable primarily through increasing grams of plant-based and traditional

foods, but they also underscore that closing the remaining gaps will likely require structural shifts in the food-environment through policy and increased community control.

4.3.1.2 Projected diet (2050) vs Adaptation optimal diet for Females in Tla'amin Nation

Table 26 Overall Comparison for the Predicted and Adaptation Models for Females in Tla'amin Nation

Metric	Predicted	Adaptation	Absolute change	Percentage change
Total energy (kcal/day)	2880	2880	−2.60	−0.0900%
Total diet cost ($/day)	9.97	12.5	2.57	25.8%
MeHg exposure (ng/day)	387	418	31.3	8.09%
TF intake (g/day)	20.8	154	133	639%
TF energy (kcal/day)	38.5	160	121	316%
TF share of total energy (%)	1.34%	5.56%	+4.22 pp	316%
MF energy (kcal/day)	2840	2720	−124	−4.37%
MF share of total energy (%)	98.7%	94.4%	−4.22 pp	−4.28%
Total diet weight (g/day)	2070	2290	219	10.6%
MF intake (g/day)	2050	2130	86.6	4.23%

pp = percentage points

Total energy intake is effectively held constant (2879.61 vs. 2877.01 kcal/day; −0.09%), demonstrating that the adaptation solution achieves its improvements through food substitutions rather than changes in overall caloric intake. This is important analytically because it indicates that observed differences in diet quality, MeHg exposure, and affordability reflect compositional reallocation, rather than being driven by higher or lower total intake.

Despite the near-identical energy level, the adaptation-optimized diet is notably more expensive. Total daily diet cost increases from $9.97 to $12.53 (+25.76%), indicating that meeting nutritional goals and feasibility constraints under the food environment requires a higher food basket cost. This cost escalation highlights a central vulnerability in remote and rural

coastal food systems: nutrient adequacy is achievable in principle, but it is financially sensitive to market food and harvesting costs. In this context, the adaptation result underscores the potential importance of community initiatives that offset market food dependence, as practical solutions that could reduce the effective household cost of achieving a nutritionally adequate diet.

A defining feature of the adaptation diet is the substantial increase in TF. TF intake rises from 20.78 to 153.50 g/day (+638.84%), while TF energy increases from 38.48 to 159.96 kcal/day (+315.65%). Consequently, TFs share of total energy increases from 1.34% to 5.56% (+4.22 percentage points; +316.03%). Although TF remains a minority contributor to total calories, the magnitude of relative change signals that the optimization identifies TF as an efficient pathway to improve dietary quality. This shift is consistent with the role of TF particularly seafood and game meat in providing high-quality protein and key micronutrients within culturally meaningful dietary patterns.

MF continue to provide most dietary energy, but their contribution is reduced in the adaptation solution. MF energy declines from 2841.13 to 2717.05 kcal/day (−4.37%), and MF share of total energy decreases from 98.66% to 94.44% (−4.22 percentage points). At the same time, MF intake in grams increases slightly (2045.16 to 2131.76 g/day; +4.23%) and total diet weight increases from 2065.94 to 2285.25 g/day (+10.62%). This divergence higher total grams but lower MF calories suggests a shift toward less energy-dense, higher-volume foods, replacing highly processed market options. From an adaptation perspective, this pattern implies that improving nutrient adequacy under projected conditions require not only dietary substitution but also changes in food access and affordability that enable consistent procurement of high-volume, nutrient-dense foods.

Finally, the adaptation diet increases MeHg exposure from 387.14 to 418.45 ng/day (+8.09%), consistent with the increased TF contribution and likely higher seafood intake. The increase is modest relative to the scale of dietary restructuring and occurs alongside improvements in dietary composition and nutrient delivery. As a result, the model outputs highlight a key adaptation trade-off: strengthening nutritional adequacy and cultural food sovereignty through greater TF intake may incrementally increase MeHg exposure. Taken together, these results show that the adaptation-optimized diet maintains caloric adequacy while redistributing intake toward traditional and nutrient-dense foods, but that affordability management remain central considerations for designing realistic, community-aligned adaptation pathways.

Table 27 Changes in distribution of the food groups in grams for females in Tla'amin Nation for the predicted and adaptation models

Food Group	Predicted model (g/day)	Adaptation model (g/day)	Change (g/day)	Percentage change
Dairy	115	114	−1.30	−1.13%
Fats	24.3	3.07	−21.2	−87.3%
Fruit	126	200	74.5	59.2%
Grains	204	349	145	71.0%
Mixed foods	159	102	−56.8	−35.8%
Animal protein	143	119	−23.3	−16.4%
Plant protein	34.8	102	66.9	193%
Salty snacks	37.9	0.230	−37.6	−99.4%
Sweets	62.9	46.7	−16.2	−25.8%
Berries	0	29.1	29.1	New (0)
Fish	12.4	52.0	39.6	319%
Game meat	5.10	73.4	68.3	1.34e3%
Vegetables	115	223	107	93.3%

Figure 16 Changes in distribution of the food groups in grams for females in Tla'amin Nation for the predicted and adaptation models

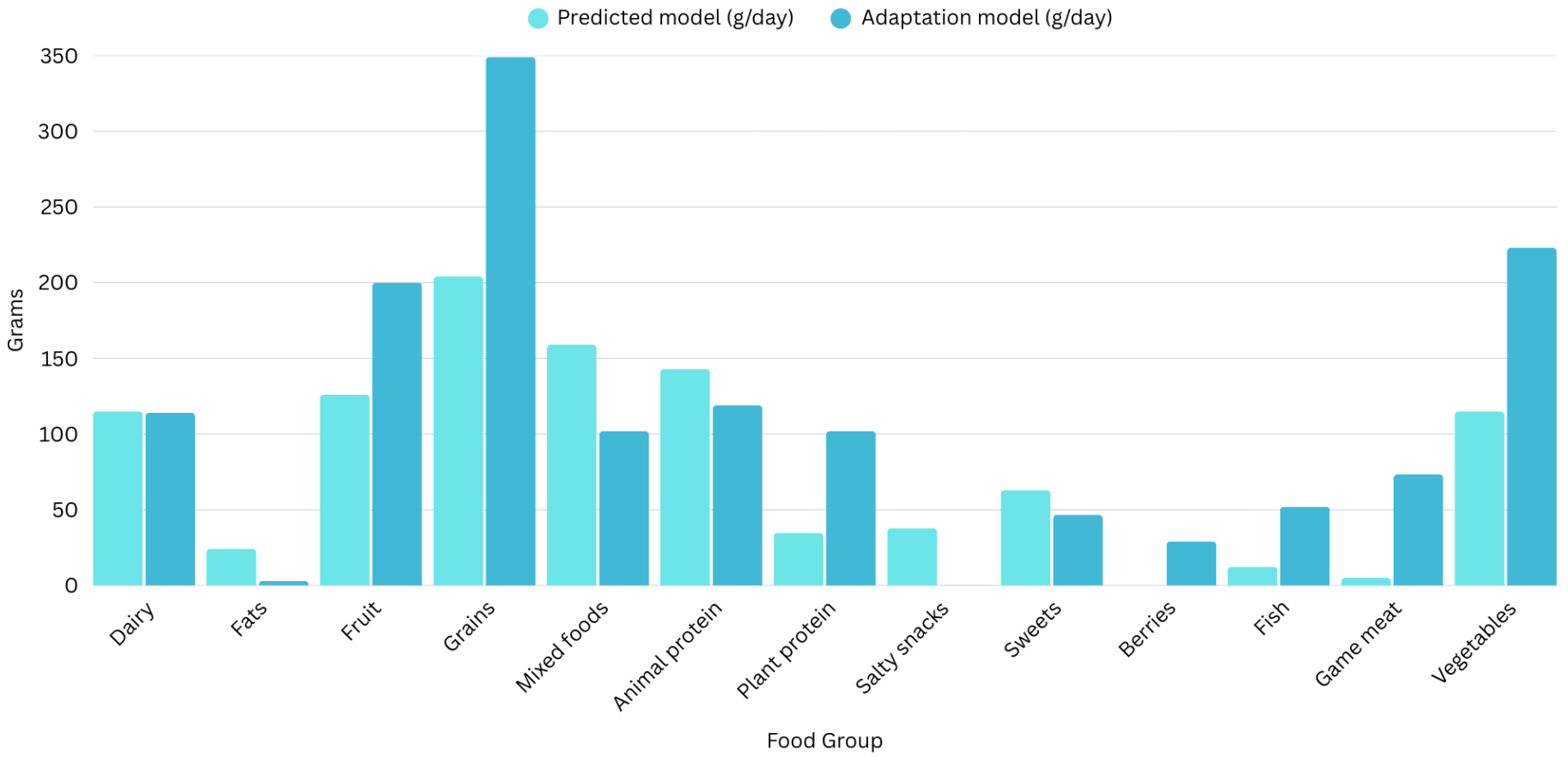


Figure 16 compares mean daily intake (grams per day) across food groups in the climate-driven predicted diet scenario versus the adaptation scenario. The adaptation model increases intake of nutrient-dense groups (notably grains and vegetables) while reducing reliance on mixed foods and several discretionary categories (e.g., salty snacks and sweets), illustrating how adaptation strategies reshape feasible dietary patterns under projected food-system change.

Note: Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.[8]

[8]

The adaptation model produces a clear redistribution away from highly processed market foods and toward nutrient-dense plant foods and traditional foods (Table 27; Figure 16). The most consequential shifts occur in vegetables, grains, fruit, and plant protein, food groups that function as the primary "nutrient delivery" levers under projected 2050 conditions. Vegetable intake nearly doubles (+107.48 g/day; +93%), while grains increase substantially (+144.88 g/day; +71%) and fruit rises by +74.48 g/day (+59%). Together, these increases indicate that the adaptation solution relies on higher-volume, lower–energy density foods to strengthen overall diet quality, particularly for fibre- and micronutrient-related targets, without increasing total energy intake.

A second major adaptation signal is the pronounced expansion of plant protein (+66.93 g/day; +193%). This shift suggests the model is diversifying protein sources away from market animal proteins (−23.33 g/day; −16%) and mixed/processed foods (−56.83 g/day; −36%), likely because plant-based protein foods offer a cost-effective way to support nutrient adequacy (e.g., fibre, folate, magnesium) while remaining feasible under availability and affordability constraints. In parallel, dairy remains essentially unchanged (−1.13%), indicating it is not a central mechanism through which the model achieves improved adequacy in this scenario.

Traditional foods increase sharply but selectively, emphasizing culturally relevant foods that also contribute meaningfully to nutrient sufficiency. Fish rises by +39.61 g/day (+319%) and game meat increases by +68.33 g/day (+1339%), while berries are introduced (0 → 29.12 g/day). These changes imply that, even under projected 2050 conditions, the optimized adaptation diet identifies traditional foods as an important and necessary pathway to improve nutritional outcomes. Importantly, the addition of berries and the increase in fish and game meat also reflect a strategy of broadening nutrient sources beyond MF dependence.

Finally, the strongest reductions occur in discretionary market foods; fats decrease by −21.18 g/day (−87%), and sweets decline by −16.23 g/day (−26%). These changes are meaningful because they reduce reliance on foods that typically contribute disproportionately to sodium, added sugars, and saturated fat. Overall, the pattern of change indicates that the adaptation solution is not simply a scaled version of the projected diet, rather, it represents a structurally different dietary composition that prioritizes nutrient density by increasing plant-based foods and strategically re-integrating traditional foods.

Table 28 Changes in distribution of the nutrients for females in Tla'amin Nation for the predicted and adaptation models

Nutrient	Unit	Adaptation	Predicted % of RDA	Adaptation % of RDA	Hard constraint	Soft constraint	Adaptation below 100% RDA
Protein	g/day	121	193	262	1	0	0
Total fat	g/day	97.0	214	216	1	0	0
Total Carbohydrate	g/day	281	193	216	1	0	0
Dietary fibre	g/day	31.8	82.4	127	1	0	0
Calcium	mg/day	773	63.0	77.3	0	1	1
Iron	mg/day	19.5	78.4	109	1	0	0
Magnesium	mg/day	497	98.8	155	1	0	0
Phosphorus	mg/day	1.68e3	190	240	1	0	0
Potassium	mg/day	3.56e3	112	137	1	0	0
Zinc	mg/day	39.5	515	494	1	0	0
Copper	µg/day	1.64	115	183	1	0	0
Vitamin A	µg RAE/day	2.42e3	192	346	1	0	0
Vitamin D	µg/day	3.17	20.7	21.1	0	1	1
Vitamin C	mg/day	93.6	78.3	125	1	0	0
Riboflavin (Vitamin B2)	mg/day	2.25	182	204	1	0	0
Niacin (Vitamin B3)	mg/day	36.8	195	263	1	0	0
Folate (Vitamin B9)	µg/day	320	48.7	80.0	0	1	1
Total saturated fat	g/day	30.0	168	150	1	0	0
Linoleic acid (Omega-6 fatty acid)	g/day	0.818	8.81	6.82	0	1	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	3.41	580	310	1	0	0
Monounsaturated fat	g/day	36.2	163	165	1	0	0
Polyunsaturated fat	g/day	18.5	281	308	1	0	0
Total sugars	g/day	82.7	422	331	1	0	0
Cholesterol	mg/day	200	97.2	100	1	0	0
Thiamin (Vitamin B1)	mg/day	1.76	121	160	1	0	0
Vitamin B6	mg/day	2.35	134	181	1	0	0
Vitamin B12	µg/day	3.78	206	157	1	0	0

Figure 17 Changes in distribution of the nutrients for females in Tla'amin Nation for the predicted and adaptation models

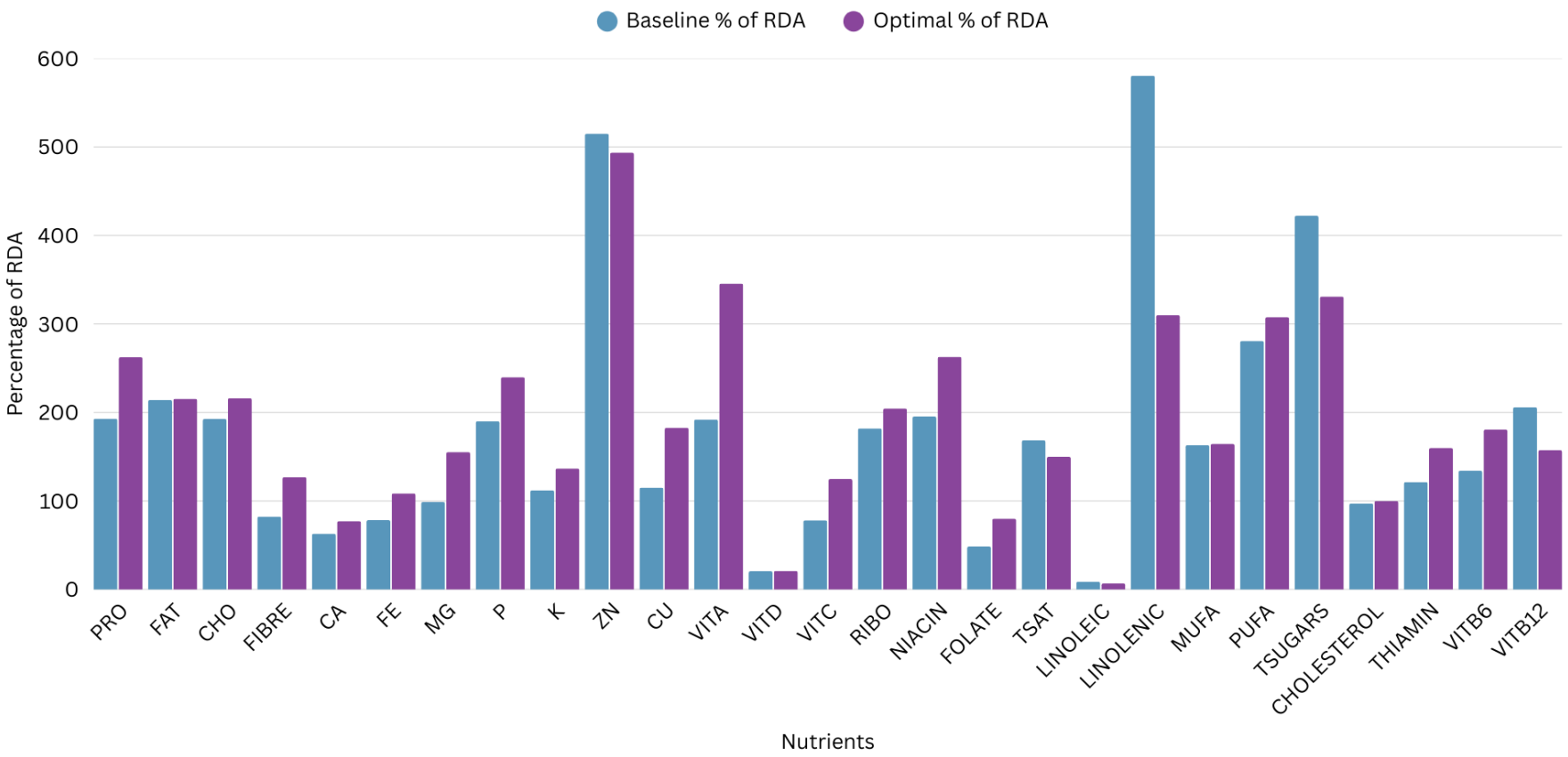


Figure 17 shows the percentage of recommended dietary allowance (RDA) achieved for each nutrient in the observed baseline diet compared with the model-derived optimal diet. The optimized solution increases adequacy for several limiting nutrients (including fibre, iron, magnesium, vitamin A, vitamin C, and folate) while reducing excessive intakes for others (notably sodium, linolenic acid, and total sugars), demonstrating how the model reallocates dietary composition to improve overall nutrient balance under feasibility constraints.

9

[9] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The adaptation model substantially improves adequacy for several nutrients that were not being met in the projected (2050) diet, while keeping most nutrients at or well above RDA (Table 28; Figure 17). The clearest improvements occur for fibre, iron, magnesium, potassium, and vitamin C. Fibre increases from 82% to 127% of the RDA, iron rises from 78% to 109%, magnesium increases from 99% to 155%, potassium increases from 112% to 137%, and vitamin C increases from 78% to 125%. These shifts indicate that the adaptation diet is not only meeting macronutrient targets but also addressing key micronutrient gaps that are often difficult to resolve under northern/coastal affordability and availability constraints.

These nutrient gains are directly explained by the food-group reallocations observed in the adaptation model. The largest increases in grains (+71%), vegetables (+93%), and fruit (+59%), along with a near tripling of plant protein (+193%), explain the observed micronutrient improvements. Higher vegetable and fruit intake plausibly drives the rise in vitamin C and contributes to higher fibre and potassium, while expanded grains and plant proteins support higher fibre, magnesium, and B-vitamins. In parallel, the model's increase in fish (+319%) and game meat (+1339%) helps explain improved iron adequacy and the maintenance of multiple B-vitamins, while also keeping protein high (262% of RDA). Importantly, the adaptation diet reaches 100% for cholesterol (200 mg/day reference), suggesting the model is managing animal-source selections and portions in a way that maintains cultural and nutritional benefits without pushing cholesterol above 200mg/day.

Despite these improvements, several nutrients remain below 100% because they were treated as soft constraints, signalling structural limits in what can be achieved through available foods under the scenario assumptions. Calcium increases only to 77%, vitamin D remains very low (~21%), folate reaches 80%, and linoleic acid remains extremely low (~7%). Collectively,

these persistent shortfalls imply that even a plant-based and TF supported adaptation diet still require complementary. In practical terms, the nutrient profile implies that community-led adaptation measures that expand access to vegetables, fruit, grains, and plant proteins (e.g., gardens, local farmer partnerships, night markets) are likely to yield measurable improvements in the most limiting nutrients, but that closing remaining gaps, especially vitamin D, will require additional food-environment interventions beyond substitution alone.

4.3.2 Diet Cost Analysis

4.3.2.1 Baseline versus Present Optimal Diet cost comparison for females

Table 29 Cost per 100% of nutrient RDA analysis for Baseline and Optimal models for Tla'amin females

Nutrient	Baseline cost per 100% RDA ($)	Optimal cost per 100% RDA ($)	Change in cost per 100% RDA ($)
Folate (Vitamin B9)	20.5	14.1	−6.39
Linoleic acid (Omega-6 fatty acid)	113	108	−5.42
Vitamin C	12.7	8.19	−4.55
Dietary fibre	12.1	8.86	−3.23
Vitamin A	5.19	2.13	−3.07
Magnesium	10.1	8.26	−1.83
Potassium	8.89	7.38	−1.52
Copper	8.66	7.22	−1.44
Vitamin B6	7.43	6.61	−0.821
Iron	12.7	12.2	−0.477
Alpha-linolenic acid (Omega-3 fatty acid)	1.72	1.38	−0.339
Polyunsaturated fat	3.55	3.24	−0.310
Calcium	15.8	15.7	−0.161
Phosphorus	5.24	5.28	0.0348
Protein	5.16	5.31	0.145
Thiamin (Vitamin B1)	8.20	8.47	0.260
Total carbohydrate	5.17	5.80	0.626
Riboflavin (Vitamin B2)	5.47	6.14	0.662
Zinc	1.93	2.64	0.702
Niacin (Vitamin B3)	5.10	5.86	0.764
Total fat	4.65	5.81	1.16
Monounsaturated fat	6.11	8.01	1.90
Total sugars	2.36	4.41	2.05
Cholesterol	10.2	12.5	2.29
Sodium	4.66	6.96	2.30
Total saturated fat	5.92	8.89	2.98
Vitamin B12	4.84	8.28	3.44
Vitamin D	48.1	59.3	11.3

Figure 18 Cost per 100% of nutrient RDA analysis for Baseline and Optimal models for Tla'amin females

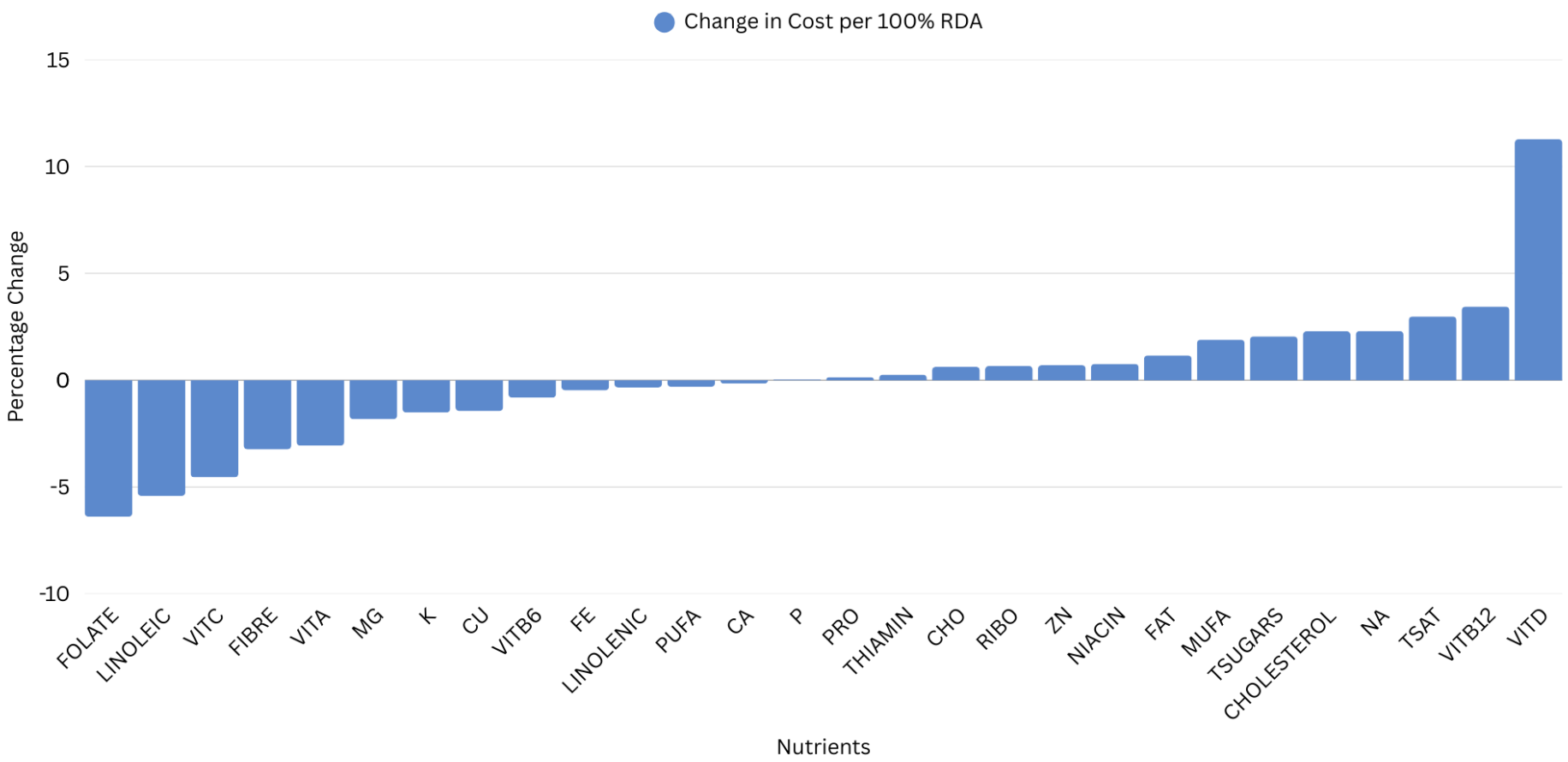


Figure 18 shows the difference in cost required to achieve 100% of the recommended dietary allowance (RDA) for each nutrient when comparing the baseline diet to the model-derived optimal diet. Negative values indicate nutrients that become less costly to meet under the optimized solution (improved cost-efficiency), whereas positive values indicate nutrients that become more costly to achieve, highlighting which nutrient targets drive affordability pressures in optimized diets.[10]

[10] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The cost-per-100% RDA metric reflects nutrient "value for money" within the entirety of the diet: it is the estimated daily diet cost divided by the proportion of the recommended intake achieved for that nutrient. Since, it is a ratio, it can move in opposite directions from total diet cost. In this model, overall diet cost increases in the optimal solution, yet many nutrients become cheaper per 100% RDA because the optimization increases their adequacy more than it increases total cost (Table 29; Figure 18). To put differently, the optimized diet buys more "nutrient adequacy" per dollar for several limiting nutrients by redistributing grams toward nutrient-dense foods.

Across nutrients, the largest declines in cost per 100% RDA occur for folate (−6.39), vitamin C (−4.55), fibre (−3.23), vitamin A (−3.07), magnesium (−1.83), potassium (−1.52), and copper (−1.44). These reductions indicate improved efficiency: the optimized diet raises the %RDA for these nutrients at a faster rate than the increase in total cost. This pattern is consistent with a shift toward foods that deliver multiple micronutrients simultaneously, so that each additional dollar contributes to a larger gain in adequacy. In contrast, nutrients whose cost-per-RDA increases, such as vitamin D (+11.27), vitamin B12 (+3.44), saturated fat (+2.98), sodium (+2.30), cholesterol (+2.29), and total sugars (+2.05), reflect cases where adequacy either improves little (or is capped by constraints/food availability) while the overall diet basket becomes more expensive, or where meeting the reference target depends on foods that are costly within the retail environment. These increases therefore do not contradict the reductions observed elsewhere, they highlight nutrients that remain expensive or difficult to optimize under realistic constraints.

The key implication is that the optimal diet is more expensive overall, but nutritionally more efficient: it reallocates spending toward foods that close important micronutrient gaps more

effectively. This distinction matters for interpretation and policy. While affordability remains a barrier, underscored by the higher total daily cost, the improved cost-efficiency for priority nutrients suggests that community-level interventions that lower the price of nutrient-dense foods (e.g., gardens, markets, local procurement, and traditional food access initiatives) could simultaneously reduce the total basket cost and preserve and/or further improve nutrient adequacy.

4.3.2.2 Predicted vs Adaptation for Females for Tla'amin Nation

Table 30 Cost per 100% of nutrient RDA analysis for Predicted and Adaptation models for Tla'amin females

Nutrient	Predicted cost per 100% RDA ($)	Adaptation cost per 100% RDA ($)	Change in cost per 100% RDA ($)
Linoleic acid (Omega-6 fatty acid)	113	90.3	−22.8
Folate (Vitamin B9)	20.5	11.8	−8.66
Vitamin C	12.7	6.87	−5.87
Dietary fibre	12.1	7.43	−4.66
Vitamin A	5.19	1.78	−3.41
Magnesium	10.1	7.05	−3.04
Potassium	8.89	6.30	−2.60
Copper	8.66	6.55	−2.11
Vitamin B6	7.43	5.82	−1.61
Iron	12.7	11.4	−1.32
Alpha-linolenic acid (Omega-3 fatty acid)	1.72	0.950	−0.770
Polyunsaturated fat	3.55	3.01	−0.540
Calcium	15.8	15.4	−0.400
Protein	5.16	5.05	−0.110
Phosphorus	5.24	5.26	0.0200
Thiamin (Vitamin B1)	8.20	8.04	−0.170
Total carbohydrate	5.17	5.31	0.140
Riboflavin (Vitamin B2)	5.47	5.54	0.0700
Zinc	1.93	1.94	0.0100
Niacin (Vitamin B3)	5.10	5.19	0.100
Total fat	4.65	4.78	0.130
Monounsaturated fat	6.11	6.55	0.440
Total sugars	2.36	2.16	−0.200
Cholesterol	10.3	10.1	−0.120
Sodium	4.66	4.90	0.240
Total saturated fat	5.92	5.79	−0.130
Vitamin B12	4.84	6.58	1.74
Vitamin D	48.1	42.1	−5.95

Figure 19 Cost per 100% of nutrient RDA analysis for Predicted and Adaptation models for Tla'amin females

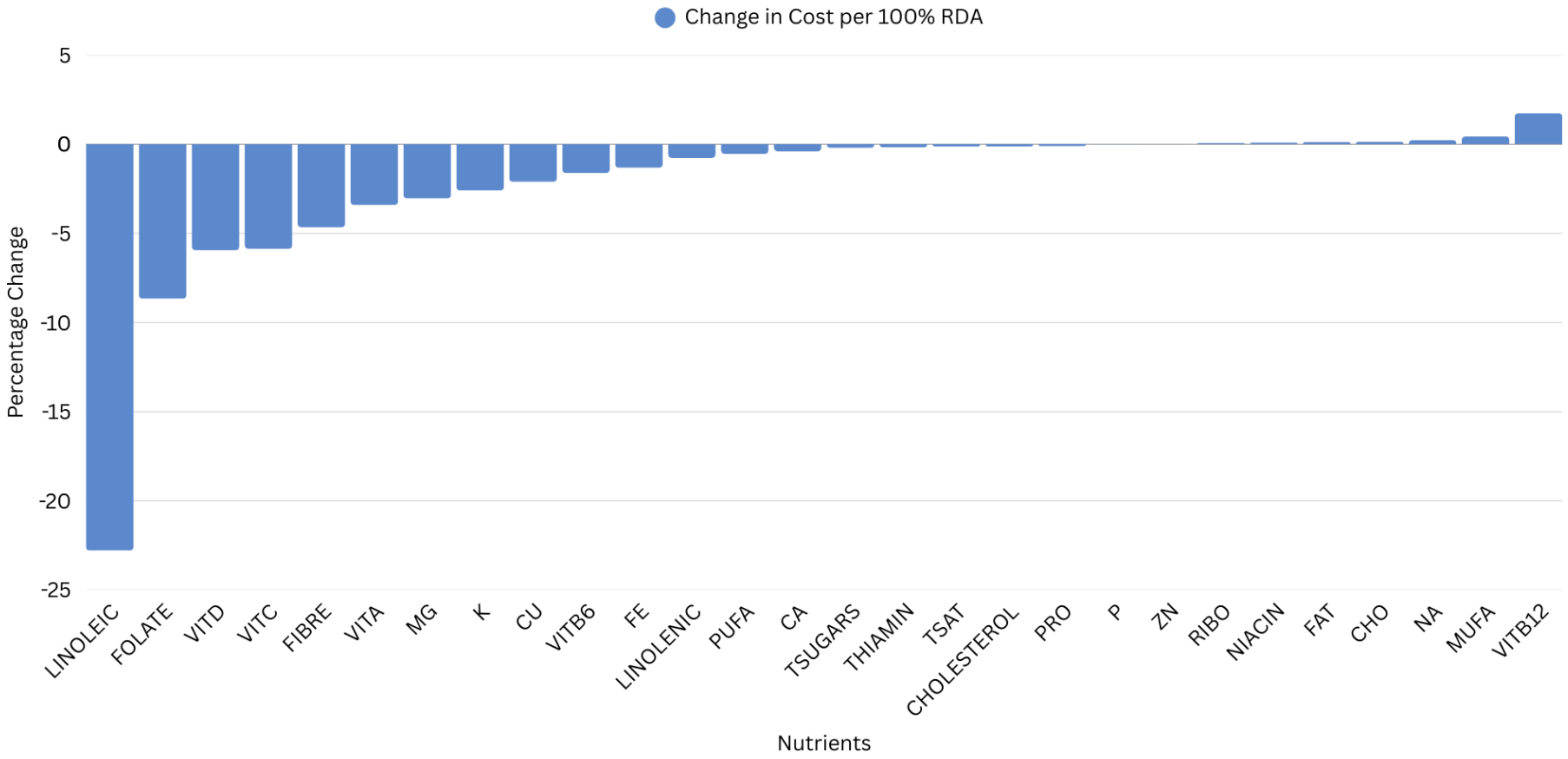


Figure 19 shows the difference in cost required to achieve 100% of the recommended dietary allowance (RDA) for each nutrient when comparing the climate-driven predicted scenario to the adaptation scenario. Negative values indicate nutrients that become less costly to meet under the adaptation model (greater cost-efficiency), while values near zero indicate minimal change; positive values indicate nutrients that become more costly to achieve, highlighting which nutrient targets shift affordability pressures under projected food-system change.

[11]

[11] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Although the adaptation scenario increases the overall daily diet cost, it simultaneously improves the cost-efficiency of meeting many nutrient targets. This is due to the fact the cost per 100% RDA metric reflects the total diet cost relative to the share of each nutrient requirement achieved. If the adaptation diet raises nutrient adequacy substantially (through more nutrient-dense food choices), the "cost per unit adequacy" can fall even when the overall basket becomes more expensive.

Across Tla'amin females, the adaptation diet delivers several nutrients more cost-effectively than the predicted diet, particularly those that were harder to meet in the projected pattern. The largest improvement is for linoleic acid (113.12 to 90.33; change = −22.79), indicating that the adaptation solution identifies a more efficient combination of foods supplying this fatty acid. Strong reductions are also observed for folate (change = −8.66), vitamin C (change = −5.87), vitamin D (change = −5.95), and fibre (change = −4.66), alongside meaningful improvements for vitamin A (change = −3.41), magnesium (change = −3.04), and potassium (change = −2.60). Collectively, these shifts suggest that the adaptation pattern reallocates intake toward foods that provide multiple limiting micronutrients at once (e.g., higher fruit, vegetable, and plant-forward selections), thereby increasing adequacy faster than costs rise for these nutrients.

At the same time, a smaller subset of nutrients becomes slightly more expensive to achieve per 100% RDA in the adaptation diet, most notably vitamin B12 (4.84 to 6.58; change = +1.74). This reflects the adaptation solution relying less on low-cost B12 sources, meaning that achieving adequacy requires relatively more expensive animal-source or fortified foods. Small

increases are also observed for MUFA (+0.44), sodium (+0.24), carbohydrates (+0.14), and total fat (+0.13).

Importantly, these nutrient-level efficiency gains occur within a higher-cost overall basket, indicating that the adaptation scenario shifts spending toward foods that improve nutritional adequacy but are more expensive in absolute terms under remote retail conditions. In other words, the optimal diet appears to be better "value per nutrient," yet costlier overall a pattern consistent with constrained food environments where nutrient-dense options carry higher cost burden. This distinction is policy-relevant as it suggests that adaptation strategies which reduce the price of nutrient-dense foods (e.g., local procurement, gardens, food programs, traditional food access supports) could lower total cost while preserving the improved nutrient efficiency observed in the model.

4.3.3 Conclusion

Overall, the Tla'amin results show that nutrient adequacy is achievable for both women and men, but the optimization reaches that outcome by balancing a set of competing objectives and constraints—most notably nutrient sufficiency, total diet cost, MeHg exposure, energy requirements, and reliance on traditional foods. The value of the modelling is therefore not only the "optimal" diet itself, but the way it reveals trade-offs: improving one dimension (e.g., micronutrient adequacy) can require accepting changes in another (e.g., higher cost or higher MeHg), which clarifies where the food system is flexible versus structurally constrained. Across both sexes, the model holds energy essentially constant, meaning improvements are achieved mainly through substitution and reallocation rather than by changing total intake. What shifts—sometimes sharply—is the composition of the diet and the "price" of adequacy. For women, the model improves adequacy primarily by moving toward a higher-volume, nutrient-

dense pattern (more vegetables, grains, fruit, and plant proteins), while increasing traditional proteins as an efficient micronutrient lever. This produces a clear trade-off structure: nutrient gains are substantial, but they are accompanied by a large increase in total daily diet cost (and, in scenarios with greater seafood contribution, a modest increase in MeHg exposure). In other words, for women the optimization often "buys" nutrient adequacy through combinations that are nutritionally efficient but financially sensitive, indicating that affordability can become (or remain) a binding constraint unless the food environment changes.

For men, the trade-off pattern differs. Under present conditions, the model achieves a major rebalancing toward traditional foods—particularly fish and game—while keeping calories constant and showing minimal change in cost and MeHg. This indicates a different kind of flexibility: the model can improve adequacy and cultural alignment for men without large cost penalties when traditional foods are accessible and feasible within constraints. However, that same result highlights a structural vulnerability: adequacy becomes highly dependent on the continued availability of traditional proteins and the infrastructure and governance conditions that support harvesting, sharing, and distribution. As climate and access constraints intensify, the model's ability to rely on seafood and other traditional foods becomes more limited, and the "burden" of adequacy shifts back toward market foods—where cost, availability, and nutrient density constraints can tighten quickly.

Seen together, the male–female comparison makes the model's balancing act clearer. Traditional foods are consistently high-leverage in both groups, but women's solutions rely more heavily on market-based plant foods to close key micronutrient gaps, whereas men's solutions more strongly re-center traditional proteins as the primary lever when feasible. In both cases, the model exposes the same underlying principle: nutrient adequacy is not only a dietary problem—

it is a feasibility problem shaped by the food system. When the system provides affordable nutrient-dense options and reliable access to traditional foods, the model finds improvements with fewer penalties; when those pathways are constrained, improvements come with larger trade-offs (especially rising cost and sometimes rising exposure).

Finally, the results show that some nutrient shortfalls remain structurally difficult to solve through substitution alone (e.g., vitamin D and essential fatty acids, and in some scenarios calcium/folate), even when the diet is substantially reorganized. These persistent gaps are important because they identify where the model is "maxing out" against real-world constraints: they point to interventions that must expand the feasible food set (e.g., improved access to culturally acceptable calcium sources, fortified foods where appropriate, strengthened produce supply chains, and climate-resilient harvesting strategies), rather than expecting further optimization within an unchanged system.

Taken together, the results support a single, adaptation-relevant conclusion: the optimization outputs function as a diagnostic of what the food system can currently deliver and what it cannot. They show that achieving nutritionally adequate diets in Tla'amin involves explicit trade-offs among adequacy, cost, exposure, and reliance on traditional foods, and that the most effective "levers" sit upstream—affordability supports for nutrient-dense market foods and sustained investments in traditional food access, harvesting capacity, and governance. A co-developed approach is therefore essential because it is the pathway that turns these model-identified trade-offs into implementable, community-aligned strategies that improve nutrition without increasing inequities.

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Chapter 5- Discussion and Conclusion

5.1 Summary of findings from Chapters 3 and 4

Although Skidegate and Tla'amin are both coastal First Nation communities, the optimization results show that different parts of their food system are the main limiting factors, meaning the "feasible diet space" is shaped by different limiting nutrients, food-group levers, and trade-offs for each community.

In Skidegate, the model repeatedly identifies traditional foods (especially seafood), as the highest-leverage pathway for meeting protein and multiple micronutrients under both present-day and climate-constrained scenarios. This makes feasibility highly sensitive to projected fish-stock changes. Thus, the model can no longer over-rely on culturally important species that are projected to decline and must diversify across what remains ecologically plausible. This constraint is not just technical, it is the mechanism that reshapes the feasible solution space under climate change, and it directly alters nutrient–cost–risk trade-offs.

At the same time, Skidegate's results show a consistent pattern of structural nutrient gaps that the model struggles to close even when it meaningfully reorganizes diets. For females, persistent inadequacy remains for fibre, folate, vitamin C, vitamin D, and linoleic acid, nutrients that depend heavily on either reliable access to high-quality produce or on a narrow set of foods (e.g., fortified foods or specific seafood/dairy pathways). For males, the present-day solution highlights a different feasibility pressure: because the baseline is energy-deficient relative to the model target, meeting adequacy requires expanding total intake, largely via increased traditional foods, which then triggers the key Skidegate trade-off, higher cost and higher MeHg exposure, despite remaining within a modeled safe threshold.

Adaptation is constrained less by "finding better foods" in the abstract and more by: i) species-specific marine availability trajectories and; ii) the limited ability of the current feasible market-food set to resolve vitamin D and essential-fatty-acid/plant-micronutrient shortfalls without expanding the food environment (e.g., produce pathways, fortification/supplement scenarios).

In Tla'amin, the binding structure is more explicitly economic: improvements in adequacy tend to be achieved through a higher-volume, nutrient-dense pattern (vegetables, grains, fruit, plant proteins) that is nutritionally efficient but cost sensitive. For women in particular, the model's pathway to adequacy often involves "buying" nutrient gains through costlier combinations, making affordability a binding constraint unless the food environment changes. This is why the adaptation scenario in Tla'amin is formulated differently: it directly encodes community-led initiatives (night markets, partnerships with local farmers, community gardens) by weighting vegetables, fruits, and bread more heavily in the feasibility structure. In Tla'amin, the adaptation scenario is framed as expanding access to nutrient-dense market foods rather than relying mainly on substituting among seafood species. This reflects two constraints that tighten the feasible traditional-food pathway: projected rapid declines in seafood within Tla'amin waters, and governance-related limits on access and harvesting that are less restrictive in Skidegate.

In practice, the model shifts toward less energy-dense, higher-volume foods (more grams with fewer calories), reflecting that adequacy under projected conditions increasingly depends on consistent access to nutrient-dense staples and produce. Nutrient behavior in Tla'amin also shows a distinct pattern: several micronutrients improve substantially but remain difficult to fully resolve through substitution alone, particularly vitamin D (still below adequacy) and in some

scenarios, calcium/folate. This echoes the “hard-to-reach nutrient” theme seen in Skidegate, but the pathway pressure differs. In Tla’amin, it is less about ecological caps on seafood and more about whether the community can reliably access, and afford, the mix of market foods needed to close those gaps while maintaining feasibility.

Adaptation is especially community-specific because the most effective levers sit upstream in local initiatives and affordability supports, interventions that change what foods are realistically available and affordable (and therefore what the model can select), rather than expecting diet shifts within an unchanged retail environment.

The community comparison indicates that the same optimization framework, with different parameterization produces distinct limiting factor patterns in Skidegate and Tla’amin. In practical terms, the nutrients that remain difficult to achieve, the food groups that function as the most effective levers, and the dominant trade-offs that emerge under climate scenarios differ across communities despite both being coastal First Nations; highlighting, the importance of both co-development and regional-specific parameterization.

In Skidegate, persistent inadequacies cluster around nutrients that are either strongly linked to consistent access to high-quality produce or are difficult to achieve through food-only pathways under realistic availability constraints. Across optimized solutions, shortfalls remain concentrated in vitamin D, fibre, folate, vitamin C, and linoleic acid, even after the model reallocates intake to minimize cost while meeting acceptability and ecological constraints. This pattern suggests that the food system has structural limitations, particularly in terms of produce and/or fortified pathways, and that nutrient adequacy becomes more sensitive to climate-driven constraints when traditional seafood availability is reduced in species-specific ways. As a result,

these nutrients function as persistent “pressure points” that the optimizer cannot easily resolve through substitution alone but must be solved through policy.

In Tla’amin, improvements in adequacy are more strongly driven by shifting intake toward vegetables, grains, fruit, and plant proteins, but the model also indicates that affordability becomes the primary limiting factor. Even when the model finds nutritionally efficient patterns, the cost required to implement them can constrain feasibility, particularly for diets that depend on higher-volume nutrient-dense foods. At the same time, vitamin D, and in some scenarios calcium and folate, remain difficult to fully resolve unless the feasible food environment expands beyond baseline retail availability. This implies that, in Tla’amin, closing nutrient gaps depends less on substitution among existing foods and more on upstream changes that improve the affordability and accessibility of the foods that supply these nutrients.

This comparison points to a dual reality in climate adaptation: some challenges are shared across coastal food systems, while the constraints that ultimately shape nutritionally adequate diets remain strongly community specific. First, some needs appear regional and structurally shared across coastal contexts. Both communities reveal nutrients that remain difficult to achieve through food-only substitution within constrained food environments, most notably vitamin D and essential fatty acids, suggesting that broader strategies such as improved access to fortification, and strengthened supply chains for nutrient-dense foods may be relevant across multiple communities. At the same time, the analysis shows that the binding constraints that define feasibility are strongly community-specific, implying that adaptation cannot take a uniform approach. In Skidegate, the feasibility frontier is highly sensitive to marine access represented as species-specific supply limits, and to contaminant-risk balancing. This means effective adaptation planning must be grounded in local seafood projections, and harvesting

capacity, rather than treating “seafood” as a single interchangeable category. In Tla’amin, the feasibility frontier is more strongly shaped by economic conditions, and community initiatives that expand access to produce and staples are not peripheral supports; they are the mechanism that alters what diets are feasible under climate stress.

In short, regional policy can address shared structural barriers and recurring “hard nutrients,” but implementable adaptation depends on the community-level constraints that bind first, whether those are driven primarily by seafood supply and contaminant trade-offs (as in Skidegate) or by affordability (as in Tla’amin).

This comparison also provides insight into how the food system functions in each community under climate stress. In Skidegate, the results describe a food system that is simultaneously ecologically constrained and structurally expensive on the market-food side. Climate impacts enter the model primarily through supply-side constraints on traditional seafood, species-by-species upper bounds that directly narrow the feasible diet space under RCP8.5. This indicates that resilience is closely tied to the availability and diversity of local marine foods: as projected availability tightens, the optimizer cannot simply scale up culturally important species and must reallocate across what remains plausible. At the same time, Skidegate’s market food environment appears to be shaped by high costs and access frictions, such that affordability and transportation constraints can amplify reliance on ultra-processed foods. This combination helps explain why plant-associated micronutrients remain difficult to resolve through substitution alone. In Tla’amin, the results describe a food system where affordability and governance play a particularly central role in shaping feasibility. Cost pressures in coastal and rural contexts, linked to transport costs, supply-chain constraints, and limited retail competition, make nutritionally adequate market-food patterns difficult to implement without targeted supports. In addition, the

climate scenario framing reflects ecological declines in key traditional seafood alongside governance-related constraints on access to local waters, increasing uncertainty around relying on seafood as the primary adaptation pathway. As a result, adaptation is represented as a food-system transformation that can be actively engineered at the community level: initiatives such as night markets, farmer partnerships, and community gardens are treated as structural interventions that increase the feasibility of nutrient-dense market foods, widening the feasible diet space under climate stress.

Overall, Skidegate's model points to climate vulnerability driven heavily by ecological availability of culturally central seafood combined with expensive/limited retail access, whereas Tla'amin's model points to vulnerability driven by economic conditions and governance over traditional-food access, with community-led market-food interventions acting as a realistic buffer that expands dietary feasibility.

5.2 Discussion

A central contribution of this thesis is the translation of established qualitative mechanisms in Indigenous food security and climate vulnerability literature into a quantitative, scenario-based decision-support framework that can be used to evaluate dietary feasibility and trade-offs under explicitly defined community-specific constraints. Existing research has established that dietary outcomes in Indigenous and remote settings are shaped by upstream determinants, yet these drivers are frequently treated descriptively and are rarely incorporated into models in a way that permits explicit testing of how they bound nutritional feasibility (Domingo et al., 2021; Kuhnlein et al., 2009; Marushka et al., 2019b). By representing "feasibility" as an empirically parameterized constraint set and evaluating the sensitivity of

solutions, this thesis operationalizes structural determinants as measurable limits on attainable nutrient adequacy, rather than as unobserved contextual factors.

Within the climate–nutrition literature, climate impacts on diet are increasingly conceptualized as indirect and mediated through interacting pathways spanning ecological production, access, affordability, governance, and stability (Marushka et al., 2019b). However, empirical analyses often implement climate change as a generalized shock or infer dietary effects from ecological outcomes without explicitly specifying the mechanisms by which ecological change modifies the set of foods that are realistically accessible and substitutable. The approach adopted here advances this literature by embedding climate-linked resource dynamics directly within the feasible choice space. In methodological terms, climate change is represented as a perturbation to the constraint structure rather than an assumed behavioural shift. This improves scenario interpretability by allowing observed changes in model outputs to be attributed to explicit, parameterized constraint changes, thereby strengthening the internal coherence of the causal narrative at the level of the modelled system.

A recurring limitation of applied optimization studies is that outputs can be highly sensitive to the specification of objectives, constraint definitions, and acceptability bounds, complicating comparison across settings and limiting generalizability (Reilly & Willenbockel, 2010). By applying a single modelling framework while implementing community-specific parameterization, the analysis enables between-community differences in optimized outcomes to be interpreted as reflecting differences in underlying food-system structure, rather than artefacts of divergent modelling assumptions. This is particularly salient in Indigenous and remote

contexts, where feasibility constraints are heterogeneous and where the validity of inferred "solutions" depends critically on how access and acceptability are specified.

A further methodological advance is the explicit integration of multiple interacting decision criteria within a single applied framework while retaining interpretability. The joint representation of nutrient adequacy, affordability, ecological feasibility, and exposure risk corresponds to an emerging direction in nutrition modelling toward multi-criteria decision analysis under environmental change. Critically, ecological constraints and contaminant risk are not treated as downstream filters applied after an optimal diet is generated; they are incorporated as co-determinants of feasibility, ensuring that trade-offs are resolved within the optimization process.

Finally, the thesis contributes to participatory modelling and Indigenous methods by operationalizing co-development as a technical requirement for model validity. Because optimization outcomes are contingent on embedded assumptions regarding access, acceptability, and feasibility cannot be specified credibly without community-grounded knowledge. By anchoring constraint calibration and parameterization in community engagement while maintaining a transparent and reproducible modelling structure, this work provides an applied example of how quantitative decision-support tools can be developed in ways that are simultaneously analytically rigorous, contextually legitimate, and suitable for scenario-based adaptation planning.

5.3 Community Implications

The modelling results have direct implications for food security and climate adaptation planning in Skidegate and Tla'amin because they do more than identify "optimal" diets; they

diagnose how each community's food system is structurally organized, and therefore which constraints become limiting factors first when households attempt to achieve nutritional adequacy under realistic conditions. Across scenarios, the model clarifies (i) which constraints most strongly determine the limits of feasible diets, (ii) which foods act as high-leverage nutrient carriers, and (iii) where upstream structural barriers whether, ecological, economic, or governance-related, limit adequacy even when diets are optimized. In doing so, the model shifts community planning from a focus on individual diet change toward the food-system features that produce or restrict feasible dietary pathways under both current and climate-constrained conditions.

A consistent finding across both communities is that diets with improved nutrient adequacy increased the contribution of traditional foods (TF), particularly seafood. This pattern reinforces a core community implication: TF are not only culturally central but also nutritionally strategic, because they deliver multiple micronutrients simultaneously (e.g., high-quality protein, iron, zinc, and B vitamins) and can reduce reliance on highly processed market foods. In both sites, increasing traditional proteins often generated disproportionate gains in difficult nutrient targets without requiring large changes across all food groups, highlighting TF as a high-efficiency pathway in the feasible diet space. Practically, this supports continued and expanded investment in harvesting, processing, storage, and sharing infrastructure (e.g., community freezer capacity, gear support, smokehouse/processing access, and nation distribution), because these interventions strengthen a nutrient pathway that the model repeatedly identifies as high leverage and not easily replaceable through market foods alone.

However, the model also shows that TF-driven pathways are constrained by different food-system bottlenecks in each community, which has important implications for adaptation

design. In Skidegate, feasibility is highly sensitive to seafood availability. Thus, climate change reshapes the diet solution primarily by narrowing access to key nutrient-dense species and forcing diversification and substitution. This indicates that Skidegate's nutritional resilience is tightly coupled to ecological availability and to the community's capacity to maintain diverse harvesting pathways. It also implies that food security planning cannot be separated from fisheries monitoring, harvesting infrastructure, and governance processes that influence access to marine foods. Where projected declines are steep, nutritional vulnerability can increase even if dietary preferences remain unchanged, because the model's feasible diet space contracts around a smaller set of ecologically plausible options.

In Tla'amin, by contrast, the model indicates that the dominant constraint is more strongly economic and retail-structure dependent. Adequacy improvements are often achieved by shifting toward vegetables, fruits, grains, and plant proteins, but affordability becomes a binding condition that limits how far these nutritionally efficient patterns can be implemented. In addition, Tla'amin's adaptation framing incorporates ecological declines in key seafood resources alongside governance-related limits on access, which increases uncertainty around relying on seafood substitution as the primary adaptation pathway. The community implication is that adaptation strategies that expand the market-food feasibility set, are likely to be particularly impactful. Community initiatives such as night markets, local farmer partnerships, and community gardens are not peripheral supports in this context; they are upstream interventions that can relax binding constraints by improving the effective accessibility, reliability, and affordability of nutrient-dense foods, thereby expanding the feasible diet space under climate stress.

Across both communities, the model also highlights that certain nutrients remain structurally difficult to meet through substitution alone, pointing to limits in the existing food environment. This implies that nutrition resilience will likely depend on a dual strategy: (1) protecting and enabling TF systems as critical nutrient pathways, and (2) reducing structural barriers to nutrient-rich market foods (including affordability, availability, and access) where persistent inadequacies remain. Importantly, the model suggests that these two strategies are complementary rather than interchangeable. TF pathways offer micronutrient efficiency and cultural continuity, while market-food interventions can reduce vulnerability where ecological decline, governance constraints, or cost pressures restrict the ability of TF to cover all nutritional needs.

Overall, the modelling indicates that community-led food security planning should be organized around food-system constraints rather than food lists. For Skidegate, this means prioritizing strategies that sustain diverse and ecologically plausible seafood pathways alongside contaminant-risk-aware planning and active participation in fisheries governance. For Tla'amin, this means prioritizing affordability- and access-oriented interventions that expand the feasibility of nutrient-dense market foods, while also addressing the governance and ecological pressures that constrain traditional seafood access. By making these structural bottlenecks explicit, the model provides a clearer roadmap for community-driven interventions that are nutritionally effective, culturally grounded, and aligned with the realities of climate-driven food system change.

5.4 Implications to Optimal diet modelling

This thesis demonstrates that optimal diet models can function not only as tools for generating nutritionally adequate diets under constraints, but as diagnostic decision-support

systems that reveal which features of a community food system most strongly determine the limits of feasibility under present and future conditions. The central novelty of the approach is the combination of (i) a single shared optimization framework applied across two communities, (ii) community-specific parameterization derived through co-development, and (iii) explicit representation of climate-driven supply-side limits and community-led interventions within the optimization structure. Rather than treating model adjustments solely through mathematical feasibility, the thesis operationalizes feasibility as an empirical, community-informed construct and uses scenario design to directly connect ecological and governance stressors to diet outcomes.

Four implications emerge for improving optimal diet modelling and increasing its policy relevance in Indigenous and climate-sensitive food environments: i) embedding supply-side constraints through fish stock availability; ii) incorporating community initiatives as endogenous components of the model; iii) formalizing co-development as a methodological requirement for defining feasibility and success; and iv) adopting multi-objective optimization to represent the true structure of diet trade-offs.

A key methodological contribution of this thesis is the explicit integration of fish stock availability as a supply-side constraint in the adaptation scenarios. Conventional diet optimization implicitly assumes foods are available whenever they appear in a food list, so long as they are not restricted by price or palatability bounds. In seafood-dependent contexts, this assumption can generate solutions that are nutritionally "optimal" but ecologically implausible, particularly when the solver concentrates intake in nutrient-dense seafood to satisfy multiple micronutrient targets efficiently. In this thesis, projected abundance trajectories are translated into availability multipliers that scale seafood upper bounds, such that foods projected to decline

cannot be selected above a reduced maximum while foods projected to increase can contribute more, subject to feasibility caps. The uncertainty of the ecological projections was addressed using a scenario-based approach, incorporating multiple climate pathways and expressed outputs as relative changed in species abundance and catch potential (Weatherdon et al., 2016). This approach used captures a range of plausible futures rather than a single prediction and improved robustness by modelling multiple species (Weatherdon et al., 2016). However, uncertainty remains in both ecological responses and in how projected changes translate into local access and consumption (Weatherdon et al., 2016). Therefore, it is important to these projections are interpreted as directional planning tools rather than precise forecasts and were used in this thesis to inform availability constrains under climate change scenarios.

This shift yields two modelling advantages. First, it strengthens interpretability: changes in seafood intake can be attributed to explicit ecological constraints rather than appearing as purely nutritional substitutions. Second, it strengthens adaptation relevance; outputs are less likely to recommend strategies that depend on increased consumption of species that are ecologically unlikely to remain available. In effect, stock constraints operate as ecological feasibility filters that restructure the feasible diet space and force diversification within seafood pathways and, when necessary, substitution into non-seafood foods to meet nutrient and affordability objectives.

A second novel element is treating existing and emerging community initiatives as endogenous levers within the optimization rather than as external context. Many communities already operate food-system strategies that materially shape access, affordability, and feasibility (e.g., night markets, local farmer partnerships, community gardens, and nation distribution programs). In standard diet models, these are often described qualitatively but not embedded in

the constraint structure, even though, they alter effective availability, affordability, and substitution pathways. In this thesis, the Tla'amin adaptation scenario demonstrates how community initiatives can be represented directly by shifting food-group constraint weights toward foods made more accessible through local initiatives (e.g., vegetables, fruits, and bread supported through night markets and gardens).

This approach is novel in that it models adaptation as a plausible expansion of the feasible market-food environment under climate stress, rather than assuming the retail environment remains static and placing the burden of adaptation entirely on household choice. The results reinforce that "optimal" is not a purely technical outcome: it is defined by values embedded in constraints, weights, and scenario assumptions. In Indigenous' food systems, where cultural food priorities, governance, and feasibility realities shape what is implementable, co-development is not optional, it is a methodological requirement for producing defensible outputs (Whelan et al., 2023).

This thesis formalizes co-development by using semi-structured interviews and community engagement to inform constraint selection, constraint calibration, and weight assignment, and by explicitly combining thematic evidence with model diagnostics to guide revisions. This approach improves modelling in three ways. First, it improves feasibility validity: only community members and practitioners can reliably specify constraints linked to harvesting frequency, seasonal access, household acceptability, and culturally appropriate substitutions. Second, it improves interpretability by anchoring results in local realities, enabling discussion of which pathways are actionable versus structurally constrained. Third, it aligns outputs with food sovereignty priorities by reducing the risk that models recommend diets that inadvertently displace cultural practices or ignore governance constraints.

Importantly, this thesis advances co-development beyond “consultation” by embedding it in a transparent, repeatable workflow: a shared framework is implemented across communities, while differences in outputs are traced to necessary community-specific parameterization rather than to fundamentally different model structures.

Finally, the findings point to the need for multi-objective optimization in dietary modelling, particularly in remote and climate-sensitive contexts where diets are not governed by a single goal. In this thesis, feasibility is shaped by the simultaneous pursuit of nutrient sufficiency, affordability, contaminant risk (MeHg), cultural food priorities, and ecological availability constraints. Single-objective models can obscure these tensions by collapsing competing goals into one priority (often cost or minimal deviation), producing solutions that are mathematically efficient but socially misaligned. By contrast, multi-objective structures (make the “price of adequacy” visible, identifying which nutrients are structurally expensive, which constraints repeatedly bind, and where upstream interventions must expand the feasible food set rather than expecting further substitution within an unchanged system.

Overall, the novelty is not any single modelling component in isolation, but the integration of: (i) climate-linked ecological limits that reshape feasible diets, (ii) community initiatives represented as actionable structural interventions, and (iii) a co-developed, comparative framework that makes explicit why feasibility and optimal pathways differ across communities.

5.5 Model Limitations

This study uses multi-objective diet optimization to examine nutrient adequacy, affordability, and climate-related changes in traditional food availability. While the modelling

framework is well-suited to testing feasible dietary solutions under explicit constraints, several limitations affect how results should be interpreted, particularly in the adaptation scenarios.

A central feature of the adaptation scenarios is the use of projected fish stock changes to adjust the feasible upper bounds of seafood items. This approach improves realism relative to unconstrained models, but it also introduces important uncertainty. Fish projections are inherently uncertain because they depend on climate pathways, ecological dynamics, fisheries management decisions, and socio-economic feedbacks that are difficult to predict to 2050 (Marushka et al., 2019b). In addition, translating ecological projections into dietary "availability multipliers" assumes that changes in abundance map proportionally to changes in community-level access and consumption potential. In practice, access to seafood is mediated by gear, fuel costs, processing capacity, harvesting time, local ecological knowledge, weather windows, and regulations. Therefore, the adaptation outputs should be interpreted as scenario-based representations of supply-side pressure on traditional food feasibility, rather than precise forecasts of future harvestable or consumable quantities.

MeHg exposure results were evaluated using mean body weights for males and females observed across the two communities. This choice supports comparability and avoids applying arbitrary weights, but it also limits individual-level interpretation. MeHg guidance values are weight-dependent, meaning that a single mean body weight will understate risk for individuals with lower body mass and overstate safety for those with higher body mass. As a result, "safe" exposure determinations in this thesis should be read as population-average approximations rather than protective thresholds for every individual. This limitation is especially relevant because dietary exposure can vary substantially across households depending on species preference, portion sizes, and seasonality of consumption.

To operationalize recommended intakes for MUFA, PUFA, TSAT, and TSUGARS, this study used the lower end of recommended ranges. This decision is defensible as a conservative modelling choice because it reduces the risk of recommending diets that overshoot upper bounds.

Traditional food costs were represented using available nation distribution costs but harvesting-related costs were not indexed for inflation over time. This matters most for the 2050 scenarios: fuel, equipment, maintenance, and time costs are likely to increase, and the real cost of harvesting could shift nonlinearly under climate impacts (e.g., longer travel distances, more weather-related downtime). Not incorporating inflation and future cost escalation may therefore understate the economic burden associated with maintaining or increasing traditional food intake in adaptation solutions.

Furthermore, a large increase in game meat consumption was identified as a solution to the decrease in projected fish stock. However, it is important to acknowledge the barriers to accessing game meat that the model cannot fully capture. In practice, access to game meat is influenced by high costs and restrictions associated with equipment, transportation and firearm licensing (Shafiee et al., 2022). As well as, time constraints related to wage-based employment can further restrict participation in harvesting activities, particularly for households with limited flexibility (Shafiee et al., 2022). As a result, it is important to not the model may overestimate the feasibility of increasing game meat consumption. These limitations highlight the importance of interpreting model outputs as indicative of potential dietary pathways under specified assumptions and conditions.

A major structural limitation is that the model cannot fully capture governance realities that shape food access, particularly for traditional foods. Broader Indigenous governance and jurisdictional constraints can materially limit the ability of communities to harvest, distribute,

and utilize foods even when ecological abundance exists. Similarly, market food access is affected by policy decisions that influence food prices and availability in remote settings. Since these constraints are complex, dynamic, and often political, they were not explicitly modelled beyond feasibility bounds. As a result, optimized diets should be interpreted as nutritionally and mathematically feasible under assumed access conditions. This is particularly important when the model "solves" nutrient adequacy through increased seafood intake: ecological availability does not guarantee legal, practical, or equitable access.

5.6 Concluding Remarks

In summary, the community implications of the modelling results extend beyond identifying "better" diets and instead clarify which parts of the local food system most strongly determine nutritional feasibility**.** Across scenarios, the model consistently points to traditional foods as high-leverage pathways for improving nutrient adequacy, reinforcing that food sovereignty and harvesting capacity are not only cultural priorities but also core determinants of nutritional resilience.

Equally important, several persistent nutrient gaps (notably vitamin D and, in some scenarios, fibre and folate) indicate that optimization within the current feasible food space cannot fully resolve structural access barriers. This underscores that community nutrition vulnerability is often less about individual choice and more about the constraints created by cost, and the limited availability of nutrient-dense market foods. Where optimized diets become more expensive or require large increases in diet volume, the results also highlight the importance of practical implementation supports, like, community freezers, and nation distribution programs.

Finally, integrating fish stock availability into the adaptation scenarios strengthens the relevance of the results by anchoring them to ecological realities. It demonstrates that climate

impacts can alter dietary adequacy indirectly by reshaping the feasible set of traditional seafood options, and that adaptation planning must therefore connect nutrition goals with fisheries governance, access rights, and community-led decision-making. Taken together, these findings support a community-centered approach to dietary adaptation: strengthening traditional food systems, addressing structural barriers to nutrient-rich market foods, and using modelling as a decision-support tool to target interventions where they will have the greatest nutritional and cultural return.

5.7 References

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Appendices

6.1 Male Results for Skidegate

This section summarizes optimal diet model outputs for men and interprets results across (i) nutrient adequacy, (ii) food-group composition, and (iii) affordability, with an emphasis on how model constraints shift diets relative to the observed baseline. Results are presented as baseline diet versus present optimal diet, and projected diet (2050) versus adaptation optimal diet and then these models are compared.

6.1.1 Food group and nutrient analysis for Skidegate males

6.1.2 Baseline and Optimal model comparison

Table 31 Comparison of baseline and optimal models for Skidegate males

Metric	Baseline	Optimal	Change	Percent change
Total energy (kcal/day)	1732.92	2000	267.09	15.4
Total diet cost ($/day)	13.58	19.26	5.69	41.9
MeHg exposure (ng/day)	2551.85	10206.8	7654.96	300
TF intake (g/day)	86.87	610.12	523.25	602.3
TF energy (kcal/day)	141.68	537.77	396.1	279.6
TF share of total energy (%)	8.18	26.89	18.71	228.9
MF intake (g/day)	1087.59	1675.14	587.54	54
MF energy (kcal/day)	1591.24	1462.23	-129.01	-8.1
MF share of total energy (%)	91.82	73.11	-18.71	-20.4
Total diet weight (g/day)	1174.46	2285.25	1110.79	94.6

Total energy rises from 1 732.92 to 2 000 kcal/day (+15.4%). This indicates that the baseline pattern is energy-deficient relative to the model constraint and that meeting recommended energy intake required expanding the feasible diet rather than redistributing calories within the same total intake. Consistent with this, total diet weight nearly doubles, increasing from 1174.46 to 2285.25 g/day (+94.6%). Importantly, this is not a pure “swap”

between MF and TF; both increase in grams (MF +54%; TF +602%), but TF expands much more quickly, indicating that the optimal solution broadens overall intake.

The TF shift is the defining outcome of the optimization. TF intake increases from 86.87 to 610.12 g/day (+602%), and TF energy increases from 141.68 to 537.77 kcal/day (+279.6%). As a result, TF's share of total energy increases from 8.18% to 26.89% (+18.71 percentage points; +228.9%). This scale of change suggests that, under the current constraint set, the model identifies TF as a high-leverage pathway for meeting energy and nutrient targets. At the same time, MF energy declines slightly (−8.1%) even as MF grams increase (+54%), implying that the MF basket shifts toward lower–energy-density items (e.g., higher water content, more bulk per calorie) while calories are reallocated toward TF.

Affordability changes in the opposite direction. Total diet cost increases from $13.58 to $19.26/day (+41.9%). This indicates that meeting the energy constraint and expanding diet mass, particularly through increased TF quantities as represented in the costing assumptions, requires a higher daily expenditure in the optimized basket. In practical terms, the model demonstrates nutritional feasibility, but the cost increase signals a likely implementation barrier creating a further importance expanding nation distribution.

The most consequential risk trade-off in this scenario is contaminant exposure: modeled MeHg exposure increases from 2 551.85 to 10 206.8 ng/day (+300%). This increase is consistent with the large rise in TF (and specifically TF energy share). However, this is at the MeHg safe intake level for males.

Table 32 Food group redistribution for baseline and optimal diets for Skidegate males

Food group	Baseline (g/day)	Optimal (g/day)	Change (g/day)	Percent change
Dairy	110.03	119.75	9.71	8.80%
Added fat	5.29	1.83	-3.46	-65.40%
Animal Protein	42.02	80.88	38.86	92.50%
Plant protein	6.93	36.58	29.65	427.70%
Fruit	76.31	109.87	33.56	44.00%
Vegetables	34.05	41.4	7.36	21.60%
Grain	92.02	145.75	53.73	58.40%
Sweets	26.47	38.15	11.68	44.10%
Salty snacks	6.41	8.23	1.82	28.40%
Mixed foods	187.52	110.82	-76.69	-40.90%
Game	0	75	75	New (from 0)
Fish	86.87	456.41	369.54	425.40%
Berries	0	78.7	78.7	New (from 0)

Figure 20 Food group redistribution for baseline and optimal diets for Skidegate males

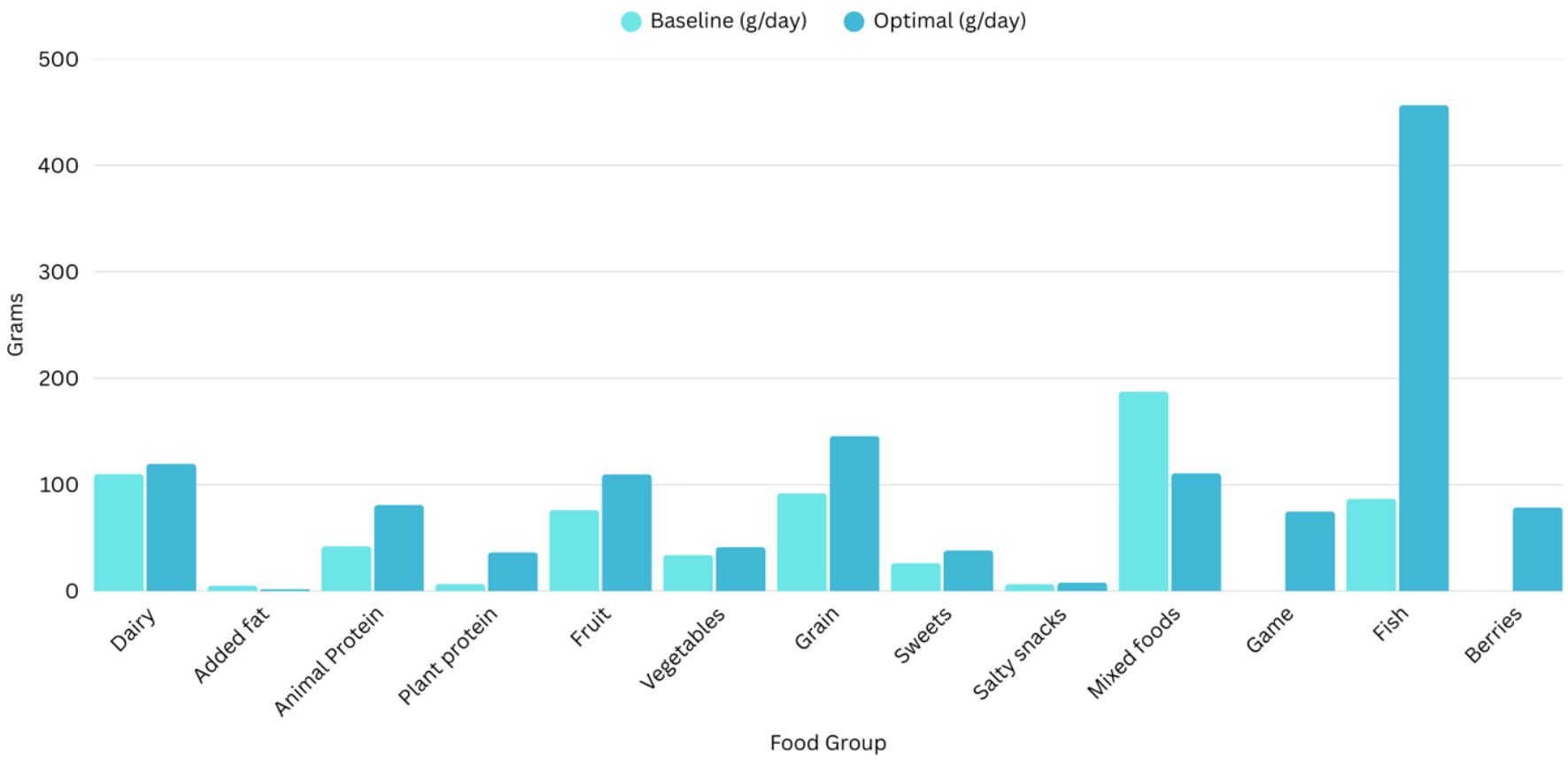


Figure 20 compares mean daily intake (grams per day) across food groups in the observed baseline diet versus the model-derived optimal diet. The optimized solution increases intake of nutrient-dense traditional and market food groups (notably fish, grains, fruit, and protein foods) while reducing reliance on mixed foods, illustrating how the model reallocates consumption patterns to improve nutrient adequacy within feasibility and food-system constraints.

The most prominent change in the optimized diet is the expansion of fish intake from 86.87 g/day in the baseline diet to 456.41 g/day in the optimized diet (+369.54 g/day; +425.4%). This single shift dominates the pattern of change and suggests that, within the modeled food environment and constraints, fish offers a uniquely efficient pathway for improving nutrient adequacy without large trade-offs in cost or feasibility. In parallel, the optimized diet introduces traditional food groups that were absent from the baseline pattern, including game (0 → 75.0 g/day) and berries (0 → 78.7 g/day). While these increases reflect model feasibility rather than observed consumption, they highlight that culturally relevant foods can play a meaningful role in achieving adequacy when supply and access constraints allow their inclusion.

Beyond seafood, the model increases both animal protein (42.02 → 80.88 g/day; +92.5%) and plant protein (6.93 → 36.58 g/day; +427.7%), indicating a broader shift toward protein-dense foods. Grain intake also rises substantially (92.02 → 145.75 g/day; +58.4%), consistent with the need to support energy balance while improving the nutrient-to-cost ratio of the diet. Fruit and vegetables increase modestly (+44.0% and +21.6%, respectively), suggesting that while plant foods contribute to micronutrient adequacy, the dominant lever in this solution is the substitution of mixed foods with more nutrient-dense traditional and core food groups.

Notably, mixed foods decrease from 187.52 to 110.82 g/day (−76.69 g/day; −40.9%), and added fats decline by 65.4%. This pattern is consistent with an optimized solution that reduces reliance on energy-dense but micronutrient-poor items and reallocates intake toward foods that simultaneously support macro- and micronutrient constraints. Smaller increases in sweets and salty snacks reflect the model's balancing of palatability and energy constraints rather than a nutritional target; these categories remain relatively minor in absolute grams compared to the major shifts in fish, grains, and proteins.

Table 33 Nutrient distribution for the baseline and optimal diets for Skidegate males

Nutrient	Unit	Optimal amount	Baseline % of RDA	Optimal % of RDA	Hard constraint	Soft constraint
Calcium	mg/day	1.00e3	49.8	100	0	1
Total carbohydrate	g/day	173	130	173	1	0
Cholesterol	mg/day	200	97.2	100	1	0
Copper	mg/day	1.56	115	174	1	0
Total fat	g/day	71.1	130	158	1	0
Iron	mg/day	18.4	78.4	102	1	0
Dietary fibre	g/day	15.9	28.7	41.9	1	0
Folate (Vitamin B9)	µg/day	356	48.7	89.0	0	1
Potassium	mg/day	3.40e3	53.9	100	1	0
Linoleic acid (Omega-6 fatty acid)	g/day	1.40	8.81	11.6	0	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	1.06	160	66.7	1	0
Magnesium	mg/day	427	44.1	102	1	0
Monounsaturated fat	g/day	23.8	64.4	72.0	1	0
Niacin (Vitamin B3)	mg/day	29.9	195	214	1	0
Phosphorus	mg/day	1.54e3	148	220	1	0
Protein	g/day	109	193	236	1	0
Polyunsaturated fat	g/day	8.24	84.6	74.9	1	0
Riboflavin (Vitamin B2)	mg/day	1.96	97.2	151	1	0
Thiamin (Vitamin B1)	mg/day	1.11	84.3	92.4	1	0
Total saturated fat	g/day	28.2	168	141	1	0
Total sugars	g/day	58.7	78.5	117	1	0
Vitamin A	µg RAE/day	900	54.2	100	1	0
Vitamin B12	µg/day	3.63	206	151	1	0
Vitamin B6	mg/day	2.03	104	156	1	0
Vitamin C	mg/day	115	78.3	153	1	0
Vitamin D	µg/day	12.0	69.8	80.0	0	1
Zinc	mg/day	13.6	88.1	123	1	0
Sodium	mg/day	1.50e3	124	100	1	0

Figure 21 Nutrient distribution for the baseline and optimal diets for Skidegate males

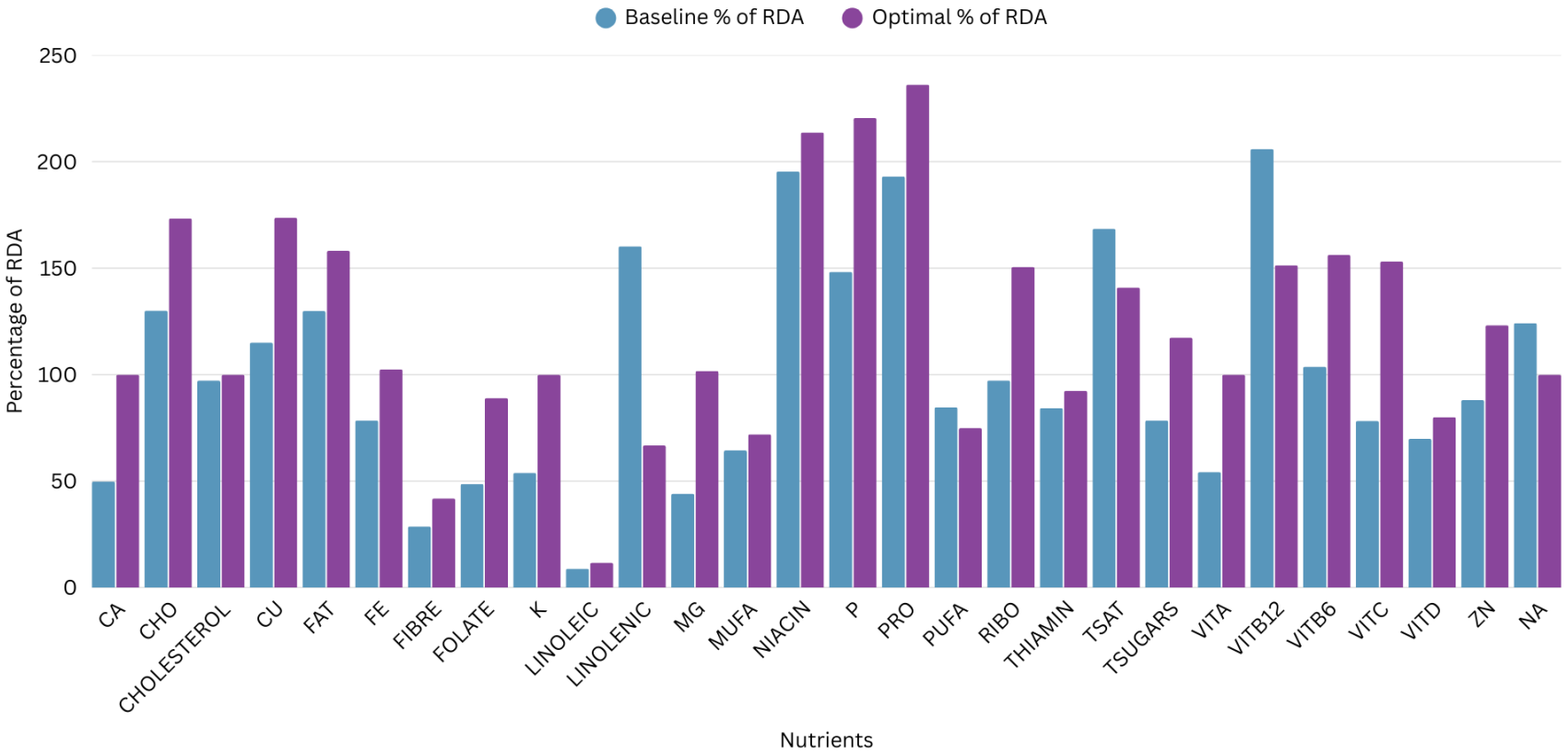


Figure 21 Comparison of baseline and optimal diet nutrient adequacy, shown as the percentage of the Recommended Dietary Allowance (RDA) achieved for each nutrient. Blue bars represent the baseline diet and purple bars represent the optimized diet; values above 100% indicate intake exceeding the RDA.
[12]

[12] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The nutrient results demonstrate that the baseline diet is most constrained by nutrients commonly challenging to achieve under cost and feasibility limitations, particularly calcium, potassium, magnesium, fibre, and folate. The optimized solution substantially improves adequacy for calcium (49.8% → ~100% RDA), potassium (53.9% → 100% RDA), and magnesium (44.1% → 101.7% RDA), indicating that the modelled dietary adjustments effectively address key micronutrient gaps. Iron and zinc also improve, with iron reaching adequacy (78.4% → 102.5% RDA) and zinc increasing from 88.1% to 123.2% RDA. However, some nutrients remain below full adequacy even in the optimized diet. Fibre increases from 28.7% to 41.9% RDA but remains substantially low, suggesting that within the feasible food set and the optimization priorities, achieving fibre adequacy would require larger departures from baseline patterns, a different weighting structure, or explicit food-group constraints that increase high-fibre foods. Folate improves from 48.7% to 89.0% RDA but remains below 100%, consistent with its classification as a soft constraint and reflecting its sensitivity to diet structure and available food options. Vitamin D remains below 100% (69.8% → 80.0%) and is also treated as a soft constraint, highlighting that adequacy for vitamin D is difficult to achieve through food substitution alone in many dietary contexts.

At the same time, the optimized diet reduces sodium from 124.1% of the target down to ~100%, indicating a meaningful improvement in alignment with recommended intake levels without compromising core adequacy constraints. This reduction likely reflects the decline in mixed foods and the substitution toward foods with lower sodium density.

6.1.3 Predicted and Adaptation diet model comparison for Skidegate males

Table 34 Comparison of predicted and adaptation models for Skidegate males

Metric	Predicted	Adaptation	Change	Percent change
Total energy (kcal/day)	1 732.92	2,900.47	1 167.55	67.40%
Total diet cost ($/day)	13.58	20.63	7.05	51.90%
MeHg exposure (ng/day)	2 551.85	2 543.19	-8.66	-0.30%
TF intake (g/day)	86.87	563.02	476.15	548.10%
TF energy (kcal/day)	141.68	579.67	437.99	309.10%
TF share of total energy (%)	8.18	19.99	11.81	144.40%
MF intake (g/day)	1 087.59	1,227.43	139.83	12.90%
MF energy (kcal/day)	1 591.24	2,320.80	729.56	45.80%
MF share of total energy (%)	91.82	80.01	-11.81	-12.90%
Total diet weight (g/day)	1 174.46	1,790.45	615.99	52.40%

The adaptation scenario produced a diet profile with changes concentrated in traditional foods, especially seafood, and accompanying improvements in several nutrients that were limiting under the predicted diet. Overall, the adaptation diet increased total energy from 1 732.92 to 2 900.47 kcal/day (+67.4%) and increased total diet cost from $13.58 to $20.63/day (+51.9%). Importantly, this higher energy intake moves the modeled diet from a clearly energy-insufficient level, below what is typically recommended for adult males, into a range that is broadly consistent with recommended daily energy needs for many men. In practical terms, the adaptation scenario therefore represents not only a more nutrient-adequate pattern, but also a more physiologically realistic diet in terms of total energy provision.

Despite the substantially larger diet and higher traditional food intake, MeHg exposure was essentially unchanged (2 551.85 to 2 543.19 ng/day; −0.3%). This exposure falls well within the recommended allowable intake of 0.1 ug/kg body weight/day. Remaining on the conservative side and using a 70kg male would mean the exposure amount would be 0.036ug/kg/day, well below the threshold. This stability is important: it indicates that the model was able to scale up

dietary intake and shift food-group composition, particularly by increasing fish and other traditional foods, without meaningfully increasing contaminant burden. Without a parallel rise in MeHg risk, is due to the redistributing of seafood choices toward lower-MeHg options and balancing increases in traditional foods with reductions in other contributors. This finding strengthens the feasibility of the adaptation diet as a realistic strategy under climate-constrained conditions.

Table 35 Food group distribution for predicted and adaptation models for Skidegate males

Food group	Predicted (g/day)	Adaptation (g/day)	Change (g/day)	Percent change
Dairy	110.03	119.75	9.71	8.80%
Added fat	5.29	1.83	-3.46	-65.40%
Animal Protein	42.02	80.88	38.86	92.50%
Plant protein	6.93	36.58	29.65	427.70%
Fruit	76.31	109.87	33.56	44.00%
Vegetables	34.05	41.4	7.36	21.60%
Grain	92.02	145.75	53.73	58.40%
Sweets	26.47	38.15	11.68	44.10%
Salty snacks	6.41	8.23	1.82	28.40%
Mixed foods	187.52	110.82	-76.69	-40.90%
Game	0	75	75	New (from 0)
Fish	86.87	456.41	369.54	425.40%
Berries	0	78.7	78.7	New (from 0)

Figure 22 Food group distribution for predicted and adaptation models for Skidegate males

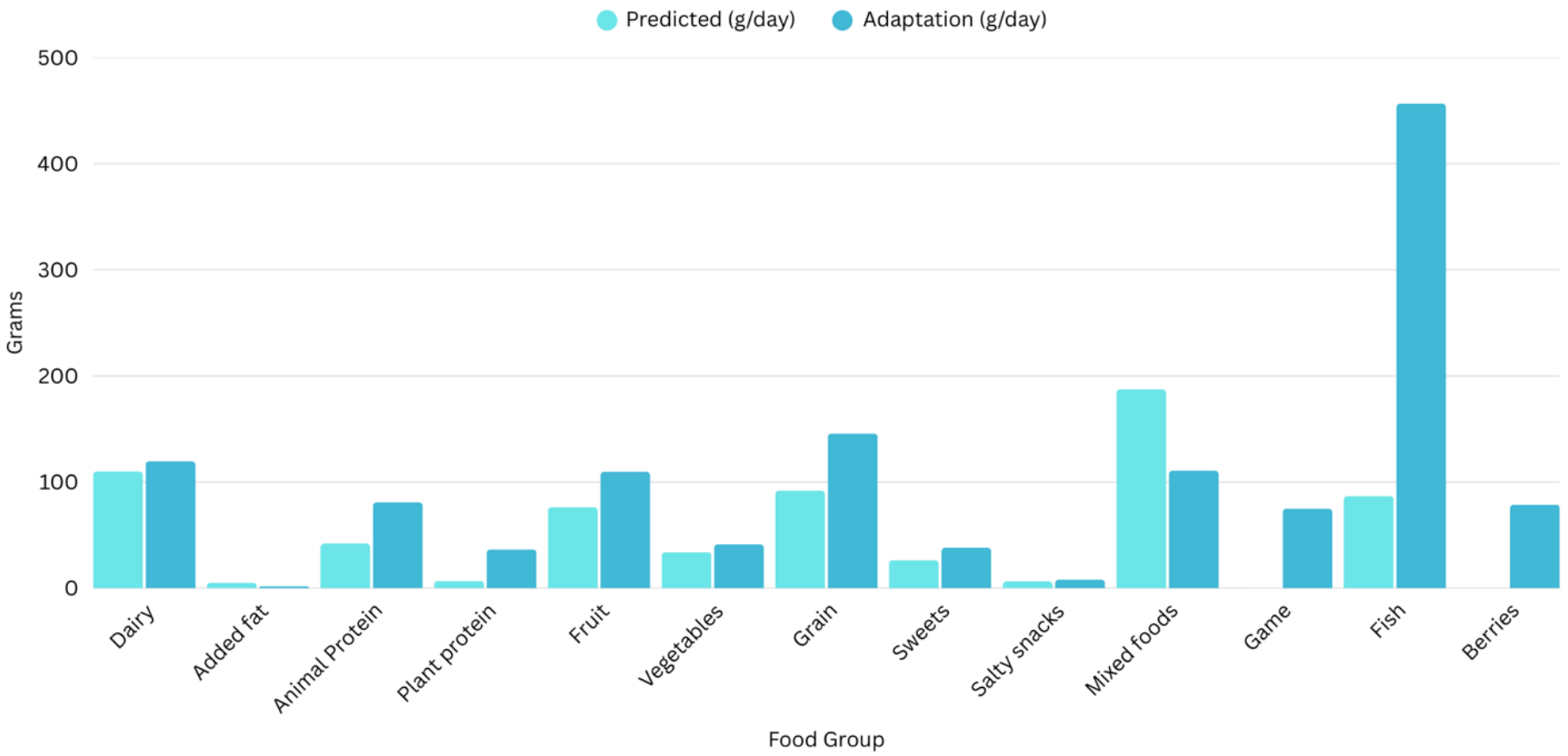


Figure 22 Comparison of predicted baseline and adaptation scenario daily food-group consumption, expressed in grams per day (g/day). Bars show changes in intake across major food groups, highlighting shifts in dietary composition under the adaptation model.

The most prominent structural change was the increase of TF. TF intake increased more than six-fold (86.87 to 563.02 g/day; +548.1%), and TF energy increased from 141.68 to 579.67 kcal/day (+309.1%). As a result, the TF share of total energy rose from 8.18% to 19.99% (+11.81 percentage points), while the MF share decreased from 91.82% to 80.01%. Importantly, the adaptation diet does not represent a simple substitution of market foods with traditional foods. While traditional food intake increased sharply (+548% by grams), MF intake also rose modestly (+12.9%). As a result, total diet weight increased by 52.4% (1,174.46 to 1,790.45 g/day). This indicates that the adaptation solution primarily expanded the feasible dietary space, by enabling greater overall intake and higher availability of nutrient-dense foods, rather than merely reallocating foods within a fixed diet volume.

Food group results show that the adaptation scenario rebalanced the diet away from mixed foods and toward whole-food groups that more directly supply limiting micronutrients. Mixed foods decreased by 40.9% (187.52 to 110.82 g/day), while fish increased by 425.4% (86.87 to 456.41 g/day). The model also introduced new or near-zero baseline categories, game (0 to 75 g/day) and berries (0 to 78.7 g/day), suggesting that, under the adaptation constraints, these culturally relevant foods became important "nutrient carriers" within the feasible solution. In parallel, moderate increases occurred across plant protein (+427.7%), grains (+58.4%), fruit (+44.0%), vegetables (+21.6%), and animal protein (+92.5%), while added fat fell by 65.4%. Taken together, these shifts are consistent with an optimization outcome that is meeting nutrient targets by moving toward nutrient-dense core food groups and away from energy-dense, mixed dishes.

Fish stock availability influences the model by changing the feasible upper bounds for seafood subgroups under future scenarios. In practical terms, projected abundance changes under

RCP 8.5 constrain which seafoods can scale up in the adaptation diet and which cannot. Foods projected to decline should face tighter caps, limiting the solver's ability to rely on them to close nutrient gaps. Conversely, foods projected to remain stable or increase (e.g., some groundfish categories) can be selected at higher levels, making them more available "levers" for meeting protein, iron, zinc, and B-vitamin needs.

This mechanism helps explain why the adaptation diet shows a very large increase in total fish grams (+425.4%) while MeHg exposure remains flat: the feasible set is not "more fish of any type," but rather "more of the fish that remain available." When availability-adjusted bounds are applied, the solver is steered toward seafood options that (i) are permitted by projected stock trajectories and (ii) deliver nutrients efficiently without violating contaminant and cost constraints. In other words, fish stock availability acts as a supply-side filter that reshapes the set of nutritionally efficient solutions, preventing adaptation pathways that depend on declining species and encouraging those that are both nutritionally effective and ecologically plausible.

Table 36 Nutrient distribution of predicted and adaptation models for Skidegate Males

Nutrient	Unit	Adaptation amount	Predicted % of RDA	Adaptation % of RDA	Hard Constraint	Soft Constraint
Calcium	mg/day	1.00e3	49.8	100	0	1
Total carbohydrate	g/day	173	130	173	1	0
Cholesterol	mg/day	200	97.2	100	1	0
Copper	mg/day	1.56	115	174	1	0
Total fat	g/day	71.1	130	158	1	0
Iron	mg/day	18.4	78.4	102	1	0
Dietary fibre	g/day	15.9	28.7	41.9	1	0
Folate (Vitamin B9)	µg/day	356	48.7	89.0	0	1
Potassium	mg/day	3.40e3	53.9	100	1	0
Linoleic acid (Omega-6 fatty acid)	g/day	1.40	8.81	11.6	0	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	1.06	160	66.7	1	0
Magnesium	mg/day	427	44.1	102	1	0
Monounsaturated fat	g/day	23.8	64.4	72.0	1	0
Niacin (Vitamin B3)	mg/day	29.9	195	214	1	0
Phosphorus	mg/day	1.54e3	148	220	1	0
Protein	g/day	109	193	236	1	0
Polyunsaturated fat	g/day	8.24	84.6	74.9	1	0
Riboflavin (Vitamin B2)	mg/day	1.96	97.2	151	1	0
Thiamin (Vitamin B1)	mg/day	1.11	84.3	92.4	1	0
Total saturated fat	g/day	28.2	168	141	1	0
Total sugars	g/day	58.7	78.5	117	1	0
Vitamin A	µg RAE/day	900	54.2	100	1	0
Vitamin B12	µg/day	3.63	206	151	1	0
Vitamin B6	mg/day	2.03	104	156	1	0
Vitamin C	mg/day	115	78.3	153	1	0
Vitamin D	µg/day	12.0	69.8	80.0	0	1
Zinc	mg/day	13.6	88.1	123	1	0
Sodium	mg/day	1.50e3	124	100	1	0

Figure 23 Nutrient distribution of predicted and adaptation models for Skidegate Males

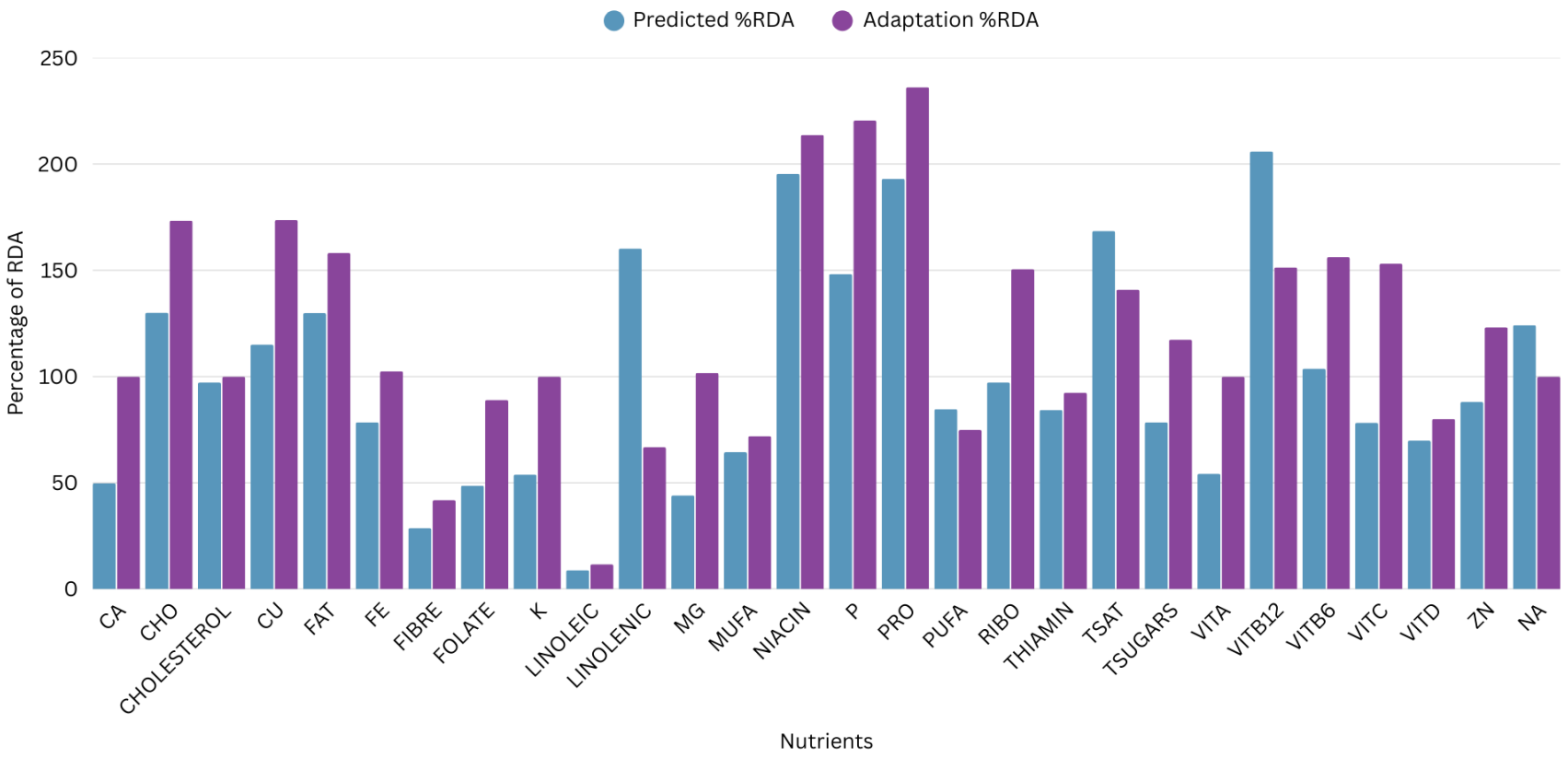


Figure 23 Comparison of predicted baseline and adaptation scenario nutrient adequacy, shown as the percentage of the Recommended Dietary Allowance (RDA) achieved for each nutrient. Blue bars represent predicted baseline intakes and purple bars represent adaptation model results; values above 100% indicate intake exceeding the RDA. [13]

[13] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Under the predicted diet, several key nutrients were well below requirements, notably calcium (49.8% RDA), potassium (53.9% RDA), magnesium (44.1% RDA), folate (48.7% RDA), and vitamin A (54.2% RDA). In the adaptation scenario, the model achieved or closely approached adequacy for many of these: calcium increased to ~100% RDA, potassium to 100% RDA, magnesium to 101.7% RDA, and vitamin A to 100% RDA. Iron also moved from inadequacy to adequacy (78.4% to 102.5% RDA). These improvements align directly with the food-group shifts: increase in seafood and game directly yielded a raise in iron, zinc, B vitamins, and high-quality protein; increase in dairy supports calcium; and the rise in fruit/vegetables and berries supports vitamin C and vitamin A, improving both adequacy and iron utilization.

Not all shortfalls were fully resolved. For example, vitamin D remained below adequacy in both scenarios (69.8% to 80.0% RDA), consistent with the common challenge of achieving vitamin D targets through diet alone. Folate improved substantially (48.7% to 89.0% RDA) but remained a soft-constrained nutrient under the model, indicating that meeting folate fully would require additional departures from feasibility, cost, and palatability constraints. Linoleic acid also remained very low (8.8% to 11.6% of RDA), reflecting meeting this target would compromise cost constraints.

Several nutrients exceeded requirements in both scenarios (e.g., protein, phosphorus, niacin, riboflavin, zinc), which is expected in optimization when certain foods efficiently satisfy multiple constraints simultaneously. However, the adaptation pattern is noteworthy because it improved the limiting micronutrients without increasing MeHg exposure.

Collectively, these results suggest that, under climate-constrained conditions, nutrition vulnerability in Skidegate is less about the impossibility of meeting nutrient needs and more

about how the feasible diet space shifts when ecological limits are made explicit. The adaptation scenario demonstrates that nutrient adequacy for key shortfall nutrients (calcium, potassium, magnesium, iron, vitamin A) can be achieved when the model is allowed to increase traditional foods, especially seafood, within availability-adjusted constraints. At the same time, the higher total cost and persistent shortfalls in vitamin D, folate, and essential fatty acids point to the limits of dietary adaptation alone and highlight where complementary strategies may be required.

Most importantly, incorporating fish stock availability makes the adaptation solutions interpretable and defensible: the model is no longer recommending nutritionally ideal diets that depend on seafood increases that are ecologically implausible by 2050 RCP 8.5. Instead, it identifies nutrient-adequate pathways that remain consistent with projected marine resource constraints, providing a clearer basis for community planning and policy discussions about which traditional foods can realistically anchor future dietary adequacy.

6.1.4 Cost analysis

6.1.4.1 Baseline and optimal diet cost comparison for Skidegate males

Table 37 Cost per 100% nutrient RDA analysis for baseline and optimal models for Skidegate males

Nutrient	Baseline cost per 100% RDA ($)	Optimal cost per 100% RDA ($)	Change in cost per 100% RDA ($)
Protein	14.4	7.48	-6.89
Total fat	13.7	10.3	-3.37
Total carbohydrate	13.7	9.43	-4.26
Dietary fibre	62.0	39.0	-23.0
Calcium	35.8	16.3	-19.4
Iron	14.3	6.38	-7.87
Magnesium	40.4	16.1	-24.3
Phosphorus	12.0	7.41	-4.59
Potassium	33.0	16.3	-16.7
Sodium	14.3	16.3	2.00
Zinc	20.2	13.3	-6.95
Copper	28.1	11.7	-16.4
Vitamin A	32.8	16.3	-16.5
Vitamin D	25.5	20.4	-5.06
Vitamin C	59.5	25.2	-34.3
Riboflavin (Vitamin B2)	18.3	10.9	-7.45
Niacin (Vitamin B3)	13.7	8.32	-5.40
Folate (Vitamin B9)	58.5	14.6	-43.9
Total saturated fat	8.88	6.75	-2.13
Linoleic acid (Omega-6 fatty acid)	189	173	-15.7
Alpha-linolenic acid (Omega-3 fatty acid)	11.1	24.5	13.4
Monounsaturated fat	27.6	22.7	-4.94
Polyunsaturated fat	21.0	21.8	0.792
Total sugars	22.7	13.9	-8.76
Cholesterol	22.2	11.9	-10.3
Thiamin (Vitamin B1)	21.1	17.7	-3.44
Vitamin B6	17.2	10.5	-6.69
Vitamin B12	5.83	5.33	-0.497

Figure 24 Cost per 100% nutrient RDA analysis for baseline and optimal models for Skidegate males

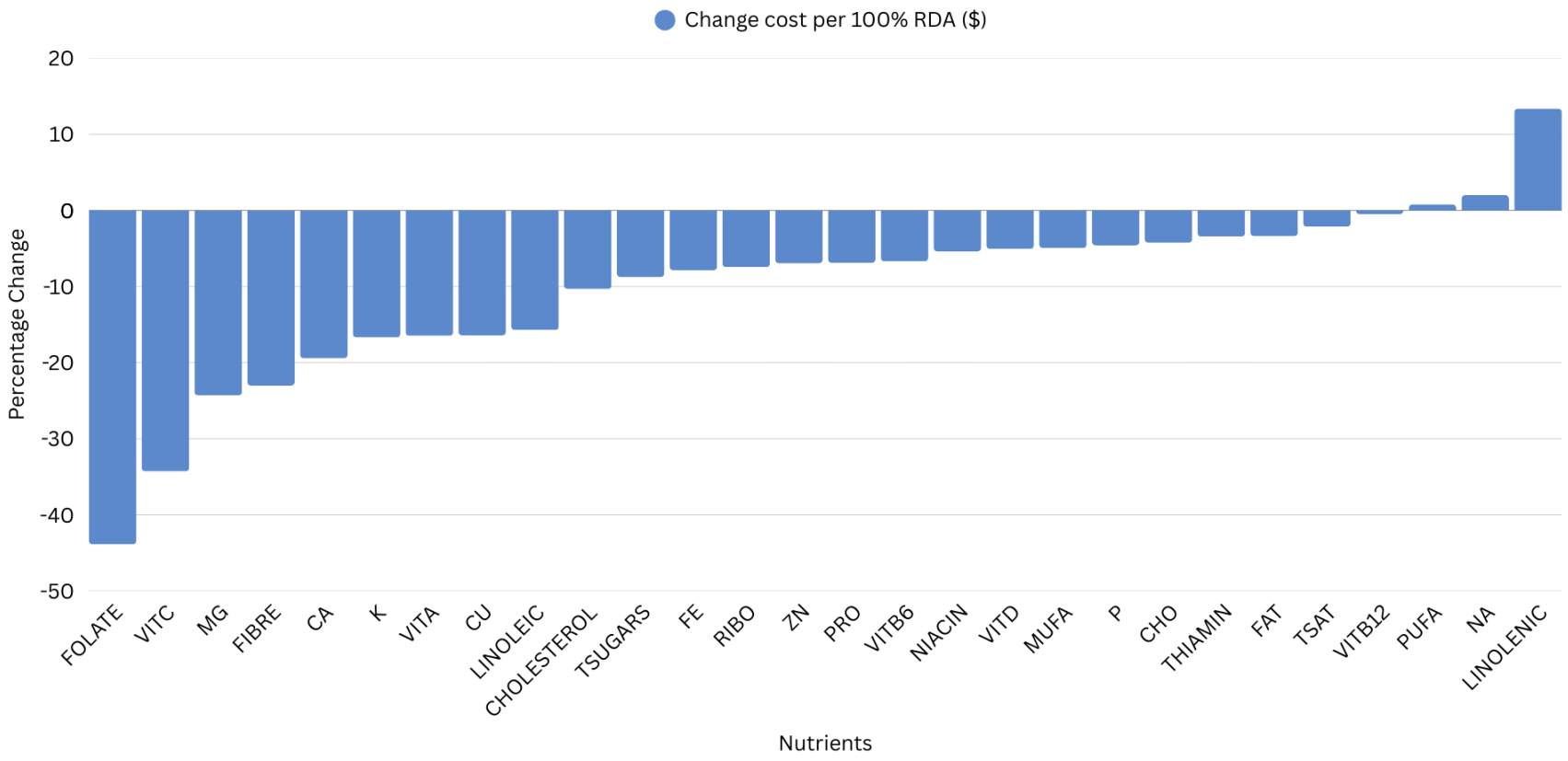


Figure 24 Change in cost per 100% RDA ($) between the baseline and adaptation diets across nutrients. Negative values indicate nutrients that became less expensive to meet under the adaptation scenario, while positive values indicate nutrients that became more expensive.

14

[14] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Changes in cost per 100% RDA indicate that the optimized diet not only improves adequacy but does so with greater economic efficiency for most nutrients. The largest reductions occur for folate (−$43.88), vitamin C (−$34.29), magnesium (−$24.32), fibre (−$23.02), and calcium (−$19.42). These improvements align with the increased intake of nutrient-dense food groups (fish, grains, fruit, and protein foods) and the reduction of mixed foods, which tend to contribute calories at a relatively higher cost per unit of micronutrient gain.

Most nutrients become cheaper to obtain at adequacy thresholds, indicating that the model identifies substitutions that increase nutrient yield without proportionally increasing cost. A small number of nutrients become more expensive in terms of cost-per-100%-RDA, notably linolenic acid (+$13.38), suggesting that the optimized diet meets other constraints in ways that reduce the efficiency of achieving omega-3-related targets. Sodium shows a small increase (+$2.00), which is consistent with the solver reducing sodium closer to its target; as intake approaches the threshold, the ratio-based cost per 100%metric can increase even when the health implication is favorable.

6.1.4.2 Predicted and Adaptation diet model cost analysis for Skidegate males

Table 38 Cost per 100% nutrient RDA analysis for predicted and adaptation models for Skidegate males

Nutrient	Predicted cost per 100% RDA ($)	Adaptation cost per 100% RDA ($)	Change ($)
Folate (Vitamin B9)	58.5	14.6	-43.9
Vitamin C	59.5	25.2	-34.3
Magnesium	40.4	16.1	-24.3
Dietary fibre	62.0	39.0	-23.0
Calcium	35.8	16.3	-19.4
Potassium	33.0	16.3	-16.7
Vitamin A	32.8	16.3	-16.5
Copper	28.1	11.7	-16.4
Linoleic acid (Omega-6 fatty acid)	189	173	-15.7
Cholesterol	22.2	11.9	-10.3
Total sugars	22.7	13.9	-8.76
Iron	14.3	6.38	-7.87
Riboflavin (Vitamin B2)	18.3	10.9	-7.45
Zinc	20.2	13.3	-6.95
Protein	14.4	7.48	-6.89
Vitamin B6	17.2	10.5	-6.69
Niacin (Vitamin B3)	13.7	8.32	-5.40
Vitamin D	25.5	20.4	-5.06
Monounsaturated fat	27.6	22.7	-4.94
Phosphorus	12.0	7.41	-4.59
Total carbohydrate	13.7	9.43	-4.26
Thiamin (Vitamin B1)	21.1	17.7	-3.44
Total fat	13.7	10.3	-3.37
Total saturated fat	8.88	6.75	-2.13
Vitamin B12	5.83	5.33	-0.497
Polyunsaturated fat	21.0	21.8	0.792
Sodium	14.3	16.3	2.00
Alpha-linolenic acid (Omega-3 fatty acid)	11.1	24.5	13.4

Figure 25 Cost per 100% nutrient RDA analysis for predicted and adaptation models for Skidegate males

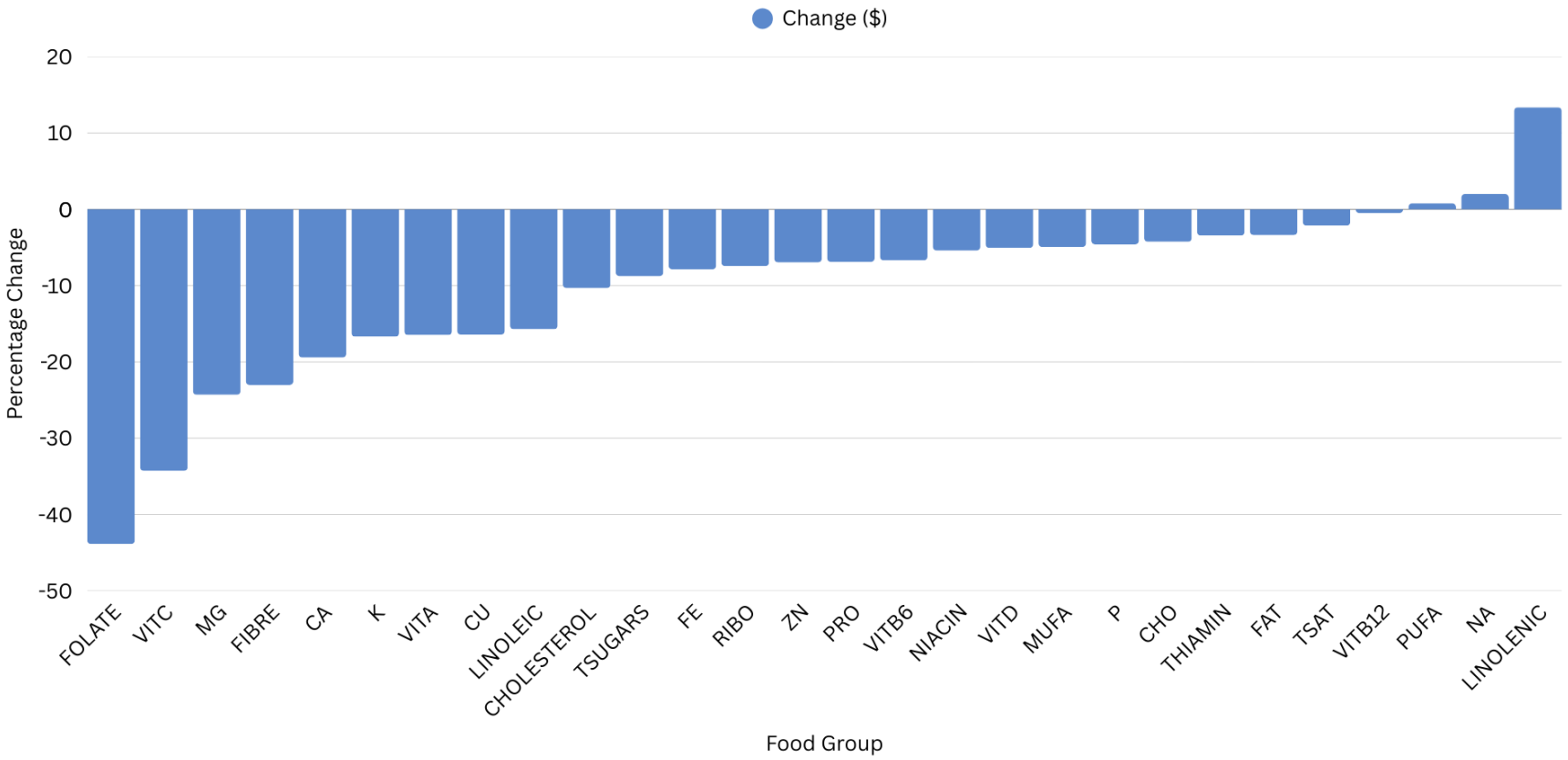


Figure 25 Change in cost ($) per 100% RDA between the predicted baseline and adaptation diets across nutrients. Negative values indicate nutrients that became less expensive to meet under the adaptation scenario, while positive values indicate nutrients that became more expensive.[15]

[15] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Although total daily cost increased in the adaptation diet (+51.9%), the cost efficiency of meeting several nutrient requirements improved markedly. The largest decreases in cost per 100% RDA occurred for folate (−$43.88), vitamin C (−$34.29), magnesium (−$24.32), fibre (−$23.02), and calcium (−$19.42). These are precisely the nutrients that were most limiting in the predicted scenario, indicating that the adaptation solution not only increased adequacy but did so more efficiently per unit of requirement. Put differently, the adaptation diet is more "nutrient-dense per dollar" for key shortfall nutrients, even while total spending rises due to the larger overall diet and greater inclusion of traditional foods.

Notably, not all nutrients became cheaper to meet, for instance, sodium increased in cost per 100% target (+$2.00) and linolenic acid increased substantially (+$13.38), meaning that achieving those targets under the adaptation composition required selecting relatively more expensive sources. This reinforces the interpretation that the adaptation diet is a compromise solution shaped by multiple constraints rather than a single-nutrient optimization.

6.1.5 Conclusion

Overall, the male results show that nutritional adequacy for Skidegate can be achieved in the model, but only through large, structurally meaningful shifts in diet composition that introduce clear trade-offs between energy adequacy, affordability, and contaminant risk. Across scenarios, the optimization consistently identifies traditional foodse as the most efficient "lever" for meeting nutrient constraints. This is evident in the baseline versus optimal comparison where TF intake increases more than six-fold (+602%) and TF energy share rises from 8.18% to 26.89%. The optimized diet therefore aligns with food sovereignty priorities by increasing culturally important foods.

Taken together, the male findings support three overarching conclusions. First, meeting energy and micronutrient needs in Skidegate is feasible within the modeled diet space, but the pathway is highly dependent on increased traditional foods, particularly fish. Second, contaminant outcomes are highly sensitive to how seafood is represented: when optimization is unconstrained, nutrient efficiency can drive MeHg upward, whereas under adaptation conditions MeHg can remain stable if seafood availability and selection shift toward lower-risk species. Third, improving diet quality does not require uniform changes across all foods; instead, a small number of high-leverage shifts, greater access to nutrient-dense traditional proteins, limiting mixed/processed foods, and targeted strategies for persistently limiting nutrients (vitamin D, folate, essential fatty acids), appear most consequential for both nutrition and feasibility.

6.2 Male Results for Tla'amin

This section summarizes optimal diet model outputs for men and interprets results across (i) nutrient adequacy, (ii) food-group composition, and (iii) affordability, with an emphasis on how model constraints shift diets relative to the observed baseline. Results are presented as baseline diet versus present optimal diet, and projected diet (2050) versus adaptation.

6.2.1 Food group and nutrient analysis for Tla'amin males

6.2.1.1 Present and optimal model comparison

Table 39 Overall Comparison for the Baseline and Optimal Models for Males in Tla'amin Nation

Metric	Baseline	Optimal	Absolute change	Percentage change
Total energy (kcal/day)	3263.81	3263.81	−0.00	−0.00%
Total diet cost ($/day)	10.48	10.73	0.25	2.39%
MeHg exposure (ng/day)	611.36	611.79	0.43	0.07%
TF intake (g/day)	35.14	256.19	221.06	629.14%
TF energy (kcal/day)	68.4	300	231.59	338.56%
TF share of total energy (%)	2.10%	9.19%	+7.10 pp	+338.56%
MF intake (g/day)	2118.05	1911.39	−206.65	−9.76%
MF energy (kcal/day)	3195.41	2963.81	−231.59	−7.25%
MF share of total energy (%)	97.90%	90.81%	−7.10 pp	−7.25%
Total diet weight (g/day)	2153.18	2167.58	14.4	0.67%

The most important finding is that the optimization achieves a major rebalancing of dietary sources without changing total energy intake (Table 39). Total energy remains identical in both diets (3263.81 kcal/day), indicating that improvements are driven by substitution within a fixed caloric envelope rather than by increasing or restricting total intake.

Despite the large compositional changes, the economic and contaminant impacts are minimal. Total diet cost rises only slightly, from $10.48/day to $10.73/day (+$0.25/day; +2.39%), meaning that the model can improve feasibility and cultural alignment with negligible additional daily cost under present-day price assumptions. Similarly, estimated MeHg exposure is essentially unchanged (611.36 to 611.79 ng/day; +0.07%), showing that the optimized solution increases traditional foods without materially increasing contaminant exposure. This is an important implication for adaptation planning: under the current food environment and constraints, greater traditional food inclusion does not inherently require a MeHg trade-off,

because the model selects traditional foods (or species/amounts) that deliver nutritional benefits while maintaining exposure near baseline.

The dominant structural outcome of optimization is the substantial increase in traditional foods (TF). TF intake increases from 35.14 to 256.19 g/day (+629%), and TF energy increases from 68.4 to 300.0 kcal/day (+339%). As a result, TF's share of total energy rises from 2.10% to 9.19% (+7.10 percentage points). While TF still provides less than 10% of total calories, this shift is meaningful because it represents a large increase of culturally relevant foods within a diet that remains nutritionally feasible and isoenergetic. In practical terms, it suggests that even modest caloric contributions from TF can translate into substantial gram-level inclusion, supporting cultural dietary priorities and potential micronutrient gains.

This increase in TF is accompanied by a clear reduction in market food (MF) reliance, indicating substitution rather than addition. MF intake declines by nearly 10% (−206.65 g/day), MF energy falls by 7.25% (−231.59 kcal/day), and MF's share of energy drops from 97.90% to 90.81% (−7.10 percentage points). Importantly, total diet weight changes very little (+0.67%), meaning the optimized diet is not simply "more food", it is different food: a pattern of replacing a portion of market calories with traditional calories while keeping the overall volume of the diet broadly stable.

Taken together, these results indicate that the present-day optimal solution for Tla'amin males primarily functions as a food-source rebalancing strategy: it substantially increases traditional food intake and reduces market food dependence, while holding calories constant and producing only trivial changes in both cost and MeHg exposure. The implication is that, at least under present conditions, increasing traditional foods appears to be a low-cost, low-risk lever within the model, supporting the interpretation that policies and programs that strengthen access,

harvesting capacity, and distribution of traditional foods would improve diet feasibility and cultural alignment without necessarily worsening affordability.

Table 40 Changes in distribution of the food groups in grams for males in Tla'amin Nation for the Baseline and Optimal models

Food Groups	Baseline (grams)	Optimal (grams)	Change in grams	Percentage change
Dairy	128.91	174.35	45.44	35.25
Fats	14.41	9.59	-4.82	-33.47
Fruit	100.67	185.72	85.05	84.49
Grains	177.24	225.87	48.63	27.44
Mixed foods	282.14	247.23	-34.91	-12.37
Animal protein	151.23	122.84	-28.39	-18.77
Plant protein	9.68	43.88	34.19	353.17
Salty snacks	50.91	0.28	-50.63	-99.45
Sweets	50.34	51.42	1.08	2.15
Berries	0	0.01	0.01	0
Fish	26.14	146.82	120.68	461.75
Game meat	4.55	100	95.45	2099.96
Vegetables	98.68	168.63	69.95	70.89

Figure 26 Changes in distribution of the food groups in grams for males in Tla'amin Nation for the Baseline and Optimal models

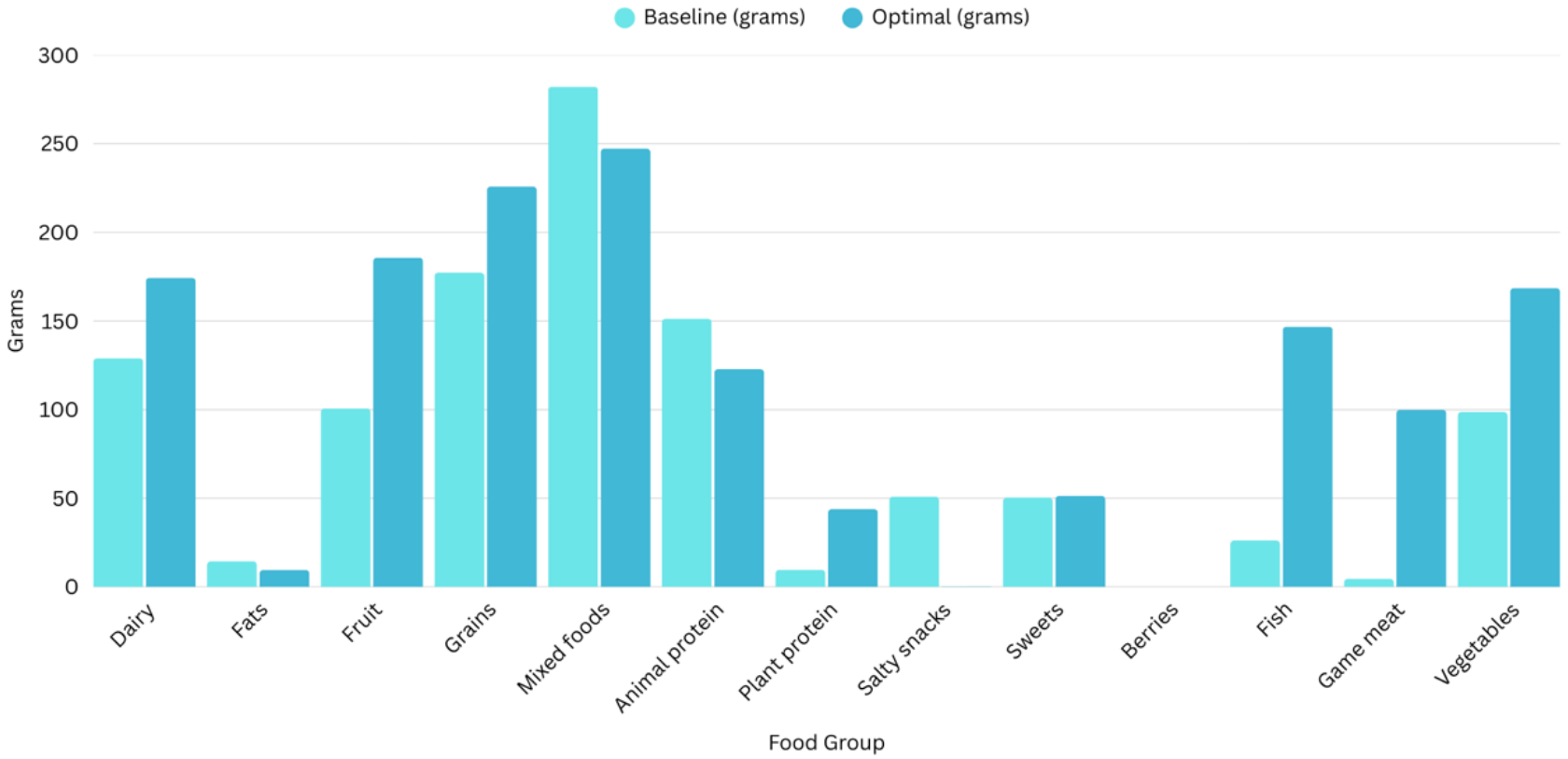


Figure 26 Comparison of baseline and optimized daily food-group consumption, expressed in grams per day. Bars show how the optimized diet shifts intake across food groups relative to the baseline pattern.[16]

[16] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Overall, the optimal solution produces a clear reallocation of grams away from ultra-processed foods and toward nutrient-dense market foods and traditional foods, indicating that improved adequacy is achieved through strategic substitutions within the existing dietary pattern (Table 40; Figure 26).

The model builds a more nutrient-dense base diet by increasing fruit (+84.49%), vegetables (+70.89%), grains (+27.44%), and dairy (+35.25%). These are high-impact shifts because they directly strengthen dietary fibre and a broad suite of vitamins and minerals while supporting feasibility and acceptability. A particularly notable change is the large relative increase in plant protein (9.68 to 43.88 g/day; +353%), indicating that the model uses plant-based protein foods as a flexible "lever" to raise nutrient density and diversify protein sources while reducing reliance on costlier or less nutrient-efficient options.

Traditional foods increase sharply and drive the strongest compositional signal in the optimized diet. Fish rises from 26.14 to 146.82 g/day (+461.75%) and game meat increases from 4.55 to 100.00 g/day (+2099.96%). While these percentage increases are inflated by low baseline values, the absolute changes are substantial (+120.68 g/day fish; +95.45 g/day game meat), showing that the model preferentially uses traditional proteins as efficient pathways to meet nutrient targets. Importantly, this occurs alongside declines in market animal protein (−18.77%) and mixed foods (−12.37%), indicating a substitution away from MF that often bundle sodium, saturated fat, and added sugars, toward culturally relevant foods with higher nutrient yield.

Smaller shifts reinforce this overall pattern. Added fats decrease by one-third (−33.47%), consistent with meeting energy needs through whole-food substitutions rather than relying on energy-dense additions, while sweets remain essentially unchanged (+2.15%). Berries remain

negligible, likely reflecting limited availability or low leverage for meeting binding constraints relative to other foods.

Taken together, these results indicate that the optimal diet for males becomes more nutrient-dense and less reliant on ultra-processed foods, while simultaneously re-centering traditional foods as key contributors to a feasible, nutritionally adequate pattern. From an adaptation and implementation perspective, this points to two practical levers: i) improving consistent access to affordable produce, grains, dairy, and plant proteins and ii) strengthening traditional food harvesting, distribution, and stewardship systems since the model repeatedly identifies fish and game as high-value pathways for adequacy and cultural alignment.

Table 41 Changes in distribution of the nutrients for males in Tla'amin Nation for the baseline and optimal models

Nutrient	Unit	Optimal	Baseline % of RDA	Optimal % of RDA	Hard constraint	Soft constraint	Optimal below 100% RDA
Calcium	mg/day	1.00e3	70.2	100	0	1	0
Total carbohydrate	g/day	198	254	198	1	0	0
Cholesterol	mg/day	241	104	121	1	0	0
Copper	µg/day	1.22e3	113	135	1	0	1
Total fat	g/day	94.9	227	211	1	0	0
Iron	mg/day	22.4	204	279	1	0	0
Dietary fibre	g/day	21.7	50.7	57.1	1	0	1
Folate (Vitamin B9)	µg/day	295	56.5	73.8	0	1	1
Potassium	mg/day	3.40e3	90.2	100	1	0	0
Linoleic acid (Omega-6 fatty acid)	g/day	1.01	6.01	5.93	0	1	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	2.44	236	152	1	0	0
Magnesium	mg/day	350	74.5	83.4	1	0	1
Monounsaturated fat	g/day	32.6	51.4	45.0	1	0	0
Sodium	mg/day	2.30e3	276	153	1	0	0
Niacin (Vitamin B3)	mg/day	28.6	166	179	1	0	0
Phosphorus	mg/day	1.56e3	211	222	1	0	0
Protein	g/day	135	177	240	1	0	0
Polyunsaturated fat	g/day	14.6	36.2	36.7	1	0	0
Riboflavin (Vitamin B2)	mg/day	2.40	169	185	1	0	0
Thiamin (Vitamin B1)	mg/day	1.38	118	115	1	0	0
Total saturated fat	g/day	31.5	101	87.0	1	0	0
Total sugars	g/day	68.0	136	83.3	1	0	0
Vitamin A	µg RAE/day	1.80e3	142	200	1	0	0
Vitamin B12	µg/day	7.67	346	320	1	0	0
Vitamin B6	mg/day	2.08	137	160	1	0	0
Vitamin C	mg/day	76.8	55.6	85.3	1	0	1
Vitamin D	µg/day	5.22	30.9	34.8	0	1	1
Zinc	mg/day	73.8	516	671	1	0	0

Figure 27 Changes in distribution of the nutrients for males in Tla'amin Nation for the baseline and optimal models

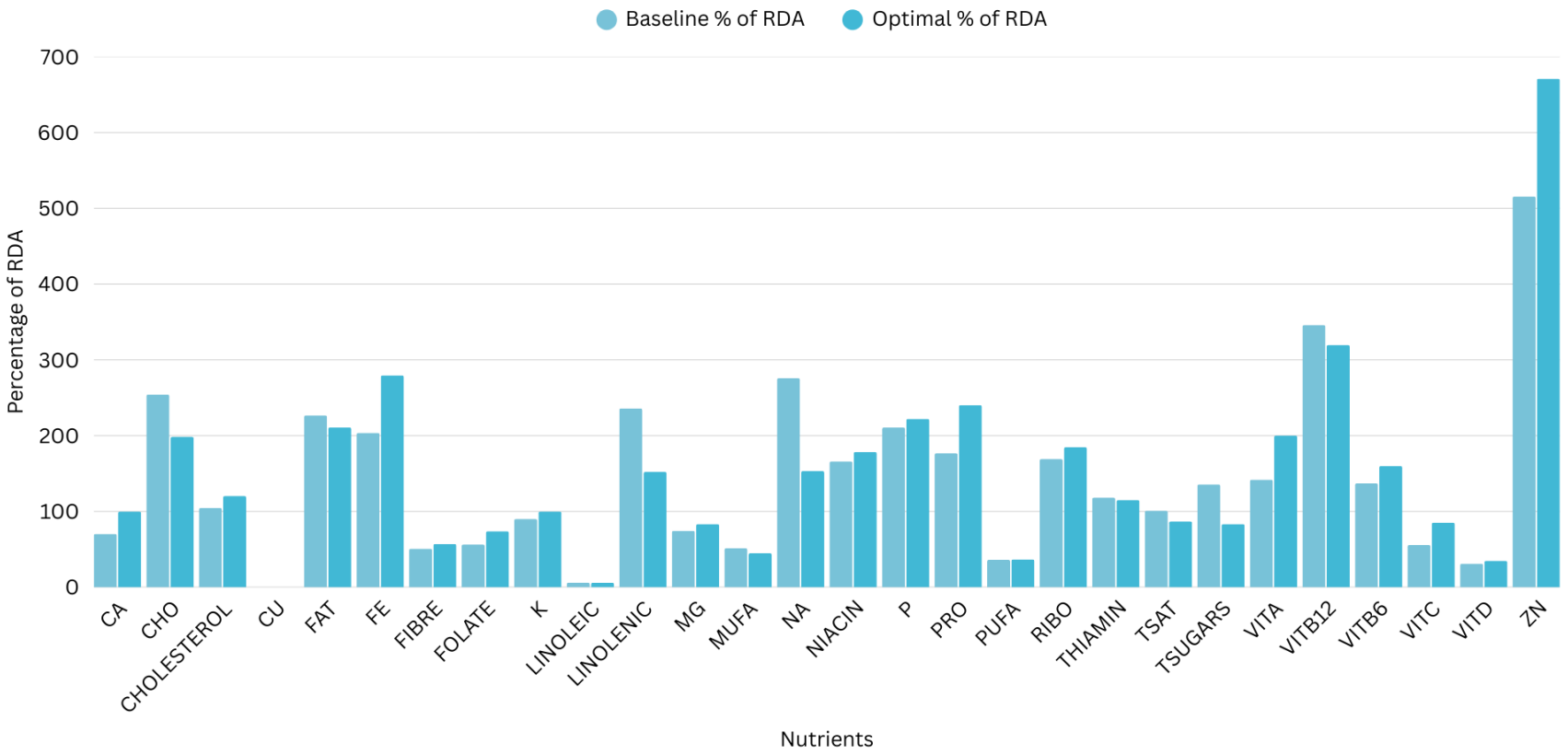


Figure 27 Comparison of baseline and optimized nutrient adequacy, shown as the percentage of the Recommended Dietary Allowance (RDA) achieved for each nutrient. Values above 100% indicate intakes exceeding the RDA.[17]

[17] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Overall, the optimized diet meets most hard nutrient constraints and closes two key baseline gaps, calcium and potassium, through targeted gram-level substitutions across food groups (Table 41; Figure 27). Calcium increases from 70.21% to 100% of the target, and potassium rises from 90.18% to 100.01%, indicating that the optimization can achieve adequacy for nutrients that were previously limiting without changing the broader dietary energy envelope. These gains are most consistent with the model's increased dairy intake (+35%) and higher fruit and vegetable grams (major contributors to potassium).

Beyond these limiting nutrients, the optimal solution sustains or further strengthens adequacy for many nutrients that were already high in the baseline. Protein increases to 240% of the target, while iron rises to 279% and zinc increases to 671%, confirming that the optimized pattern remains highly protein and mineral dense. These outcomes align with the large increases in traditional protein sources observed in the gram redistribution, especially fish (+462%) and game meat (+2100%), which provide highly bioavailable iron and zinc and help maintain very high vitamin B12 adequacy (≈320% of target). In practical terms, this indicates that traditional foods are a major contributor for high-quality protein and key micronutrients.

The model also improves several nutrients commonly associated with plant-forward diets, although not all reach 100% adequacy. Vitamin C increases from 55.62% to 85.32%, alongside modest gains in fibre (50.72% → 57.13%), folate (56.48% → 73.77%), and magnesium (74.46% → 83.36%). These partial improvements are consistent with the optimized diet's higher fruit (+84%) and vegetable (+71%) intake, plus a large relative rise in plant protein (+353%) and a moderate increase in grains (+27%). The implication is that the optimization is moving the diet toward nutrient dense food, but structural constraints in the present food

environment (availability, affordability, and accessibility) still prevent full adequacy, especially for folate and fibre-rich foods at the quantities needed.

Several remaining shortfalls highlight persistent, system-level limitations. Vitamin D remains very low (30.91% → 34.77%), and essential fatty acid targets stay extremely low (linoleic acid ≈6% of target), indicating that even after optimization diet alone cannot reliably deliver these nutrients under current constraints without fortified foods. In contrast, the model improves risk-related nutrients by reducing reliance on processed foods: sodium drops from 276% to 153% of the reference, and total sugars decline from 136% to 83%, reflecting gram reductions in ultra-processed categories.

Collectively, these results show that the optimal solution achieves a nutritionally stronger diet primarily by i) using dairy to correct calcium, ii) increasing fruit/vegetables to close potassium and raise vitamin C, and iii) centering traditional proteins (fish/game) to sustain high iron, zinc, and B12. At the same time, the persistent gaps for vitamin D, essential fatty acids, fibre, folate, and magnesium suggest that optimization alone cannot overcome the constraints of the current food system; addressing these will likely require continued support for traditional food access and distribution.

6.2.1.2 Predicted and Adaptation models comparison for Tla'amin males

Table 42 Overall Comparison for the Predicted and Adaptation Models for Males in Tla'amin Nation

Metric	Predicted	Adaptation	Absolute change	Percentage change
Total energy (kcal/day)	2879.61	2877.01	−2.60	−0.09%
Total diet cost ($/day)	9.97	12.53	+2.57	+25.76%
MeHg exposure (ng/day)	387.14	418.45	+31.31	+8.09%
TF intake (g/day)	20.78	153.50	+132.72	+638.84%
TF energy (kcal/day)	38.48	159.96	+121.48	+315.65%
TF share of total energy (%)	1.34%	5.56%	+4.22 pp	+316.03%
MF intake (g/day)	2045.16	2131.76	+86.59	+4.23%
MF energy (kcal/day)	2841.13	2717.05	−124.08	−4.37%
MF share of total energy (%)	98.66%	94.44%	−4.22 pp	−4.28%
Total diet weight (g/day)	2065.94	2285.25	+219.32	+10.62%

The most consequential shift is the marked increase in TF. TF intake rises from 20.78 to 153.50 g/day (+639%), increasing TF energy from 38.48 to 159.96 kcal/day (+316%) and raising TF's share of total energy from 1.34% to 5.56% (+4.22 percentage points). This signals that, under adaptation, TF represent an efficient and culturally meaningful pathway for meeting nutritional and feasibility targets. At the same time, TF remain a minority contributor to total energy, indicating that market foods still dominate, but the diet becomes less exclusively MF dependent.

This rebalancing comes with two key trade-offs. First, total diet cost increases substantially from $9.97/day to $12.53/day (+25.76%), demonstrating that achieving a feasible,

nutrient-adequate adaptation diet under current remote retail conditions requires a higher-cost food basket. The implication is that adaptation pathways are financially sensitive: nutritional resilience is achievable in principle, but household affordability may constrain adoption, reinforcing the importance of community and policy levers that reduce the effective cost of nutrient-dense foods and support TF harvesting/distribution systems. Second, MeHg exposure increases modestly from 387.14 to 418.45 ng/day (+8.09%), consistent with greater TF inclusion. This highlights an adaptation-relevant balance: strengthening diet quality and cultural food sovereignty through TF can slightly increase MeHg exposure.

Finally, the adaptation diet becomes a higher-volume, lower energy-density pattern. Total diet weight increases by 10.62% (2065.94 → 2285.25 g/day), while market-food energy declines (−4.37%) even as market-food grams increase slightly (+4.23%). This divergence implies a shift toward foods that add mass without adding many calories which is consistent with the model's strategy of improving nutrient delivery. Overall, Table 42 indicates that the adaptation model moves the diet toward greater TF inclusion and higher-volume nutrient-dense foods.

Table 43 Changes in distribution of the food groups in grams for males in Tla'amin Nation for the Predicted and Adaptation models

Food Group	Predicted (g/day)	Adaptation (g/day)	Change (g/day)	Percentage change
Dairy	114.96	111.39	-3.57	-3.10
Fats	24.26	40.06	15.80	65.13
Fruit	125.73	200.21	74.48	59.24
Grains	204.17	314.16	109.99	53.87
Mixed foods	158.63	112.03	-46.60	-29.37
Animal protein	142.73	114.48	-28.25	-19.79
Plant protein	34.76	72.41	37.64	108.29
Salty snacks	37.87	62.28	24.41	64.47
Sweets	62.91	62.45	-0.45	-0.72
Berries	0.00	29.12	29.12	0.00*
Fish	12.43	52.04	39.61	318.72
Game meat	5.10	72.33	67.23	1317.76
Vegetables	115.21	351.57	236.36	205.17

Figure 28 Changes in distribution of the food groups in grams for males in Tla'amin Nation for the Predicted and Adaptation model

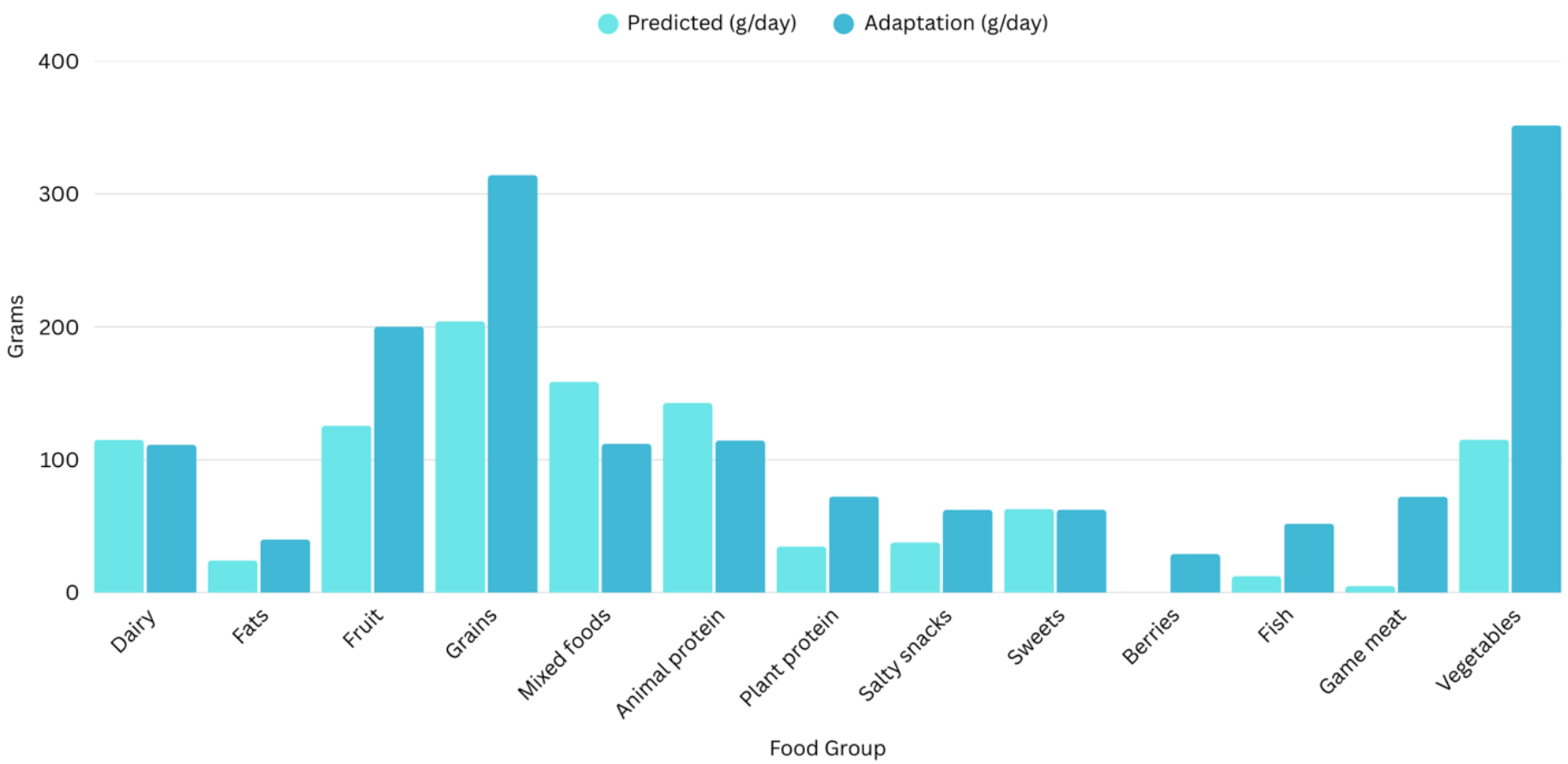


Figure 28 Comparison of predicted baseline and adaptation scenario daily food-group consumption, expressed in grams per day (g/day). Bars illustrate shifts in intake across food groups under the adaptation model relative to predicted baseline patterns.

The adaptation model for Tla'amin males produces a strong shift in the gram-distribution of the diet toward higher-volume, nutrient-dense foods and traditional foods, with the largest changes concentrated in vegetables, staple plant foods, and traditional proteins (Table 43). The most substantial reallocation is into vegetables, which increase from 115.21 to 351.57 g/day (+236.36 g/day; +205%). This dominant increase indicates that vegetables act as the model's primary lever for improving diet quality, raising fibre and micronutrients without increasing total energy, while also driving a more high-volume, lower energy-density dietary pattern.

A second set of major increases occurs in grains (+110.00 g/day; +54%) and fruit (+74.48 g/day; +59%), alongside a doubling of plant protein (+37.64 g/day; +108%). Together, these shifts indicate that the adaptation diet relies more heavily on staple, plant- foods that efficiently support multiple nutrient and help stabilize overall diet feasibility. In parallel, the model markedly increases traditional foods, particularly fish (+39.61 g/day; +319%) and game meat (+67.23 g/day; +1318%), and introduces berries (0 → 29.12 g/day). These changes imply that, when permitted within the adaptation constraints, the optimization preferentially incorporates culturally significant foods as efficient pathways for meeting protein and key micronutrient requirements, reinforcing the practical importance of access to harvesting, distribution, and stewardship systems as a determinant of nutrition resilience.

These gains are offset by reductions in several MF groups: mixed foods decline by −46.60 g/day (−29%) and market animal protein declines by −28.25 g/day (−20%), meaning a substitution away from processed items toward whole foods and traditional proteins. Dairy and sweets change little, indicating they are not central levers in the adaptation solution. However,

the model also increases fats (+65%) and salty snacks (+64%), signalling a residual trade-off where the feasible solution uses energy-dense and palatable items to satisfy.

Table 44 Changes in distribution of the nutrients for males in Tla'amin Nation for the predicted and adaptation models

Nutrient	Unit	Adaptation (amount)	Predicted % of RDA	Adaptation % of RDA	Hard constraint	Soft constraint	Adaptation below 100% RDA
Protein	g/day	109	193	236	1	0	0
Total fat	g/day	97.0	214	216	1	0	0
Total carbohydrate	g/day	281	193	216	1	0	0
Dietary fibre	g/day	35.3	82.4	141	1	0	0
Calcium	mg/day	800	63.0	80.0	0	1	1
Iron	mg/day	18.4	78.4	102	1	0	0
Magnesium	mg/day	485	98.8	152	1	0	0
Phosphorus	mg/day	1.66e3	190	237	1	0	0
Potassium	mg/day	4.42e3	112	170	1	0	0
Sodium	mg/day	4.52e3	214	301	1	0	0
Zinc	mg/day	38.0	515	475	1	0	0
Copper	mg/day	1.56	115	174	1	0	0
Vitamin A	µg RAE/day	4.12e3	192	589	1	0	0
Vitamin D	µg/day	3.17	20.7	21.1	0	1	1
Vitamin C	mg/day	115	78.3	153	1	0	0
Riboflavin (Vitamin B2)	mg/day	2.25	182	204	1	0	0
Niacin (Vitamin B3)	mg/day	29.9	195	214	1	0	0
Folate (Vitamin B9)	µg/day	356	48.7	89.0	0	1	1
Total saturated fat	g/day	28.2	168	141	1	0	0
Linoleic acid (Omega-6 fatty acid)	g/day	1.40	8.81	11.6	0	1	1
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	10.0	580	909	1	0	0
Monounsaturated fat	g/day	34.4	163	156	1	0	0
Polyunsaturated fat	g/day	23.2	281	387	1	0	0
Total sugars	g/day	71.0	422	284	1	0	0
Cholesterol	mg/day	200	97.2	100	1	0	1
Thiamin (Vitamin B1)	mg/day	1.63	121	148	1	0	0
Vitamin B6	mg/day	2.46	134	190	1	0	0
Vitamin B12	µg/day	3.63	206	151	1	0	0

Figure 29 Changes in distribution of the nutrients for males in Tla'amin Nation for the predicted and adaptation models

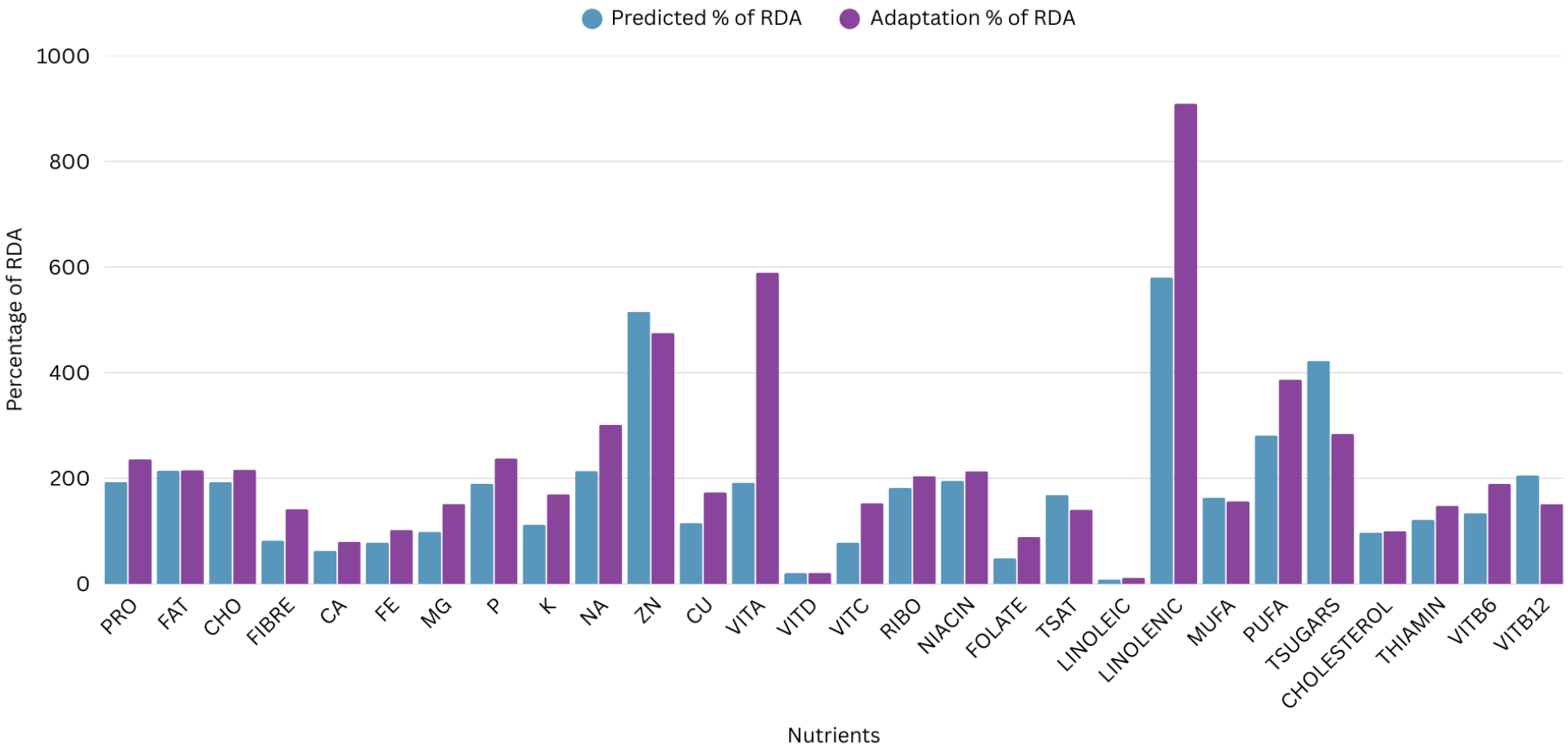


Figure 29 comparison of predicted baseline and adaptation scenario nutrient adequacy, shown as the percentage of the Recommended Dietary Allowance (RDA) achieved for each nutrient. Bars highlight nutrients that increase or decrease under the adaptation model relative to predicted baseline intake.
[18]

[18] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The adaptation model for Tla'amin males substantially improves nutrient adequacy for several limiting nutrients while maintaining strong macronutrient sufficiency, demonstrating that diet quality gains under projected conditions are achievable primarily through targeted gram reallocation across key food groups (Table 44). Protein, carbohydrate, and total fat remain well above 100% of reference needs in both scenarios, with protein increasing from 193% to 236% of RDA and carbohydrates from 193% to 216%, indicating that the adaptation pattern strengthens micronutrient delivery without compromising overall energy or macronutrient coverage.

The most improvements occur in nutrients that were previously below adequacy. Fibre increases from 82% to 141% of RDA, vitamin C rises from 78% to 153%, iron crosses the adequacy threshold from 78% to 102%, and magnesium increases from ~99% to 152%. These gains align directly with the most pronounced food-group shifts in the adaptation diet, particularly the large increases in vegetables (+205%), fruit (+59%), grains (+54%), and plant protein (+108%). Together, these plant based reallocations increase the diet's nutrient density per gram, explaining improvements in fibre and vitamin C (produce-driven) as well as iron and magnesium (supported by higher plant protein and grain contributions). Importantly, the adaptation model also increases potassium substantially (112% to 170%), consistent with higher intake of potassium-rich plant foods.

Traditional foods (TF) also play a critical role in the nutrient profile. Sharp increases in fish (+319%) and game meat (+1318%) help maintain very high protein adequacy and support key micronutrients linked to animal-source foods (e.g., several B-vitamins remain well above target). This is significant from an adaptation perspective because it shows that, within feasibility constraints, the model identifies TF, especially traditional proteins, as an efficient and culturally

aligned pathway to meet nutritional goals, reinforcing the importance of sustaining access to harvesting and distribution systems as part of food-system resilience.

At the same time, the table highlights structural gaps that persist even after adaptation, largely where nutrients are treated as soft constraints or are difficult to meet through available foods. Calcium improves but remains below adequacy (63% to 80%), vitamin D remains very low (~21%), and folate improves markedly (49% to 89%) but still falls short of 100%. Linoleic acid remains extremely low (~9% to 12%), indicating limited feasible access to the specific fat sources needed to raise this essential fatty acid. These persistent shortfalls matter because they point to where food-environment interventions, not just substitution are required (e.g., improved availability/affordability).

Overall, these results are important because they demonstrate that nutrient adequacy improvements are driven by specific, interpretable gram shifts, and they identify clear levers—both community-led (TF access, local food initiatives) and structural (availability, pricing, sodium control).

6.2.2 Cost analysis

6.2.2.1 Present and optimal model cost comparison

Table 45 Cost per 100% nutrient RDA for baseline and optimal diets for Tla'amin males

Nutrient	Baseline cost per 100% RDA	Optimal cost per 100% RDA	Change in cost per 100% RDA
Total saturated fat	10.4	12.3	1.96
Total sugars	7.72	12.9	5.15
Polyunsaturated fat	28.9	29.2	0.331
Monounsaturated fat	20.4	23.9	3.47
Calcium	14.9	10.7	-4.19
Total carbohydrate	4.12	5.41	1.28
Cholesterol	5.02e-7	4.45e-7	-5.66e-8
Copper	9.30	7.94	-1.35
Total fat	4.62	5.09	0.467
Iron	5.14	3.84	-1.30
Dietary fibre	20.7	18.8	-1.88
Folate (Vitamin B9)	18.5	14.5	-4.01
Potassium	11.6	10.7	-0.891
Linoleic acid (Omega-6 fatty acid)	174	181	6.62
Alpha-linolenic acid (Omega-3 fatty acid)	4.44	7.05	2.60
Magnesium	14.1	12.9	-1.20
Niacin (Vitamin B3)	6.31	6.01	-0.306
Phosphorus	4.97	4.83	-0.146
Protein	5.92	4.46	-1.46
Riboflavin (Vitamin B2)	6.19	5.81	-0.379
Thiamin (Vitamin B1)	8.85	9.33	0.476
Vitamin A	7.38	5.36	-2.02
Vitamin B12	3.03	3.35	0.328
Vitamin B6	7.64	6.71	-0.936
Vitamin C	18.8	12.6	-6.26
Vitamin D	33.9	30.8	-3.05
Zinc	2.03	1.60	-0.433
Sodium	3.80	7.00	3.20

Figure 30 Cost per 100% nutrient RDA for baseline and optimal diets for Tla'amin males

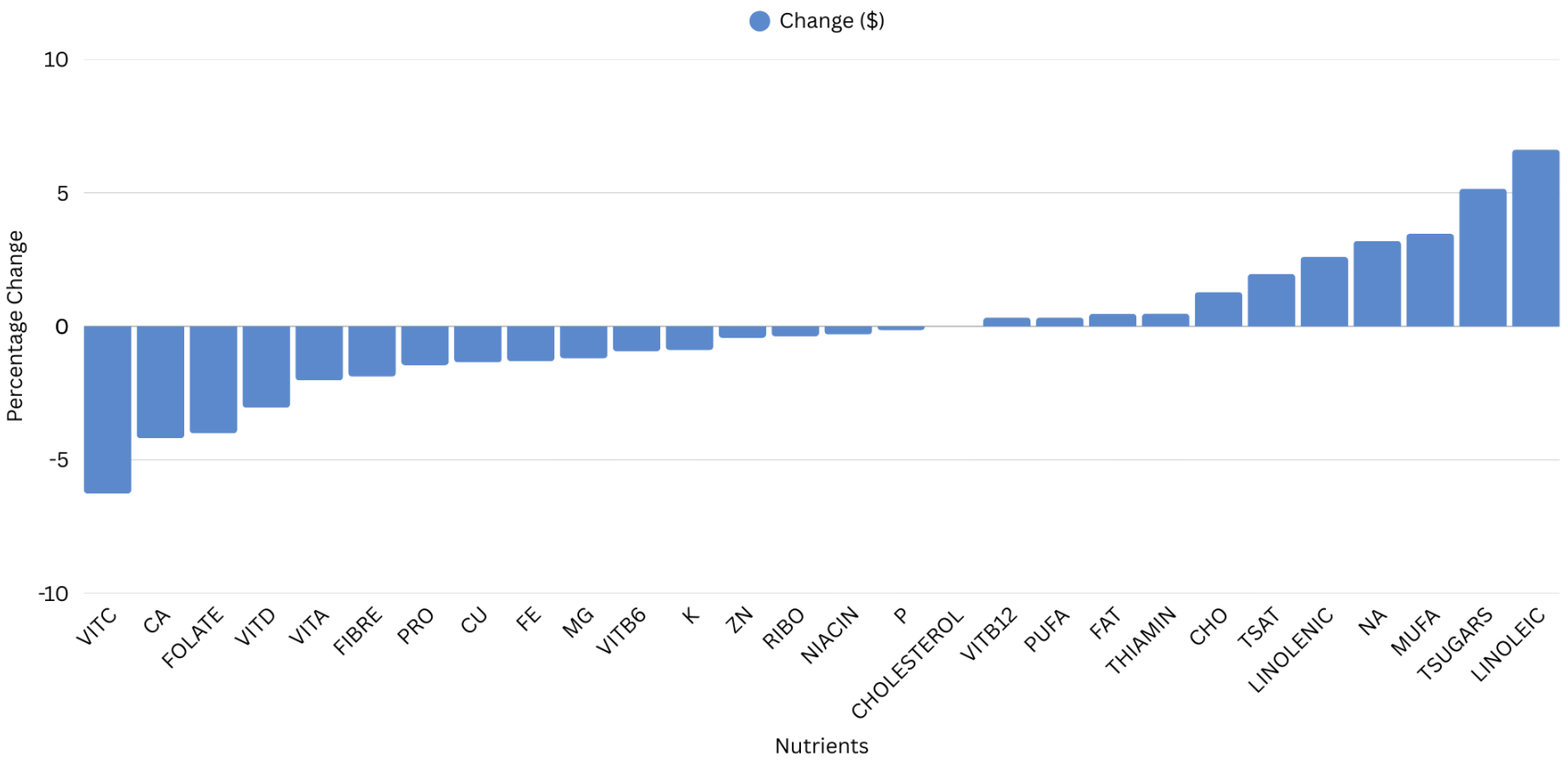


Figure 30 Change in cost ($) per 100% RDA between the predicted baseline and adaptation diets across nutrients. Negative values indicate nutrients that became less costly to meet under the adaptation scenario, while positive values indicate nutrients that became more costly.[19]

[19] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

Taken together, the cost-per-100% RDA analysis shows that the present optimal diet improves affordability for many nutritionally meaningful targets, particularly vitamin C, calcium, folate, vitamin A, vitamin D, iron, magnesium, protein, and zinc, implying that the optimized solution is not only more nutritionally adequate but also more economically efficient for delivering several priority nutrients. At the same time, shifts in the cost-efficiency metric for fats, sugars, sodium, and fatty acid subcomponents reflect trade-offs and the complexity of applying a "cost per 100% RDA" framework to variables that often function as upper limits rather than minimum adequacy targets. These patterns suggest that, under present conditions, meeting micronutrient adequacy can be achieved with relatively efficient substitutions, whereas optimizing dietary risk components and specific fatty-acid targets remains more constrained by the available food set, prices, and feasibility requirements.

6.2.2.2 Predicted and Adaptation model cost comparison for Tla'amin Males

Table 46 Cost per 100% nutrient RDA analysis for predicted and adaptation diets for Tla'amin males

Nutrient	Unit	Baseline cost per 100% RDA	Adaptation cost per 100% RDA	Change in cost per 100% RDA
Folate (Vitamin B9)	µg/day	20.5	14.1	-6.39
Linoleic acid (Omega-6 fatty acid)	g/day	113	108	-5.42
Vitamin C	mg/day	12.7	8.19	-4.55
Dietary fibre	g/day	12.1	8.86	-3.23
Vitamin A	µg/day	5.19	2.13	-3.07
Magnesium	mg/day	10.1	8.26	-1.83
Potassium	mg/day	8.89	7.38	-1.52
Copper	mg/day	8.66	7.22	-1.44
Vitamin B6	mg/day	7.43	6.61	-0.821
Sodium	mg/day	4.66	4.16	-0.502
Iron	mg/day	12.7	12.2	-0.477
Alpha-linolenic acid (Omega-3 fatty acid)	g/day	1.72	1.38	-0.339
Polyunsaturated fat	g/day	3.55	3.24	-0.310
Calcium	mg/day	15.8	15.7	-0.161
Phosphorus	mg/day	5.24	5.28	0.0348
Protein	g/day	5.16	5.31	0.145
Thiamin (Vitamin B1)	mg/day	8.20	8.47	0.260
Total carbohydrate	g/day	5.17	5.80	0.626
Riboflavin (Vitamin B2)	mg/day	5.47	6.14	0.662
Zinc	mg/day	1.93	2.64	0.702
Niacin (Vitamin B3)	mg/day	5.10	5.86	0.764
Total fat	g/day	4.65	5.81	1.16
Monounsaturated fat	g/day	6.11	8.01	1.90
Total sugars	g/day	2.36	4.41	2.05
Cholesterol	mg/day	10.2	12.5	2.29
Total saturated fat	g/day	5.92	8.89	2.98
Vitamin B12	µg/day	4.84	8.28	3.44
Vitamin D	µg/day	48.1	59.3	11.3

Figure 31 Cost per 100% nutrient RDA analysis for predicted and adaptation diets for Tla'amin males

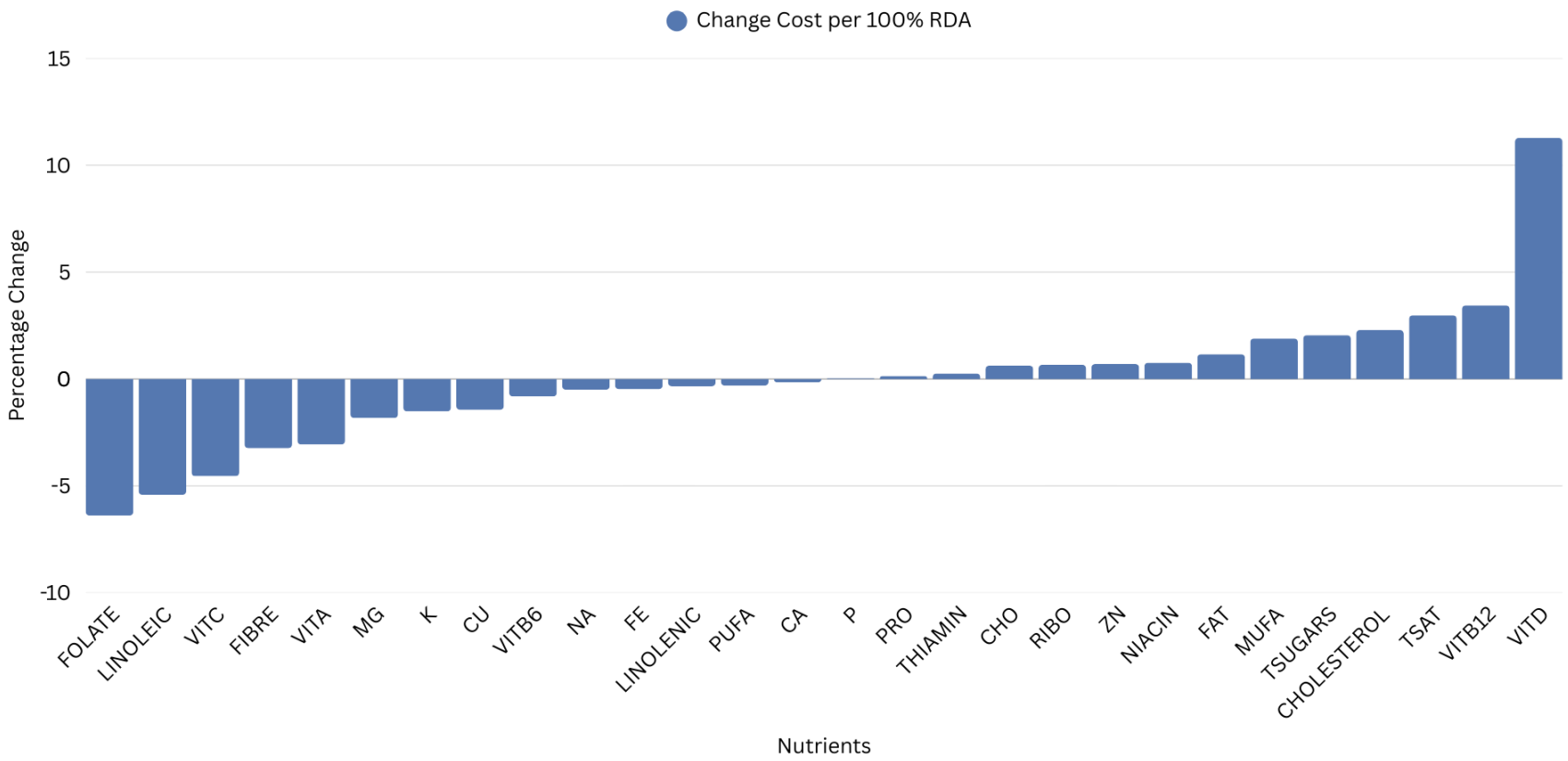


Figure 31 Change in cost per 100% RDA between the predicted and adaptation diets across nutrients. Negative values indicate nutrients that became less expensive to meet under the adaptation scenario, while positive values indicate nutrients that became more expensive.[20]

[20] **Note:** Nutrient abbreviations are defined as follows: PRO = Protein; FAT = Total fat; CHO = Total carbohydrates; FIBRE = Dietary fibre; CA = Calcium; FE = Iron; MG = Magnesium; P = Phosphorus; K = Potassium; NA = Sodium; ZN = Zinc; CU = Copper; VITA = Vitamin A; VITD = Vitamin D; VITC = Vitamin C; RIBO = Riboflavin (Vitamin B2); NIACIN = Niacin (Vitamin B3); FOLATE = Folate (Vitamin B9); TSAT = Total saturated fat; LINOLEIC = Linoleic acid (omega-6); LINOLENIC = α-Linolenic acid (omega-3); MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TSUGARS = Total sugars; CHOLESTEROL = Cholesterol; THIAMIN = Thiamin (Vitamin B1); VITB6 = Vitamin B6; VITB12 = Vitamin B12.

The cost-per-100% RDA results indicate that the adaptation diet reduced the "price of adequacy" for many nutritionally important, plant-associated nutrients, even though some nutrients remained expensive or became more costly to achieve (Table 46). The largest decreases were observed for folate (−6.39), linoleic acid (−5.42), vitamin C (−4.55), fibre (−3.23), and vitamin A (−3.07). These are meaningful improvements because they show that the adaptation pattern delivered more of these nutrients per dollar spent, making it easier economically to reach adequacy for nutrients that often constrain diet quality in remote food environments.

These declines are best explained by the adaptation model's reallocation toward nutrient-dense foods that "bundle" multiple micronutrients efficiently. In practice, increasing the contribution of vegetables, fruits, grains, and plant-protein foods raises vitamin C and fibre simultaneously (via produce and higher-volume plant foods), improves folate and vitamin A (via folate-rich and carotenoid-rich vegetables), and increases minerals such as magnesium and potassium. This bundled effect is also reflected in the moderate cost-per-RDA declines for magnesium (−1.83), potassium (−1.52), copper (−1.44), and vitamin B6 (−0.82), suggesting the model is not "paying" for each nutrient separately, but selecting foods that improve adequacy across several targets at once. Importantly, the cost-per-RDA metric can fall even if the overall diet basket becomes more expensive, as long as adequacy increases faster than cost for that nutrient, which is what is happening for these limiting micronutrients in the adaptation solution.

In contrast, a smaller subset of nutrients becomes more expensive to achieve, highlighting where the food environment provides fewer low-cost pathways. Vitamin D shows the largest increase (+11.27), reinforcing that vitamin D remains structurally difficult to obtain through available foods and constraints in this setting. Vitamin B12 also increases (+3.44), meaning the model relies less on low-cost B12 sources (or that meeting B12 is increasingly tied to costlier

animal-source/fortified options under the model's bounds). Smaller increases for fat-related measures (e.g., MUFA, total fat) and for sodium/saturated fat-related metrics reflect trade-offs in the specific foods chosen to satisfy feasibility and other nutrition targets.

Overall, the key implication is that the adaptation diet is more cost-efficient for closing critical micronutrient gaps, particularly fibre, folate, vitamin C, vitamin A, and several minerals, because it shifts grams toward foods that deliver high nutrient returns per dollar. At the same time, it identifies "hard-to-reach" nutrients (especially vitamin D, and to a lesser extent B12).

6.2.3 Conclusion

In conclusion, the male results emphasize that adaptation planning must treat dietary change as a co-developed, governance-linked process, not simply an individual behaviour shift. The model's reliance on traditional foods and plant-based substitutions suggests that the most effective levers sit upstream in food availability, harvesting capacity, infrastructure, and affordability supports. This o-development approach reinforced it is essential to (i) ensure the modelled "optimal" shifts align with lived realities and cultural priorities, (ii) identify which interventions are feasible and desirable, and (iii) translate model outputs into implementable policies that improve nutrition without increasing inequities.

6.3 Food group and Sub-food groups

Table 47 Food and sub-food groupings based on 24-hr dietary recalls

Food group	Sub-food group	TF (1=yes, 0=no)
Dairy	Milk	0
	Cheese	0
	Cream	0
	Yogurt	0
	Powered Milk	0
Added Fat	Vegetable oil	0
	Butter	0
	Lard	0
	Mayo	0
Animal Protein	Poultry	0
	Pork	0
	Beef	0
	Processed	0
	Eggs	0
Plant protein	Nuts	0
	Soy	0
	Beans	0
Fruit	Fruit	0
Vegetables	Green	0
	Red	0
	Other	0
Grains	Whole	0
	Refined	0
	Pasta	0
	Rice	0
	Potatoes	0
	Bannock	1
Sweets	Added	0
	Candy	0
	Baked	0
	Ice-cream	0
Sweets	Biscuit	0
	Spreads	0

Food group	Sub-food group	TF (1=yes, 0=no)
	Alt	0
Salty snacks	Chips	0
	Added	0
	Crackers	0
Mixed foods	Grain	0
	Protein	0
Game	Deer	1
	Elk	1
Fish	Tuna	1
	Salmon	1
	Prawns	1
	Scallops	1
	Crab	1
	Heggs	1
	Seaweed	1
	Halibut	1
	Eulachon	1
Berries	Huckle	1
	Salmon	1