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SPECIAL FEATURE: CASE REPORT

Dietary Transitions and Sustainability: Current Patterns and Future Trajectories

Diet change and sustainability in Indigenous areas: characteristics, drivers, and impacts of diet change in Gunayala, Panama

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Abstract

Many Indigenous communities around the world have been experiencing rapid and profound diet changes. This case report uses a Sustainability Science lens to understand the characteristics of diet change in Indigenous Gunas communities of Panama, as well as its drivers and sustainability impacts. We use primary information collected through interviews with 30 experts and 232 household surveys in three Gunas islands characterised by different levels of development, western influence, and cultural erosion. We observe a rapid westernization of diets that has been mainly driven by closer interaction with tourists and the Panamanian society, as well as broader development processes. However, this diet change has a series of intersecting sustainability impacts related to food security, health, and socio-cultural and environmental change. It is necessary to understand the intersection of these phenomena when designing programs and interventions that seek to prevent or mitigate negative diet changes in Gunayala, and other Indigenous contexts more broadly.

Keywords Diet transition · Diet westernization · Traditional values · Diet diversity · Food Consumption Score (FCS) · Indigenous community

Introduction

Many Indigenous communities around the world have developed lifestyles over generations that are in harmony with their ecosystems (Chanza and Musakwa 2021; Kuhnlein et al. 2013; Whitney et al. 2020). As a result, many of the social–ecological systems (SES) where Indigenous communities live are characterized by unique social and cultural practices (Parrotta et al. 2015; Reyes-García et al. 2019) that often manifest in the sustainable use of locally available resources that enable them to maintain close ties with nature (Gauvreau et al. 2017; Johnson et al. 2016).

Traditional diets are central elements of Indigenous SES as they invariably rely on the local ecosystems for the food ingredients and many of the food preparation practices (Browne et al. 2020; Milburn 2004; Sarkar et al. 2020; FAO 2021a). For example, among hundreds of relevant examples globally, the traditional Nuxalk culture of the Pacific Northwest created unique diets consisting of local fish, berries or root vegetables, while Indigenous groups in the Ethiopian highlands rely on diets based on injera (a type of local bread following a unique preparation practices) and wot (a type of local sauce) (Kuhnlein and Receveur 1996). A growing interdisciplinary body of literature has recognized many of these traditional diets as healthier and more diverse and nutritious compared to the Western diets that are often consumed by more sedentary and market-integrated local communities (Dounias et al. 2007; Parrotta et al. 2015; Reyes-García et al. 2019). Furthermore, on many occasions, these traditional diets tend to be better adapted to local environmental conditions and be more sustainable in their specific SES and Indigenous context (Finnis 2007; Sarkar et al. 2020; FAO 2021a). Studies have also suggested the

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important role of Indigenous diets for ensuring food security of large segments of population in different parts of the world (Sidiq et al. 2022; FAO 2021a). Beyond health and food security, diets are also central elements of Indigenous cultures, playing a key role in the transmission of Indigenous and local knowledge (ILK) and traditions associated with food production/harvesting and preparation (e.g., Ohmagari and Berkes 1997, The Global-Hub on Indigenous Peoples' Food Systems 2021). Thus they contribute to sustainable SES management (Moller et al. 2009) and the creation of societal bonds and cohesion that are in turn essential for the maintenance of cultural identify (FAO 2021b).

However, over the last centuries, Indigenous groups around the world have come in closer contact with other societies, and more importantly have become more embedded in the globalized capitalist economic system. This has often invariably caused changes in traditional lifestyles (Jacques and Jacques 2012; Phillips et al. 2014), eventually precipitating changes to the specific SES (Fixico 2013; Nabhan 2016). This phenomenon has accelerated and intensified in the past decades through the stronger push to "modernize" Indigenous communities in ways that do not necessarily reflect their needs and sensibilities, but adhere to broader notions of economic integration, growth, and development. This is usually through the development of infrastructure and better telecommunication networks, tourism-based economies, increased migration, and stronger national and international trade links, often reinforced by mass media and the internet (Gregory et al. 2020).

Diet change has been one of the most visible lifestyle changes in many Indigenous settings. Historical records have highlighted the very rapid diet change among Indigenous groups shortly after the commencement of communication with external societies (Johnson-Down and Egeland 2013; Sharma et al. 2013; Sheehy et al. 2013; Welch et al. 2021). For example, radical diet changes have been reported among the Inuit in the Arctic region, in Australian Aboriginal communities, and in hunter-gatherer societies in many parts of the world, usually following their integration into the market economy (Rowley et al. 2000; Kuhnlein et al. 2004; Crittenden and Schnorr 2017) or through processes of globalization and food systems commodification (Popkin 2004; Valery et al. 2012; Powell et al. 2015; Rapinski et al. 2023).

As a result, the study of the characteristics, drivers, impacts, and responses of diet change in Indigenous settings has attracted some traction in the past decades (Egeland et al. 2011; Huet et al. 2012; Sheehy et al. 2013; FAO 2021a). Many of these contemporary studies have suggested that diet change in Indigenous settings is characterized by an increased reliance on processed food, as well as food with a high concentration of fat and refined hyper-processed carbohydrates (Sarkar et al. 2020). Indeed many studies have situated these diet changes in the broader concept of nutrition transition and diet westernization (e.g., Kuhnlein et al. 2004; Fernandez 2020).

However, such diet changes tend to vary substantially between contexts, having, for example, different drivers and impacts. In particular, scholars have identified a large variety of factors driving these diet changes including globalization, climate change, industry and technology growth, land use changes, and other anthropogenic factors (Gómez et al. 2013; Keleman Saxena et al. 2016; Winson 2014; Rowley et al. 2000; Kuhnlein et al. 2004). Similarly, diet changes in Indigenous contexts tend to be accompanied by very diverse negative sustainability impacts, such as, among others, (a) landscape, agrarian and livelihood transformation (Niragira et al. 2021; Crittenden and Schnorr 2017), (b) loss of agro-diversity and dietary diversity (Conelly and Chaiken 2000; Vogliano et al. 2021), (c) pollution from the packaging of processed food (He et al. 2018), (d) rise in obesity and non-communicable diseases (Johnson-Down and Egeland 2013; Sharma et al. 2013; Sheehy et al. 2013; Rapinsky et al. 2023), (e) increased food insecurity (Shafiee et al. 2022), (f) increased economic burden through reliance on purchased food (Gao & Erokhin 2020), and (g) loss of ILK and traditional values (Kuhnlein and Receveur 1996; Sarkar et al. 2020), with subsequent effects on the broader culture and society (Dounias et al 2007).

However, most of these studies tend to focus on specific aspects of such diet changes, whether its characteristics (i.e., changes in types of food), drivers (i.e., what causes diet changes) or impacts (i.e., the outcomes of diet change). Few of such studies have tried to provide a comprehensive picture of how these elements emerge, intersect and interact. Furthermore, most studies have adopted a rather narrow lens when exploring the actual impacts of these diet changes, usually focusing on a subset of the different sustainability impacts.

The Gunas, are an Indigenous Amerindian group in Panama, which experiences many of the issues outlined above. On the one hand, their traditional diet is an integral part of their identity, and is centered around "dule" "masi" ("people's" "food"), a hearty meal based on coconut, plantain, and yam soup accompanied with smoked fish and a corn-based fermented drink (Fortis 2015; Martínez Mauri 2019). On the other hand, Gunas societies are experiencing major changes through increased communication and engagement with external societies, whether from other parts of Panama or tourists from other parts of the world. This has been facilitated by the road connection of Gunayala (i.e., the Gunas region) with the mainland since the 1990s, as well as the surge of tourism as the main formal economic activity in the region (Martínez Mauri 2018). Collectively, these circumstances have started precipitating some major changes in the Gunas values and lifestyle. One of the more visible signs has been the change in diets, which has been facilitated by the

access to mass-consumer products (e.g., soft drinks) and the associated marketing campaigns (e.g., posters, store-front sponsorships). Changing diets have been associated with different socioeconomic and environmental impacts (Vaccaro et al. 2009). Interestingly, the Gunas are characterized by strong institutions and a large degree of autonomy compared to other indigenous groups in the Americas (Orbach 2004; Velásquez Runk et al. 2011). Arguably, the strong institutions of the Gunas should have prevented many of these diet changes and negative impacts (Dam Lam and Gasparatos 2023), as has also been suggested in other Indigenous contexts (Patankar et al. 2016; Tang and Tang 2010).

Considering the above the aim of this Case Report is to understand the diet change that Indigenous Guna communities are currently experiencing, as well as its drivers and sustainability impacts. In contrast to much of the fragmented literature outlined above, here we seek to push the knowledge boundary on Indigenous diet change by providing a comprehensive picture of how diet change has unfolded (i.e., characteristics and drivers) and currently affects Indigenous communities and their environments (i.e., impacts). To achieve this, we adopt an interdisciplinary research approach drawing from Sustainability Science to comprehensively unravel how these elements emerge, intersect, and interact (see justification in Research Approach). Although interdisciplinary mixed-method approaches have been used to understand how Indigenous diet change unfolds in different contexts (Rapinski 2023; Kuhnlein et al. 2004), this is one of the few studies to employ a Sustainability Science lens. Beyond the general interest of the study on Indigenous diet changes, to the best of our knowledge this is the first study that comprehensively tracks these phenomena for the Gunas, a rather unique Indigenous group in terms of autonomy and institutions.

We start by outlining the study site and the data collection and analysis methods. Subsequently in the Results we present the characteristics of the study sample, and the type of diet change observed, as well as the drivers and impacts of diet change in Gunayala. Finally, the Discussion puts into perspective the main findings, and outlines some of the main implications and recommendations to prevent diet changes in Indigenous contexts and/or mitigate their negative outcomes.

Methods

Research approach

Sustainability Science can provide a useful lens to explore the characteristics, drivers, and impacts of diet change and food systems (Gasparatos 2020; Lindgren et al. 2018; Tatebayashi et al. 2019). Our reserch approach adopts the key principles of Sustainability Science (Kates 2011; Takeuchi and Komiyama 2006), namely (a) a problem-oriented approach, (b) an ability/approach to link social and ecological systems, (c) an inter- and trans-disciplinary focus, and (d) an open mindset to include knowledge from different systems (e.g., formal scientific knowledge, expert opinion, local knowledge).

Regarding (a), we perceive diet change as a key development challenge in the region with major ramifications for the future of the Gunas as it has been confirmed by preliminary work (Dam Lam and Gasparatos 2023). For this reason, we structured this paper around the policy-relevent questions of "what are the characteristics of diet change" (i.e., characteristics of diet change), "why has it occurred" (i.e., drivers of diet change), and "what have been its outcomes" (i.e., sustainability impacts of diet change). In Discussion, we outline some priority areas that can be targeted in order to prevent further diet change and mitigate any negative impacts in Gunayala, and other Indigenous contexts.

Regarding (b), we have perceived diet change as a multidimensional phenomenon embedded in multiple ways in the broader SES of Gunayala. We perceive diet change as both an outcome of broader socioeconomic and political processes, as well as a phenomenon interacting strongly with the natural environment and the cultural and socioeconomic structures of the Gunas. For this reason, we consider the multiple sustainability impacts of diet change in Gunayala.

Regarding (c) and (d), we capture and elicit the perceptions of different stakeholders, such as local Gunas communities, local Indigenous leaders, and practitioners and policy-makers, both inside and outside Gunayala. It is essential to understand the perceptions of such a diverse set of stakeholders to unravel the key aspects of diet changes, considering their multi-dimensionality as outlined in the Introduction. Such stakeholders often have radically different knowledge and understanding of these multi-dimensional phenomena through their personal experiences undergoing or observing such diet changes. Furthermore, we employ different analytical tools to elicit these perceptions, such as qualitative analysis of expert interviews and statistical analysis of household surveys. We deem all stakeholder perceptions as credible, as we do not wish to treat any actor/stakeholder as having priority over the others. This approach is well justified as we wish to capture the wealth of different perceptions rather than rank them. Similar multi-stakeholder approaches that elicit the plurality of stakeholder perceptions have been used to study food system sustainability in multiple other global contexts at different scales (Breeman et al. 2015; Meinhold and Darr 2021).

We should point out that although our study is interdisciplinary, integrating notions, and concepts from different fields of the social (mainly) and natural sciences (secondarily), it does not follow a strong notion of transdisciplinarity (e.g., co-design approaches to mitigate diet change impacts

Table 1 Characteristics of the study islands

	Gardi Sugdub	Soledad Miria	Nargana
Total population	927	896	1215
Adult population	563	459	690
Development level	Medium	Low	High
Western influence/traditional value erosion	Medium	Low	High
Total sample size	90	98	82
Young men	23	24	20
Adult men	23	26	22
Young women	21	24	20
Adult women	23	24	20

Population source (INEC 2010)

or design interventions to foster sustainable diet transitions) (Schwarz et al 2021; Lang et al. 2012). Still the experts involved in this study did not simply provide the information reported in the Results, but informed practically all aspects of the research, from identifying the importance of understanding diet change (i.e., the actual problem) (see Dam Lam and Gasparatos 2023) to informing the methodology (e.g., island selection, types of western food items).

Study sites

The study identifies the characteristics of diet change in three communities of Gunayala (see Table 1). Gunayala is an autonomous region within Panama governed by Indigenous Guna people (Castillo 2005; Davis 2014; Martínez Mauri 2008). There are 49 Guna communities and most of them are located in islands near the coast. As mentioned in the Introduction, the Gunas have experienced major socioeconomic changes triggered by the increased connectivity with other societies that started in the 1980s and continued until the early 2000s with the introduction of better road access, as well as a booming tourism sector (Orbach 2004; Pereiro 2016).

In this study, we focus on three island communities that represent various stages of development and have experienced different degrees of western influence and traditional value erosion (see Table 1). Between them, the three study islands provide a good cross section of the Gunas society. The islands were selected following expert interviews and consultations with Guna regional authorities. Figure S1 in the Supplementary Material illustrates the location of the three study islands.

Data collection and analysis

In this study, we used a combination of expert interviews and household surveys to elicit the different aspects of diet change in Gunayala. The characteristics of diet change and the proximate drivers were identified through household surveys in three Gunas islands (see "Household surveys"), while the underlying drivers and impacts were elicited through expert interviews (see "Expert interviews").

Expert interviews

In particular, we conducted a total of 30 expert interviews between February–March 2018. The list of experts can be found in Table S2 in the Supplementary Material. Collectively the interviewees represented actors from the main institutions relevant to Gunayala's development, having a deep knowledge for the processes underlying Gunayala's transition, including diet change. Consistent with the Sustainability Science lens adopted in this study (see "Research approach"), the participants spanned different types of institutions (e.g., government, NGOS, religious and cultural institutions, including representatives from the main regional and local Indigenous institutions.

Each interview lasted on average about 60 min. and was semi-structured with open-ended questions where respondents were free to expand based on their perspective. All interviews were conducted in Spanish, apart from two interviews that were conducted in Gunagaya (Guna language). During these two interviews, an interpreter familiar with the research provided simultaneous translation. All interviews were digitally recorded and transcribed to facilitate the coding for the content analysis.

It should be noted that beyond indicating the underlying drivers and impacts of diet change in Gunayala, the information collected from the expert interviews assisted the subsequent design of the household survey (including to identify some of the characteristics of the unfolding diet changes), definition of sampling groups (see below), and identification of suitable communities that would represent a reliable cross-sectional snapshot of Guna society and their diet changes.

Expert interviews were transcribed and manually coded for qualitative analysis in order to elicit the drivers and impacts of diet change in Gunayala. To ensure consistency, the coding was conducted manually solely by the corresponding author using programming of custom functions and macros in Excel to keep track of similar references between interviews.

Household surveys

The characteristics of the diet change and the proximate drivers were elicited through household surveys in three Gunas islands. Based on the insights collected through expert interviews and preliminary site visits, we identified four study groups for the household survey. The study groups

were divided based on age and sex. Given the accelerated western influence through the expansion of the tourism sector since the early 2000s, there seems to be a divide between younger Gunas (< 30 years old) that have lived mostly under the influence of tourism and adult Gunas (> 30 years old) that still preserve many traditional practices and knowledge. Moreover, women are often perceived as guardians of Guna culture through their cooking, dresses, and artisanal handicraft. On the other hand, men are responsible for working in agricultural fields and fishing (mainly older Gunas) and working in the tourism sector (mainly younger Gunas).

Household surveys elicited: (a) the general characteristics of the respondents (e.g., income/livelihoods, education), (b) dietary diversity currently and in the past, and (c) reasons for the observed diet change.

To understand the characteristics of diet change, we use a modified version of the Food Consumption Score (FCS), which is a metric of dietary diversity (World Food Programme 2008) that has been used in many studies across the world as a metric of dietary quality (e.g., Miller et al. 2020). This modified FCS allowed us to analyze the diet changes across time and across food groups. Essentially, the FCS categorizes the food items consumed by households (both within and outside the household) into eight food groups, with each food group further classified into individual food items (World Food Programme 2008). In this study, we have retained the same food groups and weights proposed by the World Food Programme that has developed the FCS. However, to understand how diets have changed, we have introduced two modifications. First, in order to capture the diet change between traditional and western diets, we defined 11 food items to match the research goals and the preliminary observations from the expert interviews and preliminary site visits. In other words, expert interviews informed what food items within each food group are characteristic of a western diet. These food items essentially seek to identify the diet changes associated with switches from traditional food items to food items associated with westernized diets. This included traditional meat sources and imported meat sources, and traditional drinks and soft drinks consumption, among others (see Table 1, Supplementary Material for more details). Second, in order to capture diet change over time, each respondent completed two FCS modules, with the first asking their average weekly consumption of food groups prior to their diet change, and the second about their current consumption. In tandem with the FCS methodology, in both these FCS surveys, respondents were asked to provide their average consumption of each food item per week (7 day period) for each of the 11 food items defined in this study. The survey was conducted in a period outside major festivities or harvest celebrations during which diet patters change. This was done to enable the capture of habitual dietary patterns. Enumerators were trained to capture all food consumed inside and outside the households.

In order to ensure a random sampling at each study island, we relied on remote sensing tools. In particular, we used QGIS version 3.4.4 to assign a random ID number to each structure at each study island (see Fig. S2, Supplementary Material). Next, we used the random function to select which ID numbers to survey for each of the four sampling groups. Overall, 232 surveys were conducted between March and April 2019 in the study islands. Surveys were collected through local enumerators in each island that were hired and trained locally to both prevent any concern regarding research motivations and generate trust among respondents and Indigenous local authorities.

The household surveys were analyzed through descriptive and inferential statistics to characterize and identify statistical differences between sampling groups. All analyses were conducted using SPSS Statistics version 26. When comparing more than two groups, we use one-way ANOVA with Bonferroni correction for the post hoc test. Welch's ANOVA with Games–Howell post hoc test is used instead if the homogeneity of variance assumption was violated (i.e., income). For non-parametric data, we use the Kruskal–Wallis and Bonferroni correction for post hoc test. The paired t test is used to analyze the FCS module pre- and post-diet change for each sampling group. A spider web graphic is used to provide a quick snapshot of the characteristics of diet change across all 11 food items (Bremer 2020), showing the frequency of consumption of each type of food item within a 7 day period.

Synthesis of findings

The linkages between the characteristics, drivers, and impacts of diet change identified through the expert interviews and household surveys are systematized using a causal loop diagram (CLD) graph. CLDs are tools drawn from system dynamics modeling that are often used to depict complex systems characterized by multiple interactions and feedback mechanisms, including in contexts of diet change (Ahmed et al. 2023). CLDs allow the representation of linkages between multiple variables in a system, identifying the polarity of these relationships (i.e., positive or negative), and the feedback loops that occur when two or more variables influence each other in a closed cycle (Sterman 2000). These feedback loops are considered to have a "reinforcing" behavior when the polarities of their relationships generate an effect in the same direction, creating "vicious" or "virtuous" cycles. Conversely, a loop is considered to have a "balancing" behavior if its polarities compensate or regulate each other (similar to the functioning of a thermostat), attempting to reach equilibrium (Sterman 2000; Meadows 2009).

For our study, the CLD is constructed by one of the co-authors using the Vensim PLE Plus software. The loops are labeled with a letter "R" or "B" indicating whether they reflect a balancing or a reinforcing behavior (see paragraph above), followed by consecutive numbers. Subsequently, the graphs are validated by the entire research team to assure that the CLDs reflect the findings of the study adequately.

Permissions and ethical considerations

The Gunas enjoy very strong administrative and cultural institutions (Dam Lam and Gasparatos 2023), and a strong degree of autonomy compared to other Indigenous settings in the Americas (see "Introduction"). The study followed the ethical guidelines and data management procedures stipulated by the authors' affiliated academic institution, received permission from appropriate Gunas authorities, and acknowledged throughout the process the free, prior, and informed consent (FPIC) established by the Declaration on the Rights of Indigenous People (United Nations 2007).

We received permission from Gunas institutions at the regional (Gunayala) and local (island) levels before engaging with research at the three local communities (i.e., household surveys, interviews with local experts). In particular, through a lengthy and iterative process with the Gunas Cultural Congress (one of the highest regional Gunas institutions that is the body responsible for overseeing such activities), we explained the overall research and the methodological protocol aspects. This included the information expected to be collected and the mode of information collection. In accordance with local beliefs and ethics, we made modifications to the protocol and had to adhere to specific rules such as not to interview underage children or to always ask permission to take photographs inside private property. The permission was granted through an iterative explanation and deliberation process, which lasted for approximately one year. Without this process to ensure that our research complies with local sensibilities, it would not have been possible to receive the final permission document to enter Gunayala for research purposes.

Once written permission was obtained from the Gunas Cultural Congress at the regional level, we started official communication with local leaders explaining again the research aim, the type of data to be collected, and how the information will be collected and used. We received permission from each community Sagla, before being allowed to collect information in each of the three study islands.

During the actual data collection, we explained to each expert interviewee and survey participant the purpose of the research, we clarified that at any moment, the research participants were free to stop engaging in the expert interviews and household surveys, and that any such decision will not have any adverse effects. We informed the household survey participants that the collected information (which contained private information) will be anonymised and will not be possible to be tracked. As the expert interviewees did not provide private or sensitive information, we received their consent to be identified by affiliation.

Finally, we need to also reflect on the positionality of the research team. Although the corresponding author is Panamanian, none of the authors are Guna or from any of the nine recognized Indigenous groups of Panama. Thus, the authors acknowledge the potential cultural biases and/or reflexivity shortfalls that might not capture properly the reality of Guna people's concerns (Kwame 2017). To minimize this risk, we implemented a mix-method research approach where interviews with a broad range of experts from the Guna community informed the characteristics, drivers, mechanisms, and implications of the ongoing diet change among the Guna people. Furthermore, the study design and implementation were performed with the feedback and on-the-ground support of The University of Panama Indigenous People Office (OPINUP). The OPINUP is operated by Indigenous people with the main goal of reducing the gap between academia and the needs of Panama's Indigenous groups. For these reasons during this research, we (a) conducted all expert interviews within Gunayala with the presence of a Guna guide to help us navigate Guna customs, (b) employed local Guna enumerators to conduct household surveys, and (c) adopted multiple roles through a reflexivity process as outsiders, fellow Panamanian, and researchers to become recipients of the knowledge to be shared by the interviewees (Kwame 2017).

Acknowledgements, challenges and limitations

Despite the comprehensive focus of this study on the characteristics, drivers, and impacts of diet change in Gunayala, we need to acknowledge that some of the methodological decisions have certain limitations and uncertainties that must be considered when using our results to understand diet changes in Gunayala and generalizing in other Indigenous contexts. These relate to the (a) selection of the of the diet diversity metric, (b) recollection period, (c) inability to differentiate between the sources of food items, and (d) impact elicitation through respondent perceptions.

For (a), the selection of the appropriate tool to capture dietary diversity (and more broadly food security) has certain trade-offs between the fitness for the purpose of the application (i.e., ability to recreate short- and long-term diets in this this study), acceptability in the literature, ease of comprehension by respondents and data collectors, and ability to enable accurate recollection (especially for longer periods) (FAO 2010; Carletto et al. 2013). When designing this study, we considered different alternatives, including some that can be more comprehensive, such as the HDDS (FAO 2010), 24-h dietary recalls (Gibson and Ferguson 2008),

or the Food Frequency Questionnaire (FFQ). However, we ultimately decided to adopt and modify the FCS since it provided the best balance between the above considerations. In particular, for recent recollection periods, we consider that the 7 day period of the FCS is more appropriate compared to tools with 24 h recollection periods such the HDDS and the 24-h dietary recalls, as this prevents potential risk of biases based on the day of the week the survey is conducted (e.g., day with unusual diets). Moreover, the FCS uses broad diet categories rather than listing all/individual food items consumed in a given period such as 24-h dietary recalls or the FFQ. This arguably makes its modification easier to address the study objective of recalling household diets over long periods before the transition. In this sense, the selection of the FCS was a trade-off between comprehensiveness of food items and accuracy in the recollection of short- and long-term diet patterns. Although we believe that the modified FCS was the best compromise to increase the accuracy of diet recollection in the short- and long-term, its selection (and some methodological decisions) causes certain omissions and inaccuracies, and particularly the inability to consider detailed micronutrient intake such as salt, which could lead to negative health implications.

For (b), due to the lack of accurate data about diet composition before the dietary transition, we had to resort to self-reported changes in food item consumption. This inserts certain uncertainties in pinpointing the timing of diet change and reporting the food items consumed (and their frequency) in the past. We acknowledge that while the major socioeconomic changes in Gunayala started in the early 2000s due to the development of the main roads, increased migration of young Gunas, and expansion of the tourism sector (see "Introduction"), not all households changed their diet at the same time. Therefore, in order to identify the diet change period, we first asked each respondent if they had perceived a change in their diet patterns in the past. If respondent noticed a diet change, we then proceed to ask how many years back this change occurred.[1] For respondents that noticed a diet change, we use the self-reported reference year that they noticed this change to ask the past and current consumption of the different food items. For those respondents answering that they did not notice any diet change (see first section of "Results" for their number for each study group and island), we defined a 10-year recall period based on our expert interviews. We should note also that long recall periods might insert uncertainties in the reporting of the consumption of different food items. To avoid to the extent possible such problems, we (a) asked only the frequency of consumption of the different food items rather than their actual quantity, and (b) set a maximum of 15 years of recall to reduce further the challenges of long recall periods. In this sense, the results should be perceived as a qualitative understanding of the main characteristics of diet change rather than an exact quantitative estimate. We resorted to this approach, as it was not possible to identify high quality individualized nutrition data to allow us to conduct a robust temporal analysis.

For (c), although it is important to understand the origin of food items when exploring diet changes in Indigenous contexts (e.g., farms, forests, marine areas, markets) (Jones 2017), in this paper, we purposely avoided compounding the issues changing food item consumption and the origin of food items. Items in most food categories are obtained both from markets and local agroecosystems, but it is difficult to divide them in terms of origin accurately. While it might be possible to achieve this for a recent recollection period (e.g., 24 h or 7 days before survey) with a different modification of the tool, it would have been particularly difficult to achieve it for the long-term recollections (i.e., before the diet shift). For this reason, and in order to meet study objectives, and avoid burdening respondents and increasing response uncertainty, we opted to not capture the origin of food. Yet we do agree that this information would have offered a more nuanced picture of diet changes in Gunayala.

For (d), we acknowledge that our approach to assess the impacts of diet change through perceptions (rather than quantitative data for each individual impact) creates some uncertainties. Again, this reflects the point made above about the general lack of available data due to the fact that the Gunas are quite understudied, with only a handful of studies exploring environmental and socioeconomic change in Gunayala in the academic literature. In this sense again, the results of this analysis should be seen as qualitative evidence that points to the most prevalent impacts of diet change in Gunayala (and not necessarily the most severe) and a roadmap for identifying priority areas for robust future impact assessments.

Results

Sample characteristics

Table 2 contains the general characteristics of each study group. There is no statistically significant difference in income levels at Gardi Sugdub between sampling groups where some level of development has occurred (Table 2), with the tourism sector gradually becoming a key source of income and a driver for the development of healthcare and education facilities (Guna Cultural Congress, personal communication, February 16, 2018). Respondents in Soledad Miria have the lowest income levels across all respective sampling groups in the other study sites, reflecting its

[1] Approximately 83% of the respondent noticed a diet change reporting the change occurring 8.7 (SD = 6.8) years in the past, though this varied by island and study group (see first sub-section of Results).

Table 2 General characteristics per study group by study island

	Young men	Adult men	Young women	Adult women	Sig.
Gardi Sugdub					
n	23	23	21	23	
Age	24	52	23	48	0.000***
Education (years)	12	9	12	8	0.032*
Income (USD/month)	326	447	235	345	0.595
Diet change (years)	11.6 (*n* = 18–78%)	10.9 (*n* = 17–74%)	7.1 (*n* = 18–86%)	12.3 (*n* = 17–74%)	0.002**
Soledad Miria					
n	24	26	24	24	
Age	23	53	24	48	0.000***
Education (years)	9	3	7	1	0.000***
Income (USD/month)	136	166	91	125	0.397
Diet change (years)	4.7 (*n* = 24–100%)	6 (*n* = 25–96%)	3.8 (*n* = 22–92%)	5.4 (*n* = 23–96%)	0.017*
Nargana					
n	20	22	20	20	
Age	25	50	24	50	0.000***
Education (years)	9	8	9	8	0.779
Income (USD/month)	398	682	105	176	0.034*
Diet change (years)	7.7 (*n* = 15–75%)	15.1 (*n* = 19–86%)	8.3 (*n* = 12–60%)	16.8 (*n* = 15–75%)	0.001**
All sites					
n	67	71	65	67	
Age	24	52	24	48	0.000***
Education (years)	10	6	9	5	0.000***
Income (USD/month)	279	417	142	216	0.008**
Diet change (years)	7.6 (*n* = – 0%)	10.2 (*n* = – 0%)	6 (*n* = – 0%)	10.6 (*n* = – 0%)	0.000***

Significance levels: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. For detailed pairwise comparisons between groups see Table S3 in the Supplementary Material

status as the least developed community with the highest preservation of traditional practices (Soledad Miria Argar, personal communication, March 14, 2018). Conversely, study groups in Nargana consistently have the highest incomes compared to their peer groups (Table 2). This reflects the fact that Nargana is the most developed study community, which has experienced the influence of western culture since colonial times, undergoing in the process the highest loss of traditional practices among Guna communities (Nargana Sagla, personal communication, March 13, 2018). The similar education level across all sampling groups and the earliest period of diet change reflects Nargana's historical influence by modern societies (Table 2).

Importantly, Table 2 also highlights the major differences in the onset of diet change between the different islands, across the spectrum of development and preservation of traditional practices. Three out of the four study groups in Nargana (most developed island) have the earliest onset of diet change among their peer groups, while all four study groups in Soledad Miria (least developed island) have the latest onset of diet change (Table 2).

Adult women tend in most cases to have an earlier onset of diet change in each island, followed by adult men, young men, and then young women. This trend is observed consistently both within individual islands, as well as in the aggregate sample (Table 2). From our analysis, it is not clear why this happens, but it might reflect the gradual ease of finding ingredients for westernized diets in the Gunas islands over time and the fact that women are usually tasked for cooking, while men spend prolonged periods of time in inland agricultural areas where access to non-traditional material is more challenging. However, we have to point to the very slight differences in the onset of diet change between adult women and adult men, which might just reflect the possibly better recollection of food items among adult women as they tend to be responsible for purchasing food (rather than traditional food that is mainly self-produced or collected from nature) and cooking it.

Characteristics of diet change in Gunayala

Results from the FCS module analysis suggest that dietary diversity within each study site remains relatively consistent

Table 3 Past and present FCS for each sampling group by study island

	Young men		Adult men		Young women		Adult women		Sig
	n	FCS	*n*	FCS	*n*	FCS	*n*	FCS	
Past FCS									
Gardi Sugdub	23	69.7	23	71.0	21	69.6	23	71.2	0.981
Soledad Miria	24	58.6	26	57.3	24	55.8	24	51.7	0.202
Nargana	20	67.9	22	65.3	20	60.6	20	65.2	0.661
All sites	***67***	***65.2***	***71***	***64.2***	***65***	***61.7***	***67***	***62.4***	0.609
Present FCS									
Gardi Sugdub	23	75.9	23	77.9	21	71.0	23	73.7	0.555
Soledad Miria	24	72.9	26	73.0	24	73.6	24	71.3	0.924
Nargana	20	76.1	22	74.2	20	73.0	20	85.5	0.250
All sites	***67***	***74.9***	***71***	***75.0***	***65***	***72.6***	***67***	***76.4***	0.442

Significance levels: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

between study groups, with no observed statistically significant difference in FCS between groups in the ame island (Table 3). Before the onset of diet changes, we observe that FCS in Gardi Sugdub are higher across all sampling groups, followed by groups in Nargana and lastly by groups in Soledad Miria. Overall, when comparing aggregate scores between groups from all three islands, young and adult men (FCS = 65.2 and 64.2 respectively) had slightly higher dietary diversity when compared to young and adult women (FCS = 61.7 and 62.4 respectively) (Table 3).

Following the onset of diet change, we see large increases in dietary diversity in terms of FCS for all study groups across all islands. Although the differences are not statistically significant for the post-diet change FCS between groups in each island, the FCS increases for each and every group over time. Indeed, when comparing the FCS before and after the diet change within the same sampling groups shows that in most cases, there is a statistically significant increase in the FCS (Table 4). The results show that overall, across all samples, the FCS increased by 18% going from an average FCS of 63.4 points (SD = 16.7) before the diet change to a FCS of 74.7 points (SD = 16.9) after the change. Soledad Miria has the highest FCS improvement with a 30% increase from an average FCS of 55.9 points (SD = 11.9) up to a FCS of 72.7 points (SD = 12.1). Moreover, the results in Soledad Miria show that this FCS improvement is observed across all sampling groups where there is a statistically significant increase in FCS after the diet change (Table 4). On the other end, the results for Gardi Sugdub show the lowest FCS improvement, with an overall 6% increase from a FCS of 70.4 points (SD = 16.1) to a FCS of 74.7 points (SD = 16.4), with this increase being significant only among the male groups (Table 4). In Nargana, only in one of the sampling groups, there is a statistically significant increase in FCS, i.e., adult women increase from a FCS of 65.2 points (SD = 20.6) to a FCS of 85.5 points (SD = 19.0) (31% increase). Interestingly, the FCS gap between study islands seems to have reduced following the onset of diet change, with groups in Soledad Miria reaching similar FCS levels with their peer groups in Gardi Sugdub and Nargana (Table 3).

Table 4 Changes in FCS after diet change within groups by study island

	n	Past FCS	Present FCS	Sig.
Gardi Sugdub				
Young men	23	69.7	75.9	0.016*
Adult men	23	71.0	77.9	0.002**
Young women	21	69.6	71.0	0.498
Adult women	23	71.2	73.7	0.234
Soledad Miria				
Young men	24	58.6	72.9	0.000***
Adult men	26	57.3	73.0	0.000***
Young women	24	55.8	73.6	0.000***
Adult women	24	51.7	71.3	0.000***
Nargana				
Young men	20	67.9	76.1	0.131
Adult men	22	65.3	74.2	0.116
Young women	20	60.6	73.0	0.059
Adult women	20	65.2	85.5	0.000***
All sites				
Young men	67	65.2	74.9	0.000***
Adult men	71	64.2	75.0	0.000***
Young women	65	61.7	72.6	0.000***
Adult women	67	62.4	76.4	0.000***

Significance levels: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

When looking at the individual food items, both the expert interviews and the household surveys suggest major changes before and after the onset of diet change. Expert interviews suggest that before the diet change, families mostly prepared traditional meals with locally produced ingredients (e.g., dule masi) and drank traditional beverages prepared with

Fig. 1 Changes in the frequency of weekly consumption of different food groups before and after the diet change. For a breakdown by sampling group and study island refer to Fig. S3 (Supplementary Material)

maize and cacao (Ministry of Health Nutritionist Officer, personal communication, February 19, 2018). After the diet change, families are opting for imported dishes (e.g., burgers, fries) and ready-to-make soft drinks and coffee, which increased their sugar intake compared to traditional food options (Ministry of Health Guna Cultural Officer, personal communication, February 19, 2018).

The in-depth analysis of food group consumption within a seven-day period sheds even more light on the characteristics of the diet change that Guna communities are experiencing. On the one hand, the results show that the consumption of traditional meals, local bushmeat, and traditional drinks is declining in favor of western food-related food groups including imported meat and carbonated soft drinks. On the other hand, there has been a consistent increase in the consumption of all other food items, such as pulses, vegetables, fruits, dairy products, and other fats (Fig. 1), which tend to be associated with food purchases (see next section). This same pattern of an increased prevalence of westernized food options and the decline of traditional options can be observed across all sampling groups and study sites (see Fig. S3, Supplementary Material). Moreover, the results suggest that for every study group across all study sites, the decline of traditional food groups and the increase of westernized food options are in most cases statistically significant (see Table S4, Supplementary Material).

Drivers of diet changes in Gunayala

The household surveys and expert interviews point to the many factors driving diet change. From the perspective of the local communities, the difficulty or ease to find certain food items/ingredients underpins most of the different types of diet change (Fig. 2), while experts tend to point to more on the underlying drivers. For example, the decline in the consumption of traditional dishes is mostly linked to the reduced availability of traditional food ingredients, while the increased prevalence of westernized dishes is mostly linked to their easier accessibility (Fig. 2).

In more detail, according to the local communities, the lack of the availability and access to the local ingredients (e.g., local varieties of cassava, yam, rice, maize) needed to prepare traditional dishes and drinks has become the main barrier to consume them (Fig. 2). According to

Fig. 2 Drivers of diet changes according to the household survey. For a breakdown of drivers by group and study island refer to Figs. S4–S5 in the Supplementary Material

several experts, the underlying reason is that such local staple food crops are no longer produced by local communities due to shifts to formal livelihood activities linked to tourism (Guna Cultural Congress, personal communication, February 16, 2018).

Furthermore, the declining production of these traditional food items due to the livelihood change essentially means that purchasing these ingredients has become the only avenue for many Gunas households to prepare traditional dishes and drinks. However, this has in turn increased their cost, leading to the second reported barrier for traditional dishes/drinks, namely high prices (Fig. 2) "life is becoming increasingly more expensive [purchase food], and then, when have forgotten how to farm" (Soledad Miria Argar, personal communication, March 14, 2018).

Another reason for the decline of traditional dishes/drinks revolves around the loss of cultural practices in Gunayala. For example, for most traditional dishes/drinks, respondents suggested that they do not know how to prepare them, in turn favoring westernized meals for their ubiquitous accessibility and convenience (see also Figure S4, Supplementary Material). Several experts alluded to the fact that the loss of traditional knowledge has been the driver of diet change among the Gunas (Vice Ministry of Indigenous Affair, personal communication, February 20, 2018).

It is interesting to note that the main drivers of diet change according to the community perspective (e.g., reduced availability and high prices of traditional ingredients, convenience and lack of knowledge) are relatively consistent between study groups and islands (Figs. S4–5, Supplementary Material).

Sustainability impacts of diet changes in Gunayala

The expert interviews identified a series of highly interlinked socio-cultural, economic, and environmental sustainability

impacts due to the diet change in Gunayala. Below and in Table 5, we summarize the main sustainability impacts and the associated mechanisms. The causal loop diagram in Fig. 3 provides a detailed depiction of the linkages and main feedback loops between the characteristics, drivers, and impacts of diet change in Gunayala.

The most important social impact of diet change in Gunayala is the loss of ILK (Loops R1, R2, R3), which is a central element of the Guna society and culture, considering that it intersects with their close link to the SES (see "Introduction" and "Research approach"). This is because food in Guna society goes beyond what is consumed, but rather represents a whole subsystem of the Gunas culture that is in a way central to the transfer of ILK between generations and provides opportunities to strengthen community ties within and between families.[2] In other words, food is not simply a material, but has important cultural and social connotations. In more detail, the traditional Gunas food ingredients are obtained through agricultural activities in the mainland (e.g., staple indigenous crops and varieties, such as native yam, yuca, and otoe, see Introduction), fishing, and bushmeat hunting (e.g., lobster, deer). These agricultural, fishing, and hunting activities that provided the main ingredients for the traditional Gunas diet have historically also offered the main opportunities for Guna elders to share their history, beliefs, traditions, and ecosystem management techniques to their grandsons. The Gunas have relied for generations on this system to pass on their culture and ILK. For example, one of the local experts reminisced: "we used to have our own education systems, but that has been lost. Before we used to take the kids for fishing, collect firewood, work the fields. There, the grandfather will teach them, guide them" (Gardi Sugdub local researcher, personal communication, March 12, 2018). At the same time, these shared community-oriented agricultural, fishing, and hunting activities led by the local chiefs strengthened community ties and provided certain food items to conduct local festivities.[3] However, with the increasing reliance on purchased food, much of this ILK is gradually declining (or even lost), as traditional food ingredients (and their production/harvesting practices) have been replaced by convenience stores. This has major ramifications for social sustainability, as for example, according to one of the Indigenous leaders: "local chiefs have forgotten their role, 40 years back, local chiefs used to lead their communities to work the fields" (Guna Cultural Congress Secretary General, personal communication, February 16, 2018).

The second major social sustainability impact of diet change relates to food security. Here we find two opposing mechanisms in that diet change can have some positive and some negative impacts on food security. On the one hand, as outlined in above, dietary diversity has improved for practically each study group in each island, which implies certain benefits for food security. Furthermore, although past FCS tended to vary between islands, these scores seem to converge currently between islands suggesting a certain diet homogenization (Tables 3, 4). However, we should point out that despite certain improvements in dietary diversity and elements of food security, these changes have not necessarily led to more healthy eating habits (see next paragraph). On the other hand, this growing reliance on purchased food can catalyze food shortages when trade routes are disrupted (e.g., during periods of tropical storms) or for some households that rely on income from the tourism sector to buy food (see economic impacts below). Regarding the former, most Gunas islands are very densely populated and most shops have limited stocked provisions. These ever-increasing disruptions due to climate change cause food shortages for marketed items and pose significant risks for food security (which is compounded from the general decrease of self-produced items as explained above). In particular, the limited capacity of local stores to stockpile more than a few days of supplies leads sometimes to food shortages during weather disruptions (Gardi Sugdub Marine Biologist, personal communication, March 12, 2018). This is further exacerbated by the loss of traditional coping mechanisms, such as the storage of family grown staple foods, such as yam, cassava, and corn, to outlast storms and disruption to food supplies (CONAMUIP, personal communication, February 24, 2018). For example, one respondent mentioned that "during high tides, people cannot cross to the mainland to get food, but our grandfathers used to extract coconut oil, smoked fish, yuca, and they will store them on calabacínes [containers made out of dried out zucchini], and we will know there is always food in the house" (Vice Ministry of Indigenous Affair, personal communication, February 20, 2018).

The third major social sustainability impact of diet change relates to its health outcomes. Similar to food security, we observe different mechanisms, some of which lead to positive and some to negative health outcomes. Although following the observed diet change, the consumption of certain food items, such as fruits and vegetables, has generally increased (see previous sub-section), the fact remains that the simultaneous consumption of many unhealthy food items (e.g., red meat, processed food, sugary beverages, oil) has also increased. Although the fast food meals and soft drinks represent an appetizing new option among young Gunas due to their low cost and easy preparation (see Fig. 2), they also have high sugar and fat content, which might increase the levels of obesity and the risks for non-communicable

[2] For a deeper explanation of the links between ILK and social cohesion/ties in Gunas society refer to a Dam Lam and Gasparatos (2023).

[3] For example, after harvesting community shared crops (e.g., maize, sugarcane) a four day celebration will follow with fermented traditional drinks made out of the harvest (Gardi Sugdub Marine Biologist, personal communication, March 12, 2018).

Table 5 Main sustainability impacts of diet change in Gunayala and associated mechanisms

Sustainability pillar	Impact category	Mechanism	Feedback loops
Social	Loss of ILK	Reduced demand for traditional food items affects cultural practices associated with food consumption and production that are important opportunities for transmitting ILK, which is central for Gunas society	R1: Non-traditional meals preparation/consumption (+) Reliance on purchased food (+) Need for income generation (+) Local engagement in tourism activities (−) Local engagement in agricultural, fishing and hunting activities (+) Opportunities for elders to share traditional knowledge (+) Indigenous local knowledge (+) Traditional food preparation knowledge (+) Traditional meals preparation / consumption (−) R2: Non-traditional meals preparation/consumption (+) Reliance on purchased food (+) Need for income generation (+) Local engagement in tourism activities (−) Local engagement in agricultural, fishing and hunting activities (+) Local ingredients supply (−) Local ingredients price (−) Traditional meals preparation/consumption (+) Strength of community and family ties (+) Indigenous local knowledge (+) Traditional food preparation knowledge (−) R3: Local chiefs' leadership (+) Local engagement in agricultural, fishing and hunting activities (+) Opportunities for elders to share traditional knowledge (+) Indigenous local knowledge (+)
Social	Food security	Increased consumption of new food items has increased dietary diversity Increased reliance on imported food has increased the vulnerability of food supply to disruptions during climatic shocks (e.g., storms) Increased reliance on food purchases for some Gunas households increases the vulnerability of food access to livelihood disruptions (e.g., decline of tourism activities)	NA
Social	Health	Increased reliance on processed food items increases the risk of non-communicable diseases Increased consumption of non-traditional instant flavored drinks has reduced urgency of boiling water and increased prevalence of communicable diseases	NA
Economic	Income generation	- Increased demand of imported food items offers income opportunities for shop and restaurant owners - Increased engagement in tourism activities for income generation, as it is more more profitable than local food production	R4: Non-traditional meals preparation/consumption (+) Reliance on purchased food (+) Need for income generation (+) Retail and food businesses (+) Income generation (+) Youth's interest in tourism sector (+) Local engagement in tourism activities (−) Local engagement in agricultural, fishing and hunting activities (+) Opportunities for elders to share traditional knowledge (+) Indigenous local knowledge (+) Traditional food preparation knowledge (+) Traditional meals preparation/consumption (−)

Table 5 (continued)

Sustainability pillar	Impact category	Mechanism	Feedback loops
Economic	Increased cost of living	Many households invest a large proportion of their income for food purchases	NA
Environmental	Waste generation and marine pollution	The plastic wrapping of many new food items is a major source of waste and marine pollution	NA
Environmental	Overexploitation of marine species	Diet change indirectly causes the overexploitation of some marine species to generate income from the tourism sector to be used for food purchases	R5: Non-traditional meals preparation/consumption (+) Reliance on purchased food (+) Need for income generation (+) Local involvement in tourism activities (+) Demand for high value marine products (+) High value marine species exploitation (−) Local ingredients supply (−) Local ingredients price (−) Traditional meals preparation/consumption (−)

diseases such as diabetes (Regional Head Ministry of Health, personal communication, February 19, 2018). However, the full scope of the health implications of these dietary changes is just starting to emerge. Health ministry officials are starting to realize the need to conduct a comprehensive investigation of the health implications of diet change. As one respondent pointed out: "so much [the diet change], that now we have [in Gunayala] hypertension and diabetes, years ago we didn't have that many, now we need to conduct preventive health census, maybe then we will be able to realize the hidden cases, the asymptomatic, and know in reality how many there are" (Ministry of Health Nutritionist Officer, personal communication, February 19, 2018). At the same time, the switch from traditional beverages based on mixing boiled water with locally produced crops (e.g., cacao, maize) to instant flavored mix drinks that do not necessarily use boiled water has removed the urgency of boiling water from freshwater sources (mainly rivers), leading to the high prevalence of some communicable diseases such as diarrhea (Regional Head Ministry of Health, personal communication, February 19, 2018).

Diet change has had a series of direct and indirect economic impacts (Loop R4). On the one hand, diet change has created the pre-conditions and opportunities for income generation for some community members through small stores that sell food items and restaurants. Although the number of such establishments is relatively limited considering the generally small size and populations of individual islands (thus involving only a small number of families in each island), they can provide rather stable income, as they tend to cater to the local communities rather than tourists that are a more seasonal enterprise.

However, the more important economic impact of diet change is the increasing allocation of money to food purchases, especially for younger Gunas (Loop R4). For many of the young Gunas, food purchases have become the main avenue for accessing food, due to their increasing engagement in tourism-related economic activities rather than traditional agriculture and fishing activities,[4] as "many young Gunas don't want to work on the land anymore, they choose tourism as the source of income" (Gardi Sugdub Tourism Leader, personal communication, March 12, 2018). However, for some community members, this income can be rather precarious, as one respondent put it aptly: "they think they can rely on the income produced from selling lobster, but when there is fishing ban, they have no money

[4] In summary, this intersects with broader changes in the livelihoods of many Gunas (as well as of the broader economic system of Gunayala), and particularly the switch from subsistence-based agriculture- and fishing-oriented livelihoods, to more formalized livelihoods relying on the expanding tourism sector. For a more detailed explanation of these phenomena refer to Dam Lam and Gasparatos (2022).

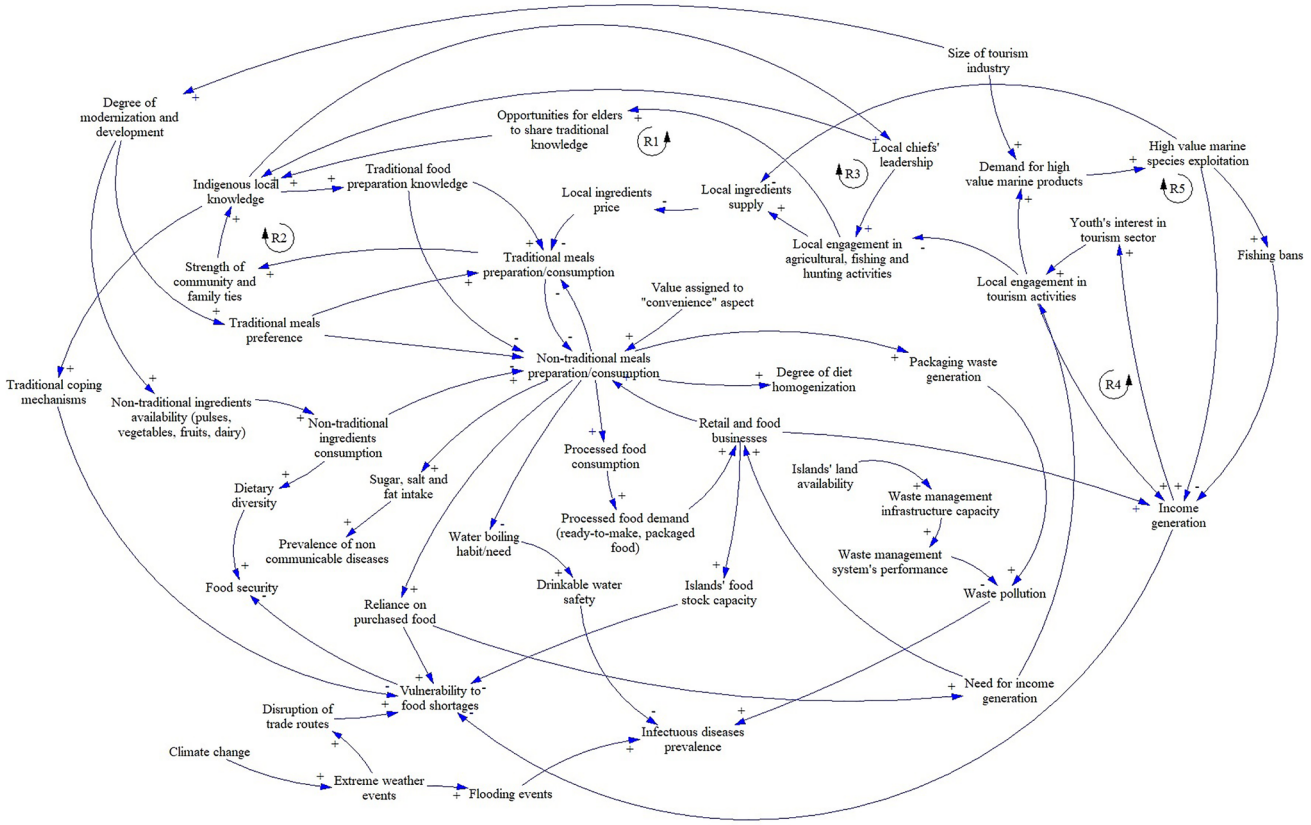

Fig. 3 Causal loop diagram of the drivers and impacts of diet change in Gunayala

to purchase food" (Vice Ministry of Indigenous Affair, personal communication, February 20, 2018). Interestingly, this implies certain trade-offs with food security for those Gunas that rely on income from selling lobsters in the tourism sector, as discussed above. Interestingly, these livelihood shifts have in turn put further pressures on Gunayala's marine ecosystem, mediating some of the environmental impacts discussed below (see overexploitation).

The main environmental impact of diet change in Gunayala relates to the pollution from the packaging of processed food, such as plastic wrapping of food items and bottles/cans of beverages. In many aspects, this is due to the fact that each island community in Gunayala essentially functions as a semi-autonomous entity and a closed system. While trash generation due to diet change has increased, waste management in Gunayala still relies on each community's/island's capabilities. This poses a new environmental challenge that Gunas have not faced in the past and are struggling to tackle currently in the midst of the unfolding diet change. For example, according to one respondent "the Guna people are very aware of the challenges we are facing now, such as their trash handling. Before, our ancestors generated trash that came from the nature, and that trash should return to nature. For instance, when we eat fish, the leftover bones go back to the ocean where they belong, and where they disintegrate. However, now as technology has entered, things have changed. We have problems with the plastic. They should return where they were produced" (Ministry of Health Sanitation Officer, personal communication, February 19, 2018). Currently, there is no effective waste management system in the Gunas islands to cope with the increase in food-related waste. For example, "there is so much trash that is impossible to recycle there. They don't have the capacity, as the islands are too small without recycling processing plants. Most of the trash goes to the ocean. I am talking about beer aluminum cans that goes to the bottom of the ocean" (AECID Indigenous Development Director, personal communication, March 2, 2018). This lack of viable waste management options has had wider environmental implications. For example coastal mangroves have been used as dumping sites, which in turn have precipitated unintended health risks. As one respondent suggested "here the trash is dumped into the mangroves, and then when a river flooding occurs, all that trash reached back here, and affects our health" (Gardi Sugdub Marine Biologist, personal communication, March 12, 2018).

The second and more indirect environmental impact of diet change is associated with the overexploitation of certain

marine species (Loop R5), such as lobsters and spider crab, which have high economic value for the tourism sector, decreasing their availability and access to Guna households (Gardi Sugdub Marine Biologist, personal communication, March 12, 2018) (see above). A respondent suggested that "tourism has increased tenfold at least. The mounting pressure in Gunayala has also increased significantly and has serious consequences in their way of life. They have exhausted their lobster to satisfy the demand" (AECID Indigenous Development Director, personal communication, March 2, 2018). In a sense, the Gunas have essentially traded the availability of traditional marine resources to gain access to western food items via the booming tourism sector.

Surprisingly, despite the switch to a more westernized diet that contains more meat (Fig. 1), the respondents did not allude to forest degradation for meat production. Although the forest located on Gunayala's mainland has traditionally played a minor role in their diet beyond providing occasional bushmeat,[5] it remained unaffected by the socioeconomic changes: "cattle raising is forbidden in Gunayala, because we believe that it destroys [the grasslands], and requires a lot of space, because the Gunas have a belief of mother earth and protecting the resources" (Vice Ministry of Indigenous Affair, personal communication, February 20, 2018).

Discussion

Associating observed diet change in Gunalaya with trends in other Indigenous contexts

Some of the characteristics, drivers and impacts of diet change in Gunayala reflect trends observed in other Indigenous contexts. Although it is possible to identify some convergences and divergences in some of these trends, it is not always possible to establish direct comparisons with other Indigenous contexts due to the differences in the aims, objectives and methods of the underlying studies.

When looking at the characteristics and drivers of diet change in Gunayala, it can be argued that it has been more of a by-product of broader development processes rather than a purposeful and concerted effort to improve Gunas food security. In particular, although diet change has resulted in improved dietary diversity as evidenced by the increase in FCS consistently across study groups and islands (these changes are in most cases statistically significant, Tables 3, 4), the past FCS were adequate across all groups regardless of gender, age group, or level of development (despite some differences between islands) (Table 3). In fact, the Gunas largely enjoyed a stable and readily available local selection of staple food crops, fish, and wild food, before gaining access to a new and wider variety of food groups (i.e., western dishes, processed food) (Nargana Sagla, personal communication, March 13, 2018). This reflects studies in other Indigenous contexts that have found both that (a) local diets can be rather diverse and meet the food security and nutritional requirements of local communities (Iannotti and Lesorogol 2014, Iragamo 2016) and (b) diet changes are not necessarily the outcomes of coordinated actions to improve the food security of local communities, but rather an offshoot of (often unchecked) development processes (Beaumier and Ford 2010; Duhaime et al. 2002; Sarkar et al. 2020; Valery et al. 2012; Powell et al. 2015).

Here it is important to note the actual characteristics of diet change, which again show some similarities and divergences with other Indigenous communities. On the one hand, the increased intake of sugar, fats, soft drinks, and coffee is consistent with other case studies (Sharma et al., 2010, Port Lourenço et al. 2008). However, the overall diet is less skewed toward starchy staple foods and leafy vegetables compared to other Indigenous communities (Reyes-García et al. 2019), possibly achieving a better balance among the different food groups by increasing the intake of protein and dairy products.

Yet despite these generally positive effects on diet diversity, we need to point out that the new diet is not necessarily healthy or less vulnerable to disruption. For example, increases in dietary diversity are not necessarily healthy (e.g., Parrotta et al. 2015; Kuhnlein and Receveur 1996, 2004), with this dual outcome of diet change on the one hand improving food security, but on the other hand having negative public health outcomes observed in other Indigenous contexts (Mishra et al. 2017; Sharma et al. 2013; Yuen 2015; Rapinski et al. 2023). Although currently there are no conclusive studies about the possibly negative health outcomes of the observed diet changes in Gunayala, some of the newly introduced food groups have been directly associated with diabetes, obesity and other non-communicable diseases that have been reaching epic status among Indigenous people in other parts of the world (e.g., Valery et al. 2012, van Vliet et al. 2015).

Beyond the changes in food items, an important dimension of diet change in Indigenous areas also entails the changes to the origin of the food (Galvin et al. 2015, Lourenco et al. 2008). In Gunayala, there is a marked shift in the origin of food, from seascapes and inland agricultural areas (less from forest) to shops in populated islands. These shifts in food origin (and essentially in the food production

[5] The forest rather plays a role of the community pharmacy, providing the bulk of the medicinal plants to the community healers "the forest has a deep cultural root for us, we believe the trees are our brothers, like a great chief used to tell us, the forest is our pharmacy, from there we get our medicine" (Guna Cultural Congress, personal communication, February 16, 2018).

and harvesting process), have a series of socioeconomic and cultural implications as unpacked below.

First, reliance on purchased food items might create vulnerabilities in access to food, and essentially some aspects of food security. In particular, the new western-influenced food system increases the availability of (and improves the access to) some food items through small convenience stores. This new market system is governed by supply and demand, and essentially dictates the access that households have to any given type of food item that is a marked departure from the traditional food system where communal food production/harvesting and sharing was the dominating social norm (see below) (Vice Ministry of Indigenous Affair, personal communication, February 20, 2018). Similar observations have been made in other Indigenous contexts (Finnis 2007; Sheehy et al. 2013). More importantly, reliance on purchased food items might increase food access vulnerability to livelihood disruptions and/or price increases, as for example evidenced during the COVID-19 pandemic (Stanger-McLaughlin et al. 2022; Ghosh-Jerath et al. 2022). Similarly natural hazards such as storms (that are exacerbated by climate change) have been compromising on occasions the access of Gunas to imported food through disruptions of food value chains, something that has been observed in other Indigenous contexts (FAO 2021b, Zavaleta-Cortijo 2020).

Second, the increasing reliance on purchased food rather than food traditionally produced in the inland farms has arguably affected social cohesion to some degree via the highly interlinked changes in food production and loss of ILK (Dam Lam and Gasparatos 2023). The traditional community-based food cropping and fishing systems of the Gunas have relied on the fact that all participating households shared equal responsibility for food stocks and the equal availability and access to stable stocks of food across the community, which arguably has changed with increased reliance on markets for food. Similar effects of diet change on social cohesion via the transformation of traditional food systems have been observed in other Indigenous communities (Kuhnlein et al. 2013; Sylvester et al. 2016). An equally important route to social cohesion loss is via the erosion of ILK again through the transformation of community-based food cropping and fishing systems, which were essential for the transmission of ILK through engagement in communal activities (partly due to diet change and partly due to livelihood shifts) (Dam Lam and Gasparatos 2023). The erosion of ILK and traditional values has also been linked to diet change in other Indigenous contexts (Gartaula et al. 2020; Mihiranie et al. 2020).

Finally, the changes in the origin of the food have had some interesting intersections with the natural landscape. On the one hand, they did not seem to have affected the forest, as there was no significant reported forest conversion to grassland over time for meat production due to the Gunas beliefs. The reported decline in the amount of bushmeat consumed over time (Fig. 1), mainly due to increasing scarcity (Fig. 2), is not due to overexploitation or loss of habitat from forest conversion, but due to the increasing reluctance of younger generations to engage in such hunting activities (see also Dam Lam and Gasparatos 2023). Conversely diet change intersected with livelihood transformation to have a more pronounced effect on the coastal environment. Here the increased harvesting of lobster has created some signs of overexploitation, and general degradation of the seascape (Dam Lam and Gasparatos 2023). However, here the interesting aspect is that this lobster is not consumed so much within Gunas, but is used to receive income to buy food from the retail market.

Delineating intersecting drivers and impacts through a sustainability science lens

Elucidating the characteristics, drivers, and impacts of the diet change in Gunayala through a Sustainability Science lens allows us to unpack the intricate linkages between Indigenous food systems and their broader social-ecological context. Our results indicate that the traditional food system in Guna links to practically all domains of sustainability (i.e., social, economic, and environmental) through changes in food preference, the processes of food production, harvesting, and preparation, the origin of food, and the embedded culture and values. In this sense, the diet change arguably affects the physical, mental, emotional, spiritual, cultural, and social wellbeing of the Guna communities and their ecological performance in the long run. The inextricable linkages between the food system, Indigenous people, and their environment have been identified for various previous studies, for instance tracking the importance of Indigenous food in environmental and cultural integrity (Kuhnlein et al. 2013), social support and networks (Sarkar et al. 2020), conservation of ILK (Egeland et al. 2009), and human rights, identity, and heritage (Damman et al. 2013).

An important observation is that the drivers and impacts of the diet change intersect and interact strongly with each other in often complex ways characterized by multiple feedbacks between them. For instance, the loss of traditional practices and values due to development processes is one of the main drivers of diet change in Gunayala. This leads to changes in the characteristics of the diet toward more western-based meals and less traditional dishes and ingredients. This diet change causes the further erosion of ILK and the cultural values associated with the food system (i.e., impact), in turn further intensifying the loss of traditional food practices (i.e., driver). The increased reliance of the Gunas on tourism for income generation (i.e., driver) has another reinforcing effect of their diet change, which contributes to the overharvesting of marine species used in traditional diets

(i.e., impact) to generate tourism income for purchasing food items (i.e., characteristic). Interestingly, such feedbacks are not only visible between the impacts and the drivers, but also between different types of impacts, for example economic changes can trigger an enormous shift in the socio-cultural system and vice versa.

Such complex linkages between the types, drivers, and impacts of diet change have been identified in different studies in the Global South beyond Indigenous contexts (Morgan and Fanzo 2020). Yet, we should point out that in the context of Indigenous communities these feedbacks are exceptionally difficult to predict and comprehend considering our limited understanding of their very unique relations with nature (FAO 2021a). Such complex human–nature relationships in the Indigenous food system have been widely studied in the literature (Kuhnlein and Damman 2008; Mazac and Tuomisto 2020; Turner and Turner 2008). However the often-reciprocal and multi-directional feedback loops within the food system, although recognized in studies on Indigenous food insecurity mitigation and adaptation (Lugo-Morin 2020), have been limitedly extrapolated and incorporated in policy-making processes. This study strengthens the argument proposed in a large number of recent works on Indigenous traditional food systems (Ford 2009; Guyot et al. 2006; Kuhnlein et al. 2013) and brings attention to the importance of these feedback loops in designing appropriate interventions for ensuring the food security of Indigenous communities.

Policy implications and ways forward

Positioning our findings from Gunayala within a broader Indigenous context, we observe both divergence and convergence in diet change patterns compared to other indigenous contexts (Rowley et al. 2000; Kuhnlein et al. 2004; Crittenden and Schnorr 2017; Powell et al. 2015) (see above). However, beyond the nutritional dimensions of this diet change, our research explored critically the underlying drivers and unfolding impacts, contributing empirical findings to the current knowledge at this interface. One conceptual implication of this research is that in Indigenous contexts where food production and consumption systems are interlinked with the local culture, the landscape and practically every facet of society, we need to move beyond narrow discussions of health and nutrition impacts toward a broader social–ecological system perspective of how the diet changes unfold (FAO 2021a). To achieve this, we employed a Sustainability Science lens that helped explore in-depth the pathways linking the drivers of the diet change, the actual changes and their impacts in a holistic manner (see previous section).

Here we need to point out that these interrelations between the drivers and impacts of diet change discussed above have not been unnoticed within Gunas society. In the past few years, the Guna authorities have been actively trying to preserve their traditional food system (including the traditional diet and food production systems), as a means of reversing some of these changes. Toward that end one of the respondents pointed out that "we need to cherish our native crops, for instance, we don't see [people farming] any more in Gunayala the sweet potato" (Guna Cultural Congress Production Director, personal communication, February 16, 2018). For example, a regional program has sought to recover local food production, and has been designed and pursued as a top priority in the region. According to one respondent, "local food production has declined; therefore, we created a special commission to assist local communities" (Guna Cultural Congress, personal communication, February 16, 2018). Furthermore, while other programs have tried to address the escalating trash collection problems in Gunas islands (partly due to food packaging), the remote location of Gunayala and the dispersion of communities across dozens of islands have created many challenges for the long-term management of the drivers or impacts of diet change. For example, according to a respondent "at one point, we tried to organize in some communities trash collection centers, but we couldn't find a way to make it work […], the first issue there is to send the trash from the islands to a location in the coast and then send a truck there every day" (Ministry of Health Regional Director, personal communication, February 19, 2018).

In this context of mitigation efforts, our research findings have some major implications for policy and practice in Gunayala, and Indigenous food systems more broadly. First, they point to the very integrated nature of the drivers and impacts of diet change, and second to the often bidirectional nature of these relations.

First, policies, programs and related interventions (including nutrition interventions) should seek to build upon, leverage or at least not disrupt the ties between Indigenous communities, their natural environment and traditional food systems. As has become clear from our case study, the current diet change driven by a multitude of processes is likely to have negative health, socio-cultural and environmental outcomes in the long-term (Fig. 3). A possible way forward would be to engage and offer opportunities to Indigenous people to play a leading role in preserving their local food system through integrating ILK with modern scientific knowledge and technology. A potential pathway to achieve this integration is by co-designing school curriculum tailored to Gunas' needs. Practical hands-on classes targeting young Gunas can help preserve traditional farming methods, indigenous crops, and traditional food insecurity coping strategies.

As outlined above, ILK and traditional practices permeate practically every stage of the food system starting from food production/harvesting, to food preparation, consumption, and the long-term management of food-related natural resources. In this sense, the traditional food system cannot be effectively preserved if these ties to the environment are severed. Strengthening these ties (or even reconnecting eroded ties) would, however, require concerted effort between sectors directly and indirectly linked to the food system.

Second, when designing such programs and interventions, we emphasize the importance of understanding the multi-directional feedback loops permeating the Indigenous food system, and utilizing them to reinforce positive societal and behavioral change in relation to diets. For instance, by leveraging certain positive feedback loops between the preservation of ILK (a major policy priority of Gunas authorities) and behavioral change toward traditional foods, it might assist the active design of interventions aiming to influence diet-related behavior in the broader population. Similarly, understanding negative feedback loops (e.g., the link between tourism, income generation, overexploitation of traditional food items, and food purchases) could assist in balancing the negative consequences. We need to point out that many of these feedback loops are already happening without our recognition. Thus, we argue that being aware of these feedback loops and knowing how the system operates (as well as its sensitive points) can leverage the success of related programs and interventions. Yet, despite the possible advantages of incorporating these feedback loops in decision-making processes, there have been few studies in the current literature in the food sector in general (and in the Indigenous context in particular). This could be an important future research direction to ensure sustainable food systems and food security in Indigenous contexts.

Beyond Gunalaya, our research findings have some broader implications for other Indigenous contexts experiencing rapid and profound diet change and food system transformation. First, if anything, Fig. 3 suggests the complex interlinkage between different and simultaneously unfolding types of diet change, through equally diverse drivers and with equally diverse impacts. Although each Indigenous food system is likely to experience different transformations and dietary change, the fact remains that these entail highly interconnected processes, with intimate links to the values, cultural dimensions, and characteristics of the SES (FAO 2021a). This implies the need for systemic approaches to understand, prevent and/or curb the negative impacts of diet change. Second, by engaging closely with ILK holders, this exercise shows very well how it is possible to integrate their insights when exploring how diet changes unfold. The ability to obtain such deep insights further supports the calls made to be more holistic in engaging Indigenous people in policy discussions for food systems sustainability globally (The Global-Hub on Indigenous Peoples' Food Systems 2021).

Conclusion

This Case Report unraveled the characteristics, drivers, and impacts of diet change in Gunayala (Panama) through a Sustainability Science lens. We combined insights from national and local experts engaged in different ways in development processes in Gunayala, as well as household surveys from three islands characterised by different levels of development and preservation of traditional values. Although we relied on the recollection of household respondents to identify diet changes, there seems to be a clear trend toward diet westernization across all gender/age groups and focus islands. Although this diet change seems to have resulted in greater dietary diversity (as a proxy of food security), experts overwhelmingly suggested that this comes with a series of negative health, socio-cultural, and environmental outcomes.

However, there is significant intersection between the different drivers and impacts of diet change. This includes interrelated processes of livelihood changes due to the growing reliance on tourism, changes in traditional agrarian/fishing/hunting practices, overexploitation of certain traditional food items for commercial use in the tourism sector, reliance on purchased food items, and the erosion of ILK, traditional values and social cohesion. We argue that it is important to adopt inter- and trans-disciplinary research approaches anchored on Sustainability Science to understand such diet changes (and their multiple interconnected processes), if we are to develop effective and sustainable interventions to prevent diet changes or mitigate their impacts in Gunayala, and Indigenous areas more broadly.

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