Dietary composition in the context of development: a re-examination of the nutrition transition

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Abstract

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A representation of the quality of an individual's dietary consumption in its entirety through a single measure that is succinct yet holistic has been sought by those within the nutrition research community for many years. The emergence of the Alternate Healthy Eating Index (AHEI) and its subsequent association with some of the greatest contributors to both morbidity and mortality globally has renewed interest in gathering a better understanding of what social, cultural, and economic forces might explain differences in consumption across populations and through time. To date, there has been no systematic evaluation of the variation in overall diet quality by country, year, age, and sex. Our analysis aims to fill this gap in knowledge through first gathering each of the 11 nutrient and food item components of the AHEI from the Risk Factors analysis of the Global Burden of Disease Study to construct a validated measure of aggregate diet quality. Further, we looked to use this measure to understand and explore the relationship between diet quality and a host of development indicators in order to test the underlying theory of the "Nutrition Transition". Then, with validated indicators of development, we built a predictive model to generate estimates of expected diet quality. We then used the ratio of observed to expected diet quality to benchmark country performance. Notably, the highest observed score was 65.6 (56.4 – 76.4, 95 UI) from Cuba in 2017, while the lowest score, 38.1 (32.1 – 45.9, 95 UI), was observed in Mongolia. Generally, index scores were shown to increase with both age and passage of time. In 2017, Cuba out-performed all others with an observed to expected ratio of 1.34, while Mongolia significantly underperformed with a ratio of 0.78. Through this analysis, we were able to demonstrate the variation observed in diet quality can be partly explained by indicators of development and energy intake. Additionally, we provide a means of comparison for those countries with lower quality dietary consumption than their peers of similar circumstance so they might have a point of reference to guide future improvement.

INTRODUCTION

With much of the world experiencing a rapid shift in overall disease burden away from infectious and parasitic diseases and towards more chronic, non-communicable diseases, a greater interest has developed in understanding what might be driving the increase in prevalence of diseases with this profile. Previous systematic analyses have identified a suboptimal or low-quality diet as the second largest cause of both death and disability globally.[1] Yet, significant challenges remain when attempting to accurately measure the entirety of the effect of dietary consumption and how it relates to our growing non-communicable disease burden. Further, the question of what are the most significant drivers of change in diet quality remains. While development status has long been suggested,[2] it has yet to be systematically evaluated in a way that leverages all available data on dietary consumption.

Within epidemiological studies of nutrition, investigators have generally chosen from among three different units of analyses when looking to study the health effects associated with the food that we eat: food items, nutrient content, and dietary patterns. Analyses based off of food item consumption have long been viewed favorably for the reason that recommendations given to the consumer are traditionally in the same form the food is eaten and is therefore easier to understand and follow. Alternatively, while analyses that focus on macro and micronutrient content of the foods we eat may present as a more analytically precise measure, they often lack the ability to capture the complex synergistic or antagonistic interactions at play within foods that are commonly consumed together. But, even with these complex interactions accounted for, following recommendations of nutrient content can also prove challenging for the fact that adequate food labeling is not readily available to the consumer globally. With this in mind, many systematic analyses aimed at quantifying the health burden associated with dietary consumption have focused primarily on food items, with the exception of nutrients considered as additives and those particularly important from a policy perspective, such as sodium or trans fatty acids.[1] It has only been more recently that identification of dietary patterns and their association to specific health outcomes has emerged as a promising aggregate measure of dietary quality.[3-4] These dietary patterns have demonstrated utility in both the generation of novel patterns among consumers as well as the being amenable to the application of a variety of existing dietary recommendations to study the patterns in aggregate.

Early efforts to measure quality of an individual’s overall diet began with the Healthy Eating Index (HEI) developed by the United States Department of Agriculture in 1995 and further updated with changing reccomendations.[5-6] But, it was in 2002 that a group of nutrition researchers presented the Alternate Healthy Eating Index (AHEI) which was built with premise that the HEI could be dramatically improve through a more specific recommendation of higher quality foods instead of focusing on macronutrient composition.[7] They went on to further hone their index to the point that was demonstrated to be twice as effective at predicting major chronic disease and CVD risk compared to the original HEI.[8-9] As a result of this, we chose the AHEI as our summary measure of diet quality to address the gap in knowledge that is the global disparity in aggregate quality of diet.

With this summary measure of quality, we can now look to systematically assess the relationship between dietary quality and accepted indicators of development previously theorized within discussions of the "nutrition transition".[2] And through an understanding of how development drives change in overall diet quality, we can assess whole country's performance through comparison of the quality of diet observed relative to what might be expected given that country's circumstance during the time of assessment.

METHODS

Dietary Intake Estimation

We incorporated all dietary data currently used within the Global Burden of Disease (GBD) Risk Factors Analysis. This included data from multiple sources including nationally and sub-nationally representative nutrition surveys, household budget surveys, accounts of national sales, as well as two comprehensive datasets from the United Nations Food and Agriculture Organization – the Food Balance Sheets and Supply and Utilization Accounts. Within our analysis, for all dietary factors other than sodium, we considered data from 24-hour diet recall as the gold standard, and adjusted each of the other methods of assessment to the gold standard method separately. For sodium, the 24-hour urinary collection was considered to be the gold standard assessment method. We used a Gaussian process regression framework that recognizes correlation in consumption over space, time, and age as well as the predictive power of specific covariates in order to estimate the mean intake of each dietary factor by age, sex, country, and year. We ran separate models for men and women. The standard deviation of each was separately estimated through a linear regression that captured the relationship between the standard deviation and mean intake in gold-standard, nationally representative surveys. The coefficient of this regression was then applied to the mean estimates to calculate standard deviation by country, year, age, and sex. Lastly, we characterized the distribution of each dietary factor at the population level. To achieve this, we used an ensemble approach that separately fits 12 distributions to individual level microdata specific to each data source's sampled population. We then use statistics measuring goodness of fit for each the 12 distributions to develop a weighting scheme that can then be used to optimize overall fit to the unique population-level distribution shape of each diet factor. This ensemble-weighted distribution shape is then applied to each of our 1000 draws of mean and standard deviation to reflect our uncertainty in our estimates to generate unique distributions of consumption by age, sex, country, and year.

Diet Quality

We then gathered the mean estimates for consumption of each of the 11 dietary factors specific to age, sex, country, and year that correspond to the components of the AHEI score. With the exception of Polyunsaturated Fatty Acids and Trans Fatty acids which are in the units of "percent of daily dietary energy", dietary factors were measured in the form of "grams per day". In order to convert the units of "servings per day" where present, we made use of traditional serving sizes recorded by the U.S. Food and Drug Administration as part of the National Labeling and Education Act passed in 1990. Then, we converted each of our estimates of consumption to their equivalent 10 point score. The cut-points for determining the scoring of sodium consumption was created through the use of deciles of global consumption. (Details on the cut-points used for each dietary factor can be found in the supplementary **Table S1**). Assuming independence between dietary factors, we randomly drew from each of the 11 distributions of dietary consumption by age, sex, country, and year to calculate a score with a theoretical maximum of 110 points.

Diet Quality and Development Status

In order to examine the relationship between diet quality and known indicators of development, we reviewed the literature and identified income, fertility, education, and urbanicity as known and reliable measures of development.[2] For income, we elected to use GDP with each year's income distributed over the previous ten years in order to simulate its lagged effect. We defined fertility as the number of live births to each woman specific to that location and year. As for education, we defined it as the mean years of education per capita specific to age, sex, location, and year. Urbanicity is defined as the proportion of population that lives within an urban environment during a given country-year. We will also assess diet quality through the use of our socio-demographic index which functions as a summary measure of differences in population fertility rate, income per capita, and education and further standardized to a value between 0 and 1. Full discussion of the methods used in its construction have been described elsewhere.[10] Beyond each of these, we chose to also control the energy consumed within each country over time given its potential to confound the relationship between development and diet quality. We then developed a predictive model that made use of each indicator of development and controlled for energy consumption through linear regression to produce estimates of what the expected value of AHEI should be. Making use of this expected value from our predictive model, we then create an observed to expected ratio using our original estimates of AHEI. This measure is intended to represent performance in the observed diet quality relative to what it would be expected to be after taking into account both energy consumption and the development status of the population for that location and year.

RESULTS

Alternate Healthy Eating Index

Global Level

In 2017, we estimated the AHEI score to be 50 (43 – 57.9, 95 UI). This varied geographically and by individual component (**Figure 1**). There was not significant variation between men and women, among only the healthy components (fruit, vegetables, nuts & legumes, polyunsaturated fatty acids, whole grains, and seafood omega-3 fatty acids) (18.5 vs. 18), unhealthy components (alcoholic beverages, red & processed meats, sugar-sweetened beverages, sodium, and trans fatty acids) (10.6 vs. 32.8), or full index (49.1 vs. 50.8), respectively. While the greatest single component difference among men and women was observed in alcoholic drink consumption with an observed 1 point difference (1.1 vs 2.1). The highest AHEI scores were consistently observed the oldest adults, those 70 years and older. From this, we observed a steady decrease to the young adults, or those less than 40 years old. Young adults exhibited the lowest index scores, a 5.7% difference relative to those of the oldest age group. This pattern held among both women and men. Between 1990 and 2017, the AHEI increased by 12.1%, with a slightly greater increase being observed in women (12.6%) than men (11.1%).

GBD Regions

Overall diet quality varied significantly by region in 2017 (**Figure 1**). This ranged from 61.1 and 59.3 with the highest scores observed in the Caribbean and Tropical Latin America, respectively, to lowest score of 42.8 observed in Oceania. Between 1990 and 2017, every region with the exception of Oceania saw an increase in overall diet quality scores, with Central and East Asia experiencing the largest with 8.94 and 7.9 point or 23.2 and 20% increases, respectively. Oceania was the sole region to have a reduction in quality where a 2.5 or 5.4% decrease was observed.

National Level

In terms of overall diet quality in 2017, Cuba demonstrated the highest score of 65.5, while Mongolia trailed behind with a score of 37.7 (**Figure 2**). Among the 20 most populous countries, Iran and Turkey demonstrated the highest scores of 63.4 and 61, respectively, while Pakistan demonstrated the lowest score of 40.6. Between 1990 and 2017, the countries that exhibited the greatest increases in diet quality were Laos and Equatorial Guinea who each saw an increase of 32.8 and 32.7% (**Figure 3**), respectively. For Equatorial Guinea, this increase was largely driven by significant improvements in fruit and vegetables consumption which represented 32.6% of the total positive or negative change in quality observed, whereas the increase in Laos was driven by an increase in vegetable consumption which represented 41.3% of the change observed. As for those with a decrease in quality, Cyprus and Bangladesh experienced the most significant with a decreases of 10.3 and 9.1%, respectively (**Figure 3**). In Cyprus, this was mostly driven by a decrease in the consumption of polyunsaturated fatty acids which represented 36.3% of the change observed, while in Pakistan this was mostly driven by a dramatic increase in sodium consumption which represented 73.5% of the change diet quality observed. Of the 20 most populous countries, the greatest improvement was observed in Vietnam with a 21.7% change. This was mostly driven by an increase in consumption of vegetables which represented 28.5% of total change. Of these same countries, the greatest reduction in quality was observed in Bangladesh with a 9.8% change. An increase in sodium consumption was the greatest contributor to this representing 46.5% of all change.

Levels of Development

The observed population-level AHEI scores demonstrate significant variation across quintiles (Low, Low-middle, Middle, High-middle, High SDI) of development as measured by our socio-demographic index (SDI) that is shown to have narrowed significantly over time (**Figure 4**). In 1990, the largest AHEI score was observed within the High SDI quintile (48.2), while the lowest was observed in the High-middle SDI quintile (41) producing a mean difference of 7.2 points. Whereas in 2017, the largest AHEI score was observed amongst those of the High SDI quintile (51.2), whereas those of the Low SDI quintile demonstrated the lowest quality diet (47.9) representing a mean difference of 3.3 points and a reduction in the gap between quintiles by 54.2%. Between 1990 and 2017, each quintile demonstrated an improvement in diet quality, with the High-middle quintile increasing the most by 17.7% and the Low quintile increasing by the least at 3.3%. The change observed in the High-middle quintile was driven primarily by an increase in consumption of vegetables and polyunsaturated fatty acids which represented 59.5% of the difference. The change in the Low quintile was driven by increases in both healthy and unhealthy components alcohol and vegetables, representing 45.6% of the overall change in diet quality.

Expected Diet Quality

In 2017, Cuba out-performed all others with an observed to expected ratio of 1.34, while Mongolia significantly underperformed with a ratio of 0.78 (**Figure 5**). Considering the 20 most populous countries, Iran demonstrated the strongest performance with a ratio of 1.29, while Pakistan underperformed with a ratio of 0.85. Among those that demonstrated a better quality diet than expected, Laos showed the greatest improvement over time with a 28.6% increase, while Cyprus's diet quality decreased the most significantly by 10.8%. When considering those under-performing, Kazakstan had the greatest improvement in diet quality relative to the expected with a 26.3% increase, while the ratio of Namibia decreased by 10.7%, more than all others under-performing.

DISCUSSION

In our systematic analysis of total dietary quality, we found that the quality of food consumed varies significantly by country, by age, and through time. Diet quality was demonstrated to increase with age. And while we observed a global increase in quality over time, this was not the case for every country with some having decreased in quality over time. Additionally, we were able to systematically evaluate the relationship between indicators of development status and diet quality and develop a means to benchmark each country's observed diet quality relative to the quality that is expected when considering their development status.

Among the risk factors assessed as part of the Global Burden of Disease 2016 study, suboptimal diet continues to be attributed to a larger percentage of overall disease burden over time.[1] This is in part due to changes in the epidemiological profiles of many countries shifting from infectious diseases to non-communicable, chronic conditions,[11] but it can also be partly explained by the quality of the food being consumed globally not shifting towards healthier choices at a commensurate rate. As we explored through our analysis, there is a significant relationship between the quality of food chosen by individuals and the level of development of their surrounding environment. This is likely tied to a generalized increase in accessibility of heavily processed, energy-dense foods with a poor nutrition profile. [12] Yet, while we were able to demonstrate that some of the relationship can be explained by differences in these development indicators, our study also highlights that there are still additional analysis needed to better understand what other factors continue to drive the remaining differences we observed.

Given this is the first time that estimates of the AHEI have been produced on such a comprehensive scale, there are few opportunities for comparison of our results with others that are directly comparable. Yet, for those that are available, we found observed AHEI scores to be quite consistent. As the result of our own independent analyses, we found that adults sampled as part of the National Health and Nutrition Examination Survey between the years of 1999-2012 demonstrated and average AHEI score of 41.8 (39.6 – 44, 95 UI) while our results for that same time period produced estimates of 41.5 (30.6 – 53.4, 95 UI). It is of particular note that each of these scores do not include the contribution of trans-fatty acid consumption as it is not measured as a part of NHANES dietary assessment. In addition, an observable positive temporal trend in

AHEI score is present in both our estimates (2.5%) and those from NHANES (4%). Also, the NHANES participants also demonstrate an increasing AHEI score with age similar to the trend observed in our results. Finding alignment between our results and well-implemented surveys such as NHANES further demonstrates the validity and reliability of this analysis.

Taking all of this into account, our findings provide the basis from which policy makers might compare historical trends in overall diet quality among men and women of different ages to ensure no one group falls behind the others. Through our analysis, they are also able to better understand where their country currently finds itself relative to other countries of similar circumstance. This idea of international benchmarking has transcended disciplines of study and proven to be a quite effective means of motivating change.[13-14] And with the results provided by our analysis, we not only provide a detailed accounting of areas that need the most improvement, but also a path towards achieving those goals.

An area that might further improve the performance of AHEI as a measure of diet quality is the exploration of a weighting scheme that better represent the relative contribution of specific components to a healthy diet. As has been shown through previous epidemiologic studies, consumption of specific dietary factors produce much greater risk of poor health outcomes than others relative to others who demonstrate significantly smaller effect sizes. An example of this is in a study by Miller and colleagues[15] where they assessed 35 mutually exclusive food groups and performed a principal component analysis to assess which food groups offered the greatest reduction in colorectal cancer incidence, in effect generating novel dietary patterns solely from those observed with the study participants. It is likely the AHEI would benefit from the introduction of an appropriate weighting scheme, especially one that might maximize a decrease the incidence of the diseases that lead to the greatest morbidity and mortality. Yet, for as much as these analyses have to offer they should be approached with caution. Patterns of diet generated through data-driven approaches may suffer from lack of generalizability to other populations.[15] It is for this reason that the AHEI needs continued validation among populations of differing consumption patterns.

The greatest strength of our analysis in its current form is its use of the best available dietary data from multiple different sources with biases accounted for in each type. Through this approach significantly more data is used, all of which then contributes to our understanding of differences in consumption between and within countries over time as well as by age and sex. This then was able to further strengthen our comprehensive estimates of diet quality as measured by the AHEI and its ability to describe global variability in all health-contributing components of a population's diet.

Another strength of this analysis is the fact that the AHEI is quantitatively derived and validated through application to individual-level, longitudinal consumption that is then associated with specific health outcomes. Something that has been further validated somewhat recently with the application of AHEI within additional cohorts beyond those used in the original analyses.[16] Only with analyses such as these can findings of associations between dietary quality and health outcomes be demonstrated as robust and lead to more widespread use of the index.

In conclusion, our analysis represents the first time that comprehensive estimates of overall diet quality have been produced at this scale. Further, we were able to demonstrate a significant association between certain indicators of development and overall diet quality providing further validation of previous described theory. It is our hope that the results of this study will be used to guide the implementation of effective population-level interventions to improve overall diet quality and combat the growing health burden associated with non-communicable diseases.

FIGURE 1. Stacked bar chart by component of full index globally and by region.

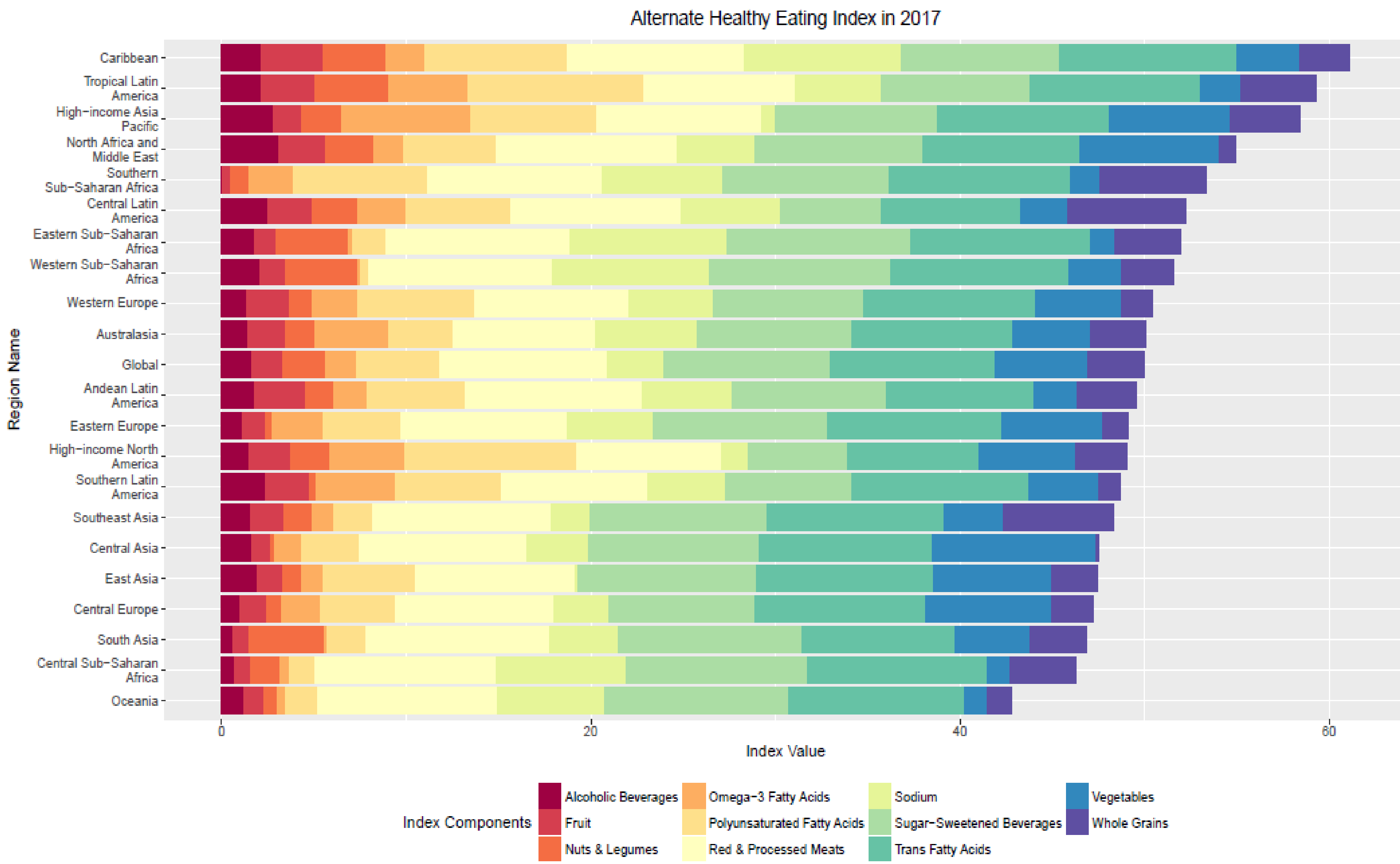

FIGURE 2. Overall Diet Quality, both sexes and age-standardized

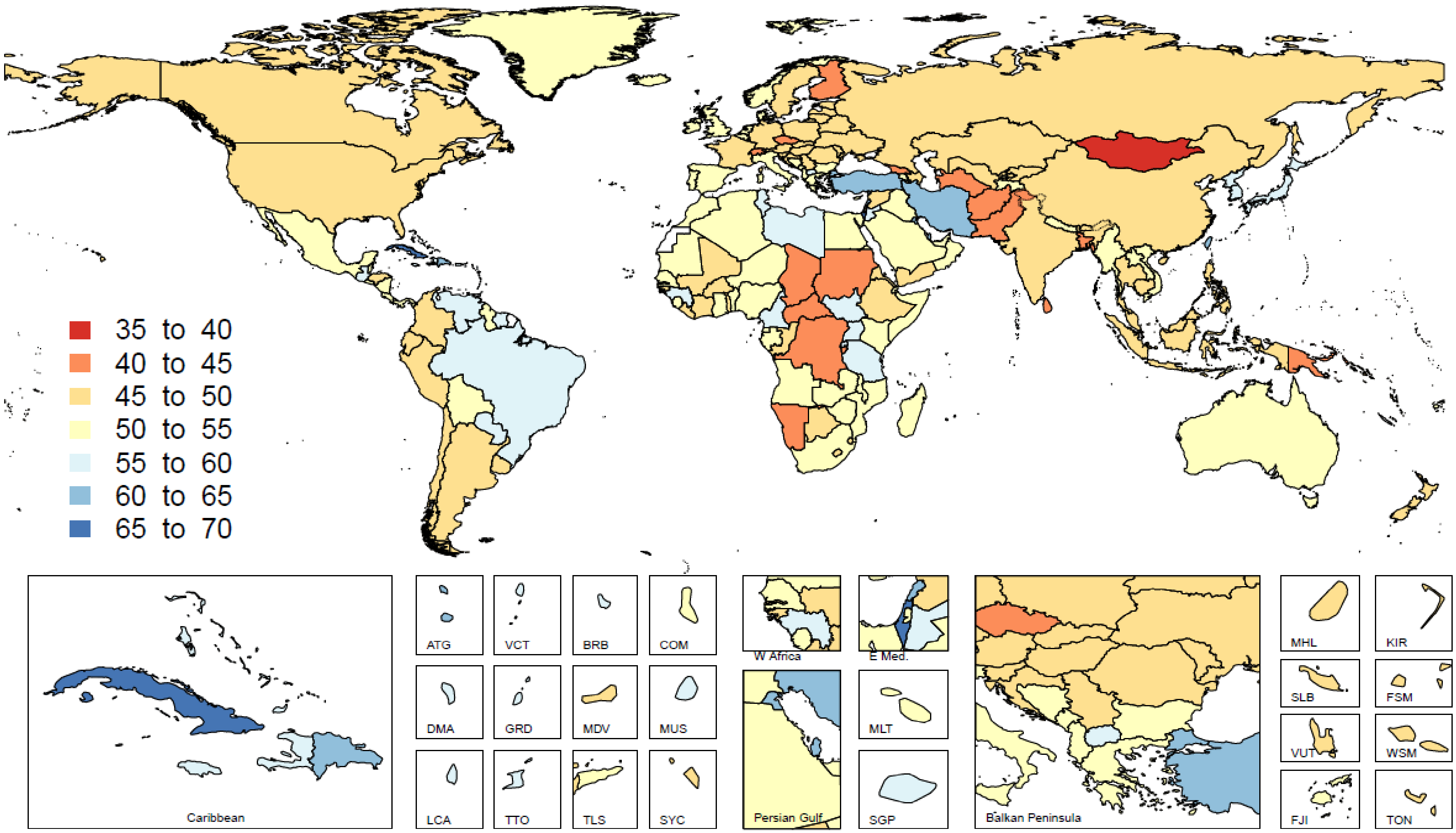

FIGURE 3. Percent Change in Diet Quality between 1990-2017, both sexes and age-standardized

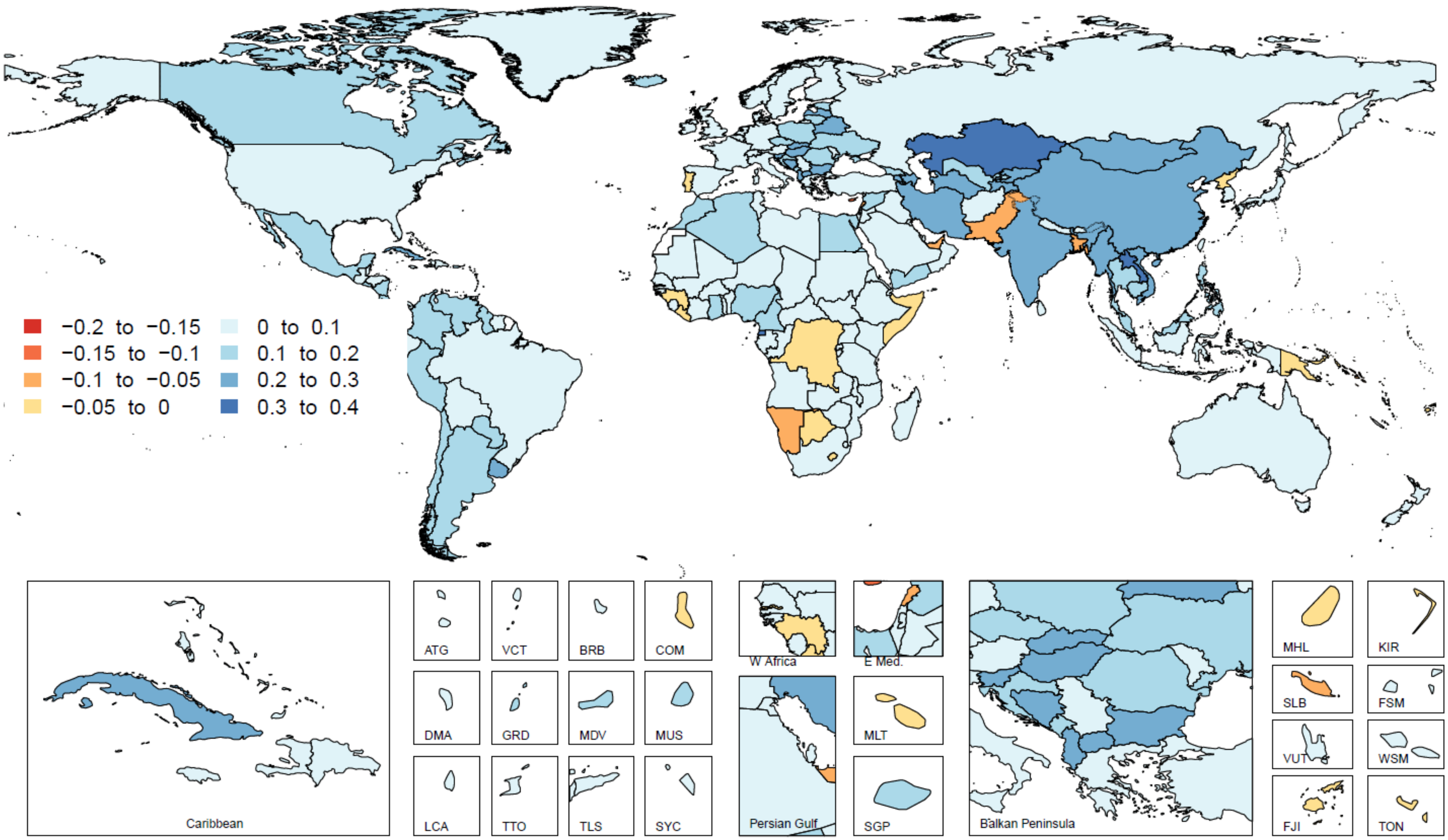

FIGURE 4. Overall Diet Quality from 1990 – 2017 divided by Socio-demographic Index quintile

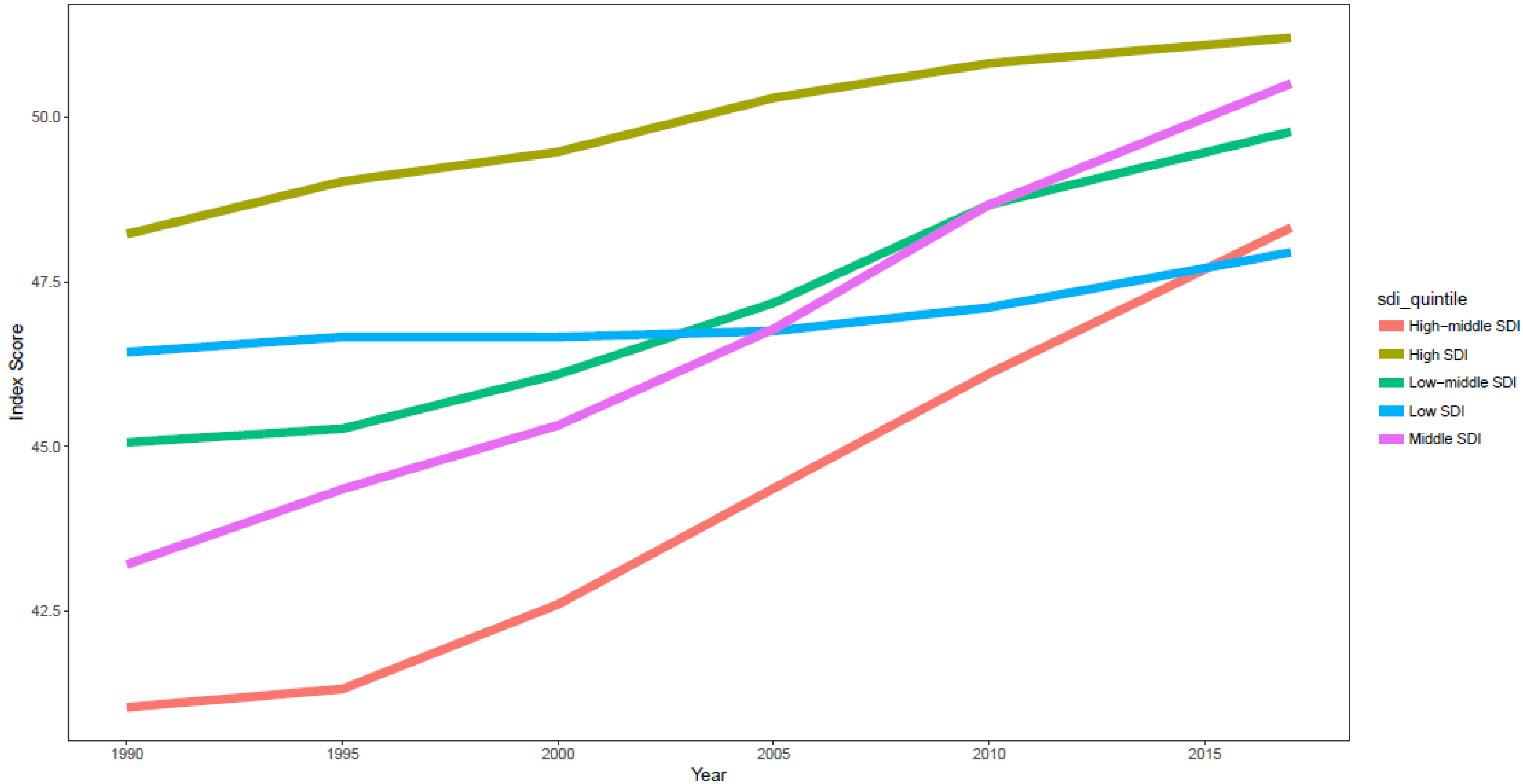

FIGURE 5. Map of Ratio of Observed to Expected Diet Quality

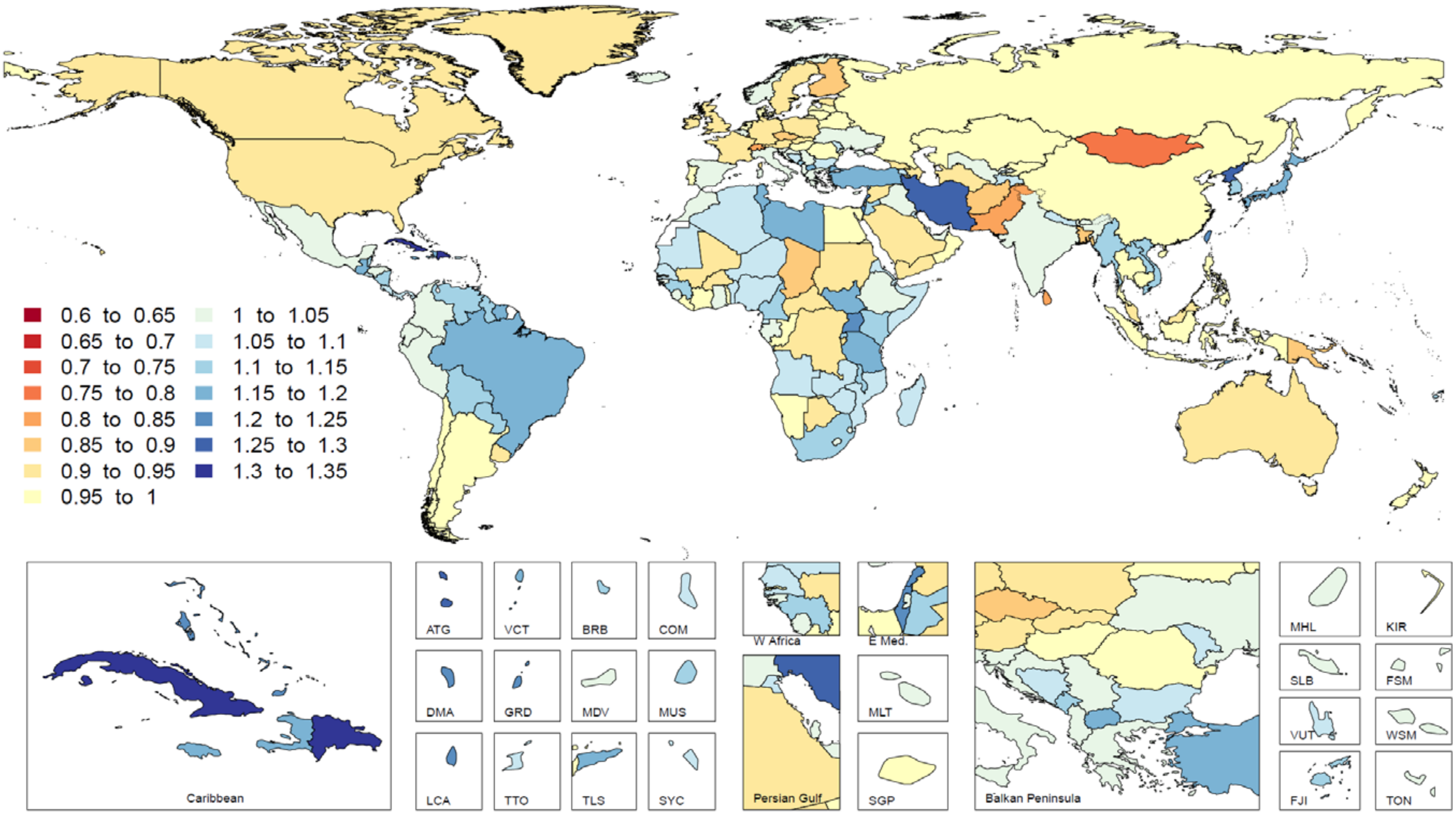

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017.

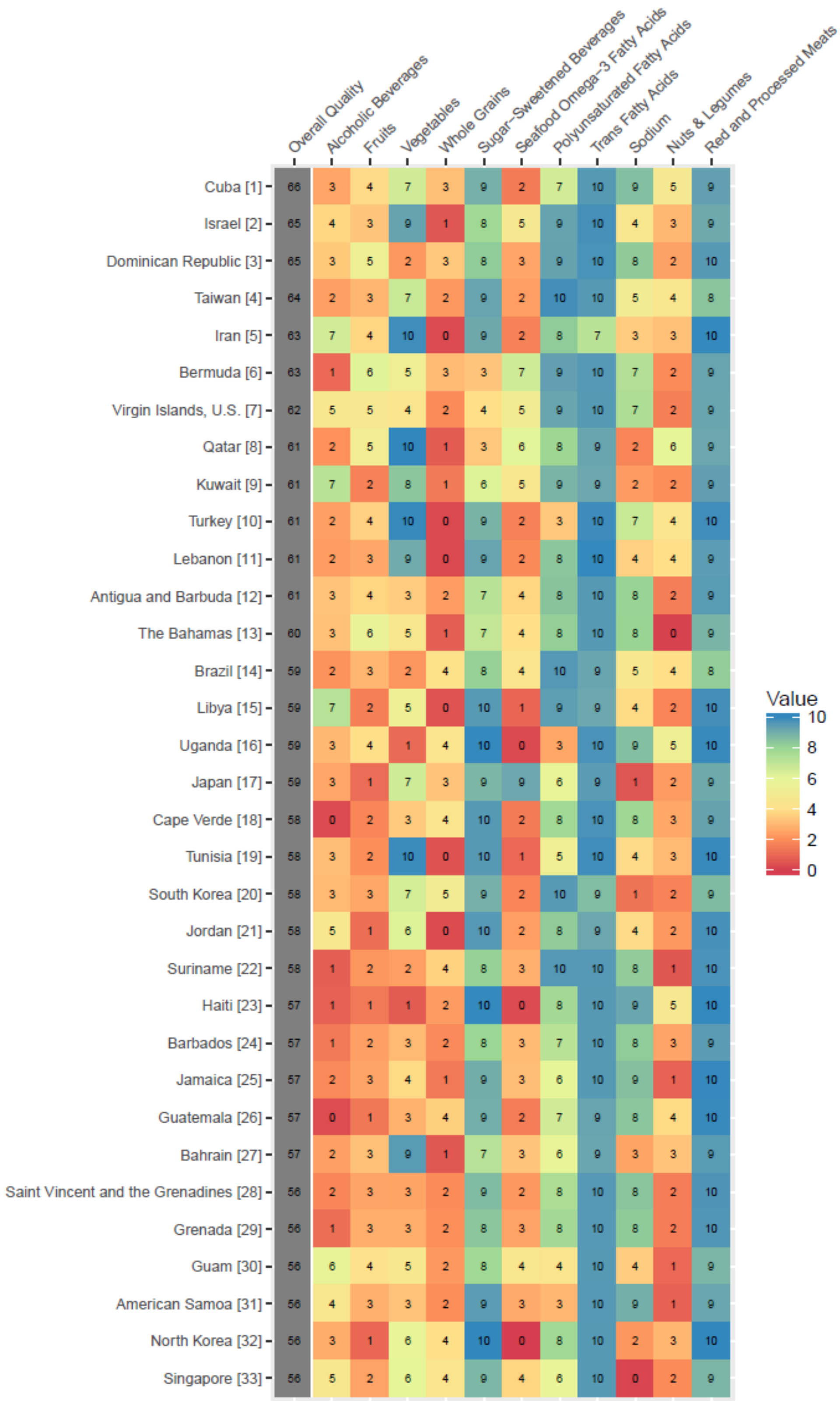

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017 (cont.).

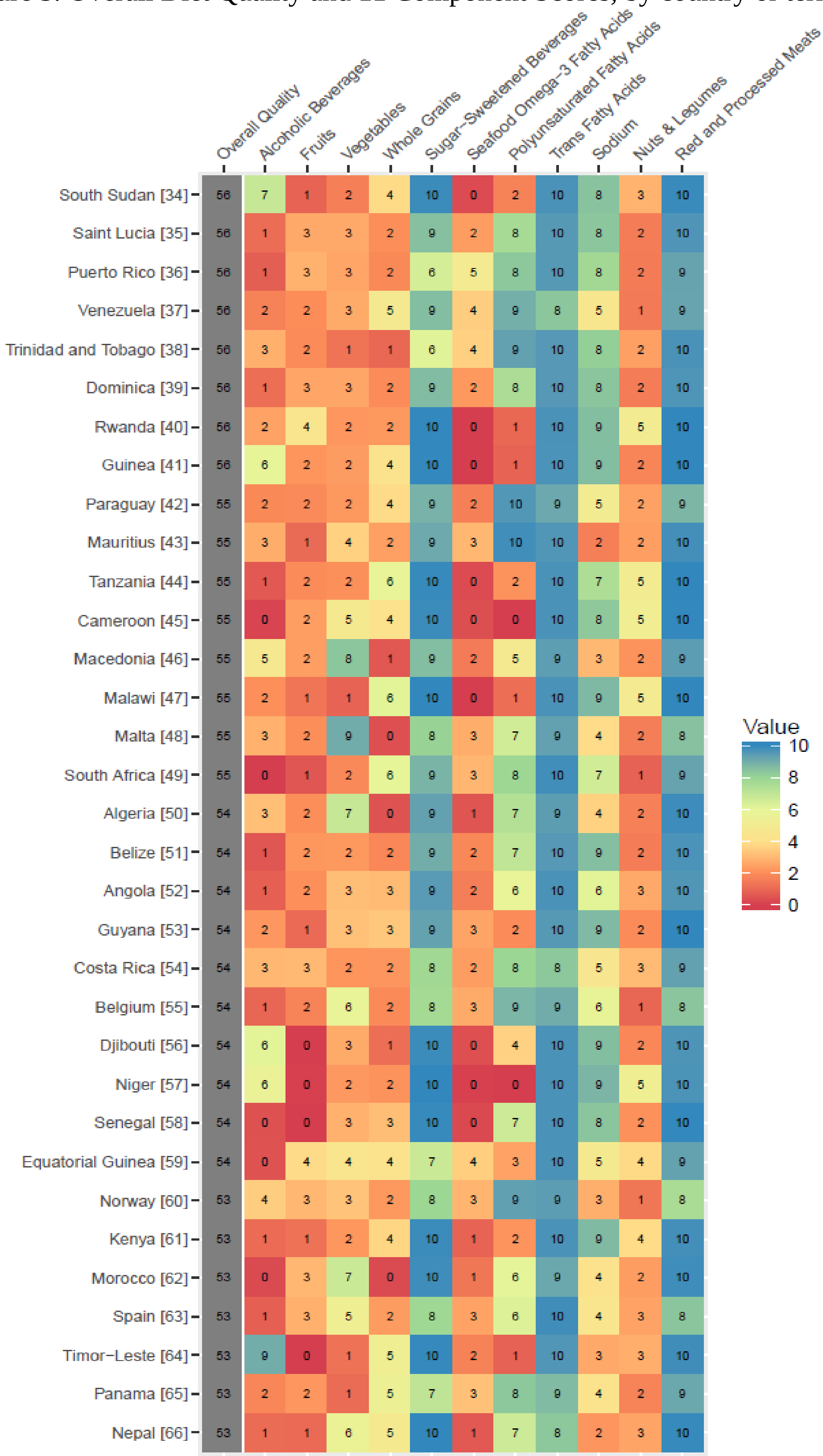

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017 (cont.).

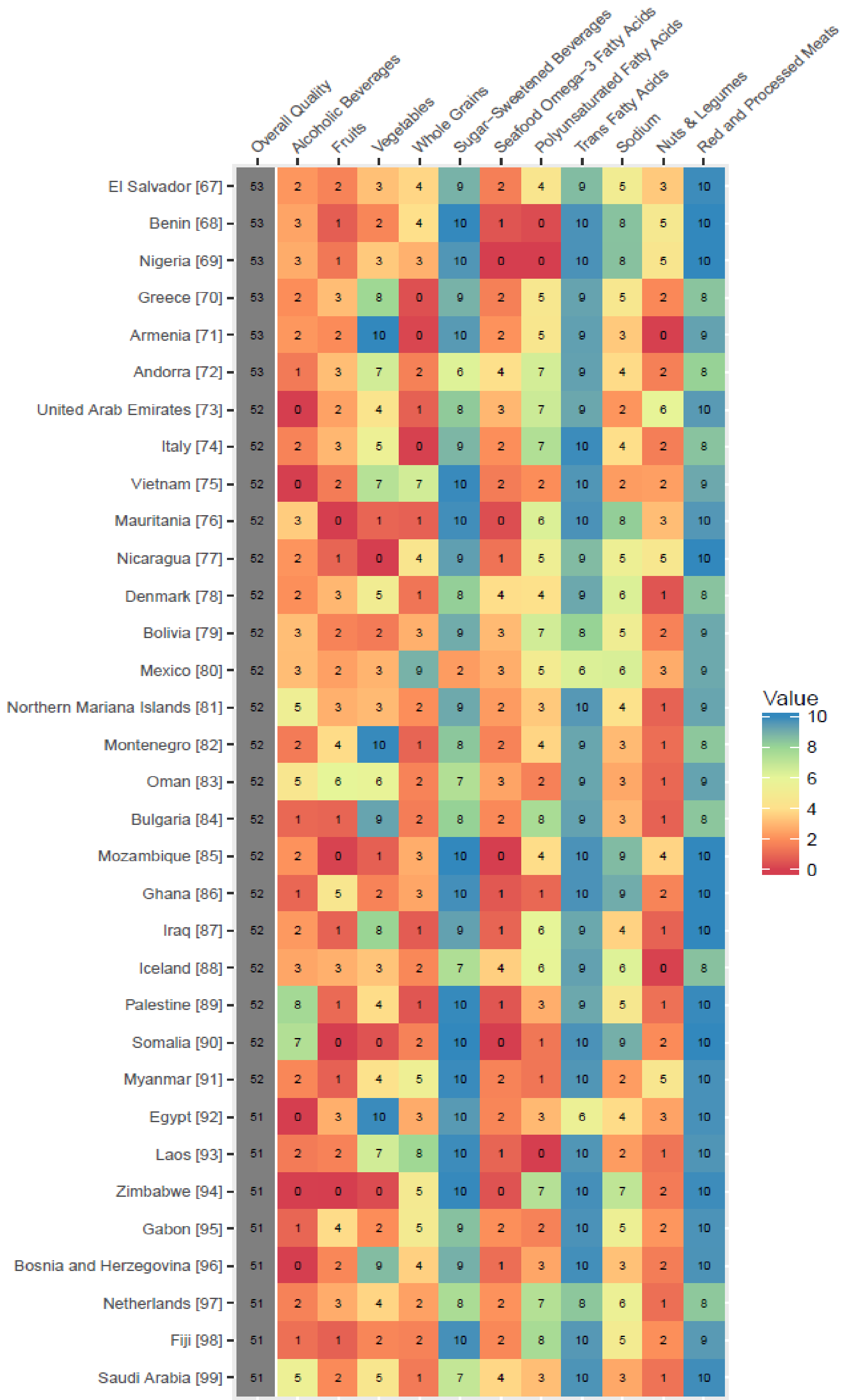

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017 (cont.).

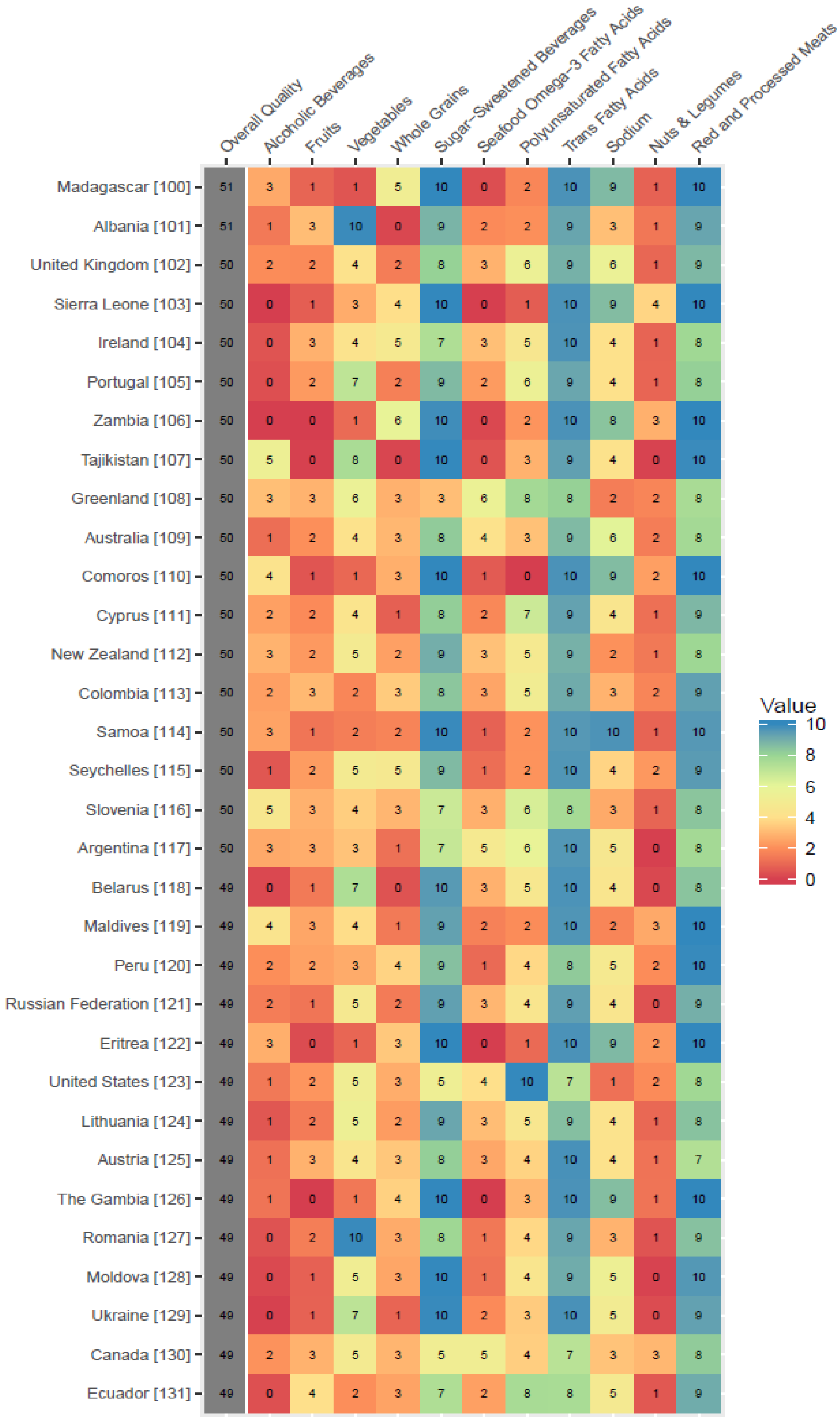

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017 (cont.).

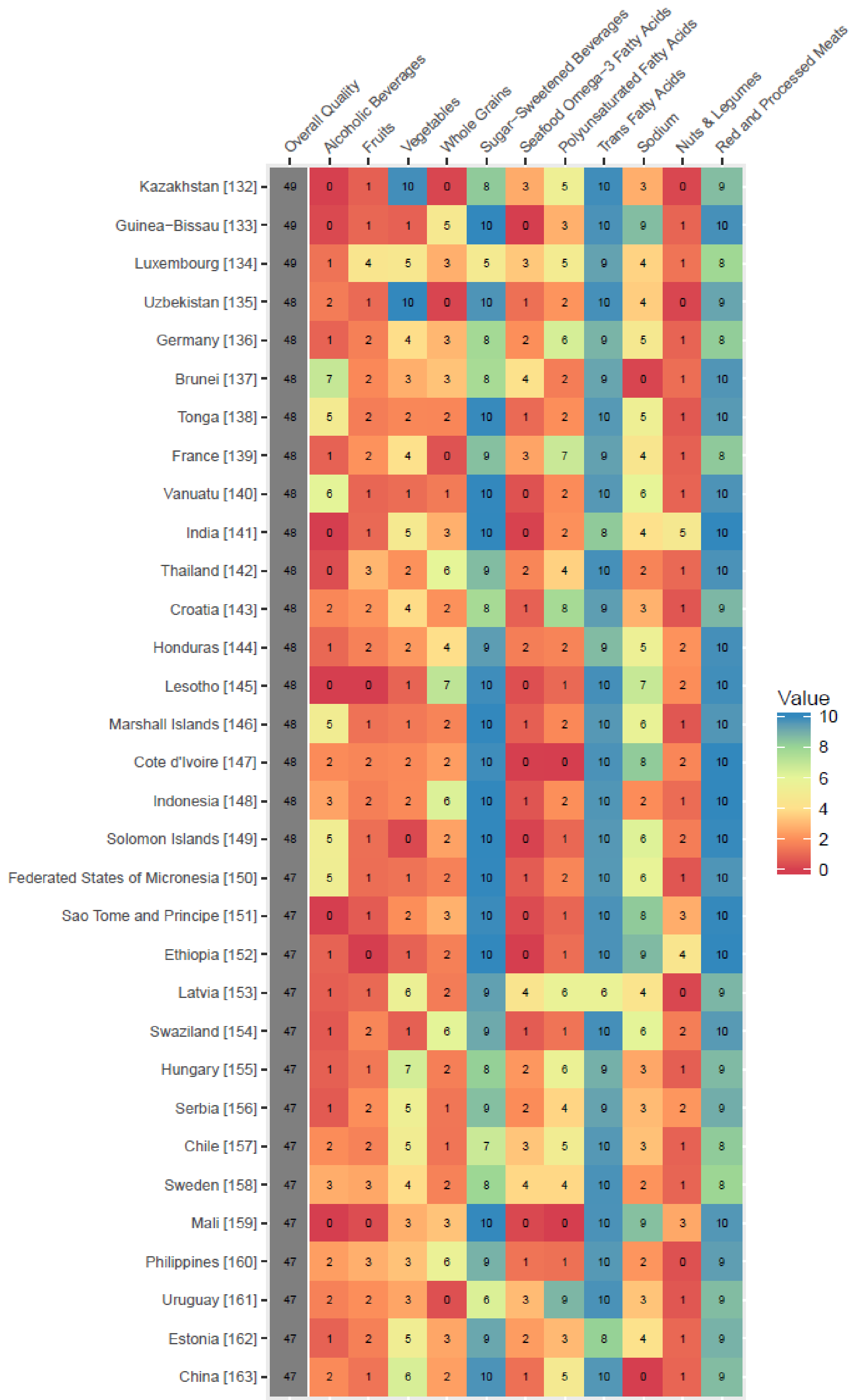

Figure 5. Overall Diet Quality and 11 Component Scores, by country or territory, in 2017 (cont.).

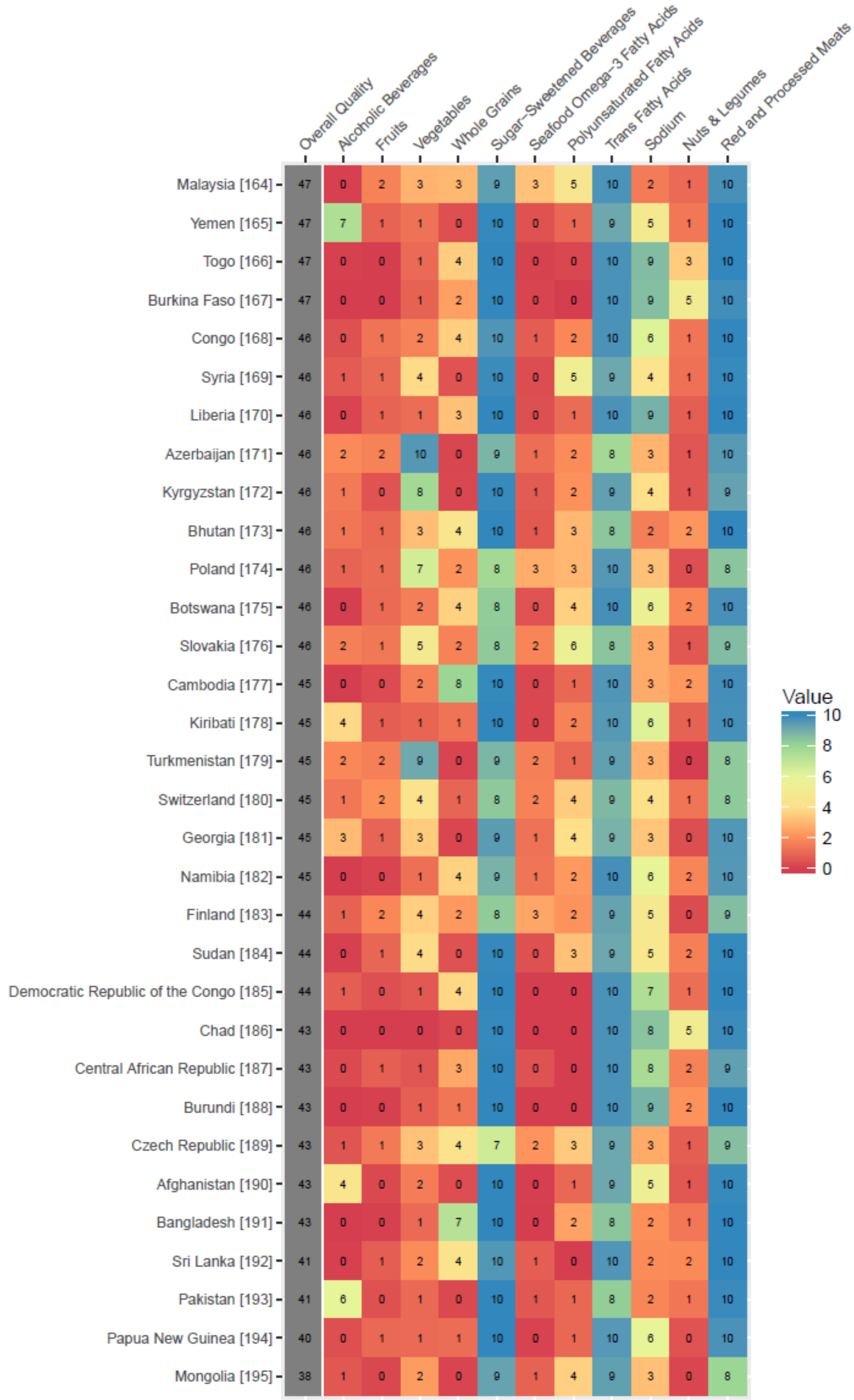

TABLE S1. Exposure definition for each of the dietary factors within the Alternate Healthy Eating Index

	Exposure Definition
Diet low in fruits	Average daily consumption of fruits (fresh, frozen, cooked, canned, or dried fruits, excluding fruit juices and salted or pickled fruits)
Diet low in vegetables	Average daily consumption of vegetables (fresh, frozen, cooked, canned, or dried vegetables, excluding legumes and salted or pickled vegetables, juices, nuts, and seeds, and starchy vegetables such as potatoes or corn)
Diet low in legumes	Average daily consumption of legumes (fresh, frozen, cooked, canned, or dried legumes)
Diet low in whole grains	Average daily consumption of whole grains (bran, germ, and endosperm in their natural proportion) from breakfast cereals, bread, rice, pasta, biscuits, muffins, tortillas, pancakes, and other sources
Diet low in nuts and seeds	Average daily consumption of nut and seed foods
Diet high in red meat	Average daily consumption of red meat (beef, pork, lamb, and goat but excluding poultry, fish, eggs, and all processed meats)
Diet high in processed meat	Average daily consumption of meat preserved by smoking, curing, salting, or addition of chemical preservatives
Diet high in sugar-sweetened beverages	Average daily consumption of beverages with ≥ 50 kcal per 226.8 gram serving, including carbonated beverages, sodas, energy drinks, fruit drinks, but excluding 100% fruit and vegetable juices
Diet low in seafood omega-3 fatty acids	Average daily intake of eicosapentaenoic acid and docosahexaenoic acid
Diet low in polyunsaturated fatty acids	Average daily intake of omega-6 fatty acids from all sources, mainly liquid vegetable oils, including soybean oil, corn oil, and safflower oil
Diet high in trans fatty acids	Average daily intake of trans fat from all sources, mainly partially hydrogenated vegetable oils and ruminant products
Diet high in sodium	24 hour urinary sodium measured in grams per day
Diet high in alcoholic beverages	Average daily alcohol consumption of pure alcohol (measured in grams per day) in current drinkers who had consumed alcohol during the past 12 months

TABLE S2. Alternate Healthy Eating Index cut-point values (with servings to grams conversion values, deciles used for sodium).

	Servings to Grams Conversion	Units	Sex	Cut-Point Value 1	2	3	4	5	6	7	8	9	10
Diet low in fruits	85	grams/day	B	42.5	85	127.5	170	212.5	255	297.5	340	382.5	425
Diet low in vegetables	85	grams/day	B	34	68	102	136	170	204	238	272	306	340
Diet low in legumes	99	grams/day	B	9.9	19.8	29.7	39.6	49.5	59.4	69.3	79.2	89.1	99
Diet low in whole grains	-	grams/day	M	9	18	27	36	45	54	63	72	81	90
			F	7.5	15	22.5	30	37.5	45	52.5	60	67.5	75
Diet low in nuts and seeds	28.3	grams/day	B	2.8	5.7	8.5	11.3	14.2	17	19.8	22.7	25.5	28.3
Diet high in red meat	85	grams/day	B	127.6	114.8	102.1	89.3	76.5	63.8	51	38.3	25.5	12.8
Diet high in processed meat	95	grams/day	B	142.5	128.3	114	99.8	85.5	71.3	57	42.8	28.5	14.3
Diet high in sugar-sweetened beverages	366	grams/day	B	366	329.4	292.8	256.2	219.6	183	146.4	109.8	73.2	36.6
Diet low in seafood omega-3 fatty acids	-	grams/day	B	0.025	0.050	0.075	0.100	0.125	0.150	0.175	0.200	0.225	0.250
Diet low in polyunsaturated fatty acids	-	% of energy	B	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8
Diet high in trans fatty acids	-	% of energy	B	3.5	3.2	2.8	2.5	2.1	1.8	1.4	1.1	.7	.4
Diet high in sodium	-	grams/day	B	5.7	4.8	4.3	4	3.7	3.4	3.2	3	2.7	2.4
Diet high in alcoholic beverages	14	grams/day	M	35	31.5	28	24.5	21	17.5	14	10.5	7	3.5
		grams/day	F	17.5	15.8	14	12.3	10.5	8.8	7	5.3	3.5	1.8

TABLE S3. Input data types included with indication of gold standard measurement definition.

	Data Sources					
	Sales	Food Frequency Quest.	Household Budget Surveys	National Accounts of Availability (FAO)	24-hr Dietary Recall	24-hr Urine Collection
Diet low in fruits	●	●	●	●	●*	-
Diet low in vegetables	●	●	●	●	●*	-
Diet low in legumes	●	-	●	●	●*	-
Diet low in whole grains	-	●	-	●	●*	-
Diet low in nuts and seeds	-	●	●	●	●*	-
Diet high in red meat	●	●	●	●	●*	-
Diet high in processed meat	●	●	●	-	●*	-
Diet high in sugar-sweetened beverages	●	●	●	-	●*	-
Diet low in seafood omega-3 fatty acids	-	-	-	●	●*	-
Diet low in polyunsaturated fatty acids	-	●	-	●	●*	-
Diet high in trans fatty acids	●	●	-	-	●*	-
Diet high in sodium	-	-	-	-	●	●*
Diet high in alcoholic beverages	●	●	●	●	●*	-

*indicates data type is treated as the gold-standard assessment method.

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