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Diets benefiting health and climate relate to longevity in northern Sweden

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ABSTRACT

Background: Diets combining adequate nutritional quality and low climate impact are highly needed for human and planet health.

Objectives: We aimed to *1*) evaluate nutrient density indexes' ability to predict mortality, and *2*) assess the effects of diets varying in nutrient density and climate impact on total mortality.

Methods: Dietary data from 49,124 women and 47,651 men aged 35–65 y in the population-based prospective study Västerbotten Intervention Programme (Sweden) were used. Greenhouse gas emissions (GHGEs) were estimated using data from life cycle assessments. Fifteen variants of nutrient density indexes were evaluated and the index that best predicted mortality was used to estimate participants' nutrient density. GHGEs and nutrient density were adjusted for energy intakes. Total mortality risk was estimated by Cox proportional hazards models for 4 groups of women and men, respectively, i.e., higher nutrient density, lower climate impact (HNutr/LClim); higher nutrient density, higher climate impact (HNutr/HClim); lower nutrient density, lower climate impact (LNutr/LClim); and lower nutrient density, higher climate impact (LNutr/HClim—reference group).

Results: NRF11.3, a Sweden-adapted variant of the Nutrient Rich Foods index, was identified to have the best ability to predict mortality in the study population. Median follow-up times for women and men were 16.0 and 14.7 y, respectively. For women a significantly lower mortality risk was found for HNutr/LClim (HR: 0.87; 95% CI: 0.79, 0.96; $P = 0.008$) and HNutr/HClim (HR: 0.87; 95% CI: 0.78, 0.97; $P = 0.011$) than for LNutr/HClim. Among men LNutr/LClim had a significantly higher mortality risk (HR: 1.10; 95% CI: 1.01, 1.21; $P = 0.033$) than LNutr/HClim.

Conclusions: Diets beneficial for both health and climate are feasible and associated with lower mortality risk in women. Further studies are needed to understand how men may transition into diets that are more sustainable from a combined health and climate perspective. *Am J Clin Nutr* 2021;114:515–529.

Keywords: climate impact, carbon dioxide equivalents, diet quality, nutrient density index, mortality, food frequency questionnaire

Introduction

Dietary habits affect both human health (1–3) and global planetary health (4–7). A nutritionally adequate diet is crucial to prevent and treat noncommunicable diseases such as obesity, type 2 diabetes, and cardiovascular diseases (1). Food production and consumption have major environmental effects and alarmingly nearly 20%–30% of global greenhouse gas emissions (GHGEs) are derived from the food system alone (8). Improvements that reduce GHGEs from the food system are possible (9) and will be necessary in combination with changes in dietary habits to meet global climate goals (6, 10–12). To identify dietary patterns that are sustainable from a climate perspective as well as from a health point of view is therefore imperative.

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Supplemental Tables 1–8 and Supplemental Figure 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: CO_2e, carbon dioxide equivalents; FIL, food intake level; GHGE, greenhouse gas emission; HNutr/HClim, higher nutrient density, higher climate impact; HNutr/LClim, higher nutrient density, lower climate impact; LCA, life cycle assessment; LNutr/HClim, lower nutrient density, higher climate impact; LNutr/LClim, lower nutrient density, lower climate impact; MRI, maximum recommended intake; NNR, Nordic Nutrition Recommendations; NRF, Nutrient Rich Foods; RISE, Research Institutes of Sweden; VIP, Västerbotten Intervention Programme; WF, weighting factor; WWF, World Wide Fund for Nature.

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Dietary recommendations have primarily been developed to promote healthy eating habits from a public health perspective and not to minimize climate or other environmental impacts (1, 13, 14). However, recently the FAO and WHO urged countries to update their national dietary guidelines to integrate both health and environmental perspectives (15). Evidence-based guidelines for sustainable diets require knowledge about multidisciplinary effects of dietary patterns, which in turn requires validated research methods integrating nutrition, health, and environmental aspects. The possibility to achieve dietary changes that provide positive synergies for health and environment has been evaluated with varying results. There are studies indicating good opportunities for sustainable diets promoting better health and benefiting the environment (16–20). However, dietary patterns with a lower climate impact will not necessarily improve nutrient density or health outcomes (21), and dietary interventions based on nutrition recommendations have moreover shown that changes toward healthier dietary patterns in practice may not lead to decreased climate impact (22). In short, choosing diets beneficial for both health and climate is not obvious for consumers, and it is also not obvious how policy and dietary guidelines should be designed to benefit both perspectives. In addition, positive long-term health effects of such diets need to be verified.

The overall aim of this study was to examine the effects of diets varying in nutrient density and climate impact on total mortality within a population-based prospective study in Sweden. More specifically the objectives were *1*) to evaluate which out of 15 different variants of the published nutrient density index, the Nutrient Rich Foods (NRF) index (23), best predicted total mortality in the target population, providing a reference to establish which method choices are most suitable for continued use in research and other applications of the method; and *2*) to examine effects of diets varying in nutrient density and climate impact on total mortality—hence to identify whether dietary patterns beneficial for both health and climate are feasible and associated with lower mortality risk. "Total mortality" was identified as the primary outcome from the planning stage of the study.

Methods

Study design and subjects

The Västerbotten Intervention Programme (VIP) is an ongoing, population-based prospective study that was initiated in 1985 in the county of Västerbotten in northern Sweden (24). Since the start, and still, the program invites inhabitants when turning 40, 50, and 60 y old (occasionally ±5 y of age) to their local health center for a standardized health screening. During a few years, also 30-y-olds were invited. A diet-and lifestyle questionnaire is completed by the participants at the health screening. This questionnaire became fully harmonized among the communities in Västerbotten and electronically readable in 1990. Therefore, the present study period runs from 1990 to 2016. The participation rate has varied over time, with a mean of 60% (24). Social selection bias, i.e., with respect to income, age, or unemployment, has been reported to be insignificant (25). The Research Ethics Committee of Umeå University, Sweden, approved the original study in 1984 and the Swedish Ethical Review Authority approved the current study in 2019 (dnr 2019–01314). Written informed consent was obtained from all participants.

Dietary assessment

At the health screening, participants completed an FFQ which before 1996 included questions on 84 foods, and since 1996 on 64 foods (see **Supplemental Table 1**). The intakes were indicated based on 9 frequencies, ranging from never to ≥4 times/d. Intakes reported by the longer FFQ have been harmonized to match the shorter version. The FFQ is semiquantitative and includes 4 pictures with increasing portion sizes of each of meat/fish, staple foods (potato/rice/pasta), and vegetables to indicate portion sizes of these 3 consumption groups. For other foods, either age- or gender-specific portion sizes or natural sizes, such as of a fruit, were used (24). The longer version of the FFQ has been validated against 10 repeated 24-h recalls in 246 study participants (26). The validation study showed that the FFQ captures a relatively lower intake of meat, fish, alcohol, and sweets, and a relatively higher intake of bread, cereals, rice, potatoes, pasta, dairy products, vegetables, and fruit, than the 24-h recalls. Apart from fish, with a Spearman's correlation coefficient of 0.21 for women and 0.15 for men, the correlations between the 2 methods ranged from 0.26 to 0.69 for different food groups, which is in line with other similar prospective cohort studies using FFQs to measure dietary intake (26).

Estimation of nutrient density of diets

The participants' nutrient intake was estimated by weighting their reported food intake (not including dietary supplements) by contents in the national food composition database at the Swedish National Food Agency (27). Intake of added sugars was calculated from unpublished information on added sugars provided by the Swedish National Food Agency (28). To evaluate effects of diet quality rather than amounts, nutrient intakes were adjusted to an energy intake of 2000 kcal for women and 2500 kcal for men.

Thereafter, a suitable index for capturing nutrient density of diets was selected, based on previous studies evaluating nutrient density scores in combination with environmental impacts of food products (29). The NRF index (23) assigns a nutrient density score based on both nutrients which should be encouraged (qualitative nutrients, *x* in **Equation *1***) and nutrients which should be limited (disqualitative nutrients, *y* in **Equation *1***):

$$\mathrm{NRFx.y} = \left(\sum 1 - x\left(\frac{\text{Qualitative nutrient}}{\text{DRI}}\right)\right) - \left(\sum 1 - y\left(\frac{\text{Disqualitative nutrient}}{\text{MRI}}\right)\right) \quad (1)$$

Sex- and age-specific DRIs and maximum recommended intakes (MRIs) were taken from the Nordic Nutrition Recommendations 2012 (NNR2012) (1). For iron and folate estimation, women were classified into 2 categories—those <51 and ≥51 y of age—to account for higher DRIs in reproductive than in postmenopausal women (30).

To evaluate the impact of key methodological choices, i.e., the number of nutrients included in the score, as well as the use of capping and/or weighting, the quality of the participants' diets was scored using 3 variants of the NRF index and 5 versions thereof. The 3 variants were *1*) the validated NRF9.3 (23); *2*) NRF9.3 plus vitamin D and folate, to account for nutrients at risk

TABLE 1 Nutrients included in the dietary nutrient scores based on the NRF index (NRF9.3, NRF11.3, and NRF21.3) and the reference values and WFs in the study population[1]

	NRF			DRI/MRI[2]		WFs	
	9.3	11.3	21.3	Women	Men	Women	Men
Qualitative nutrients							
Protein, g	✓	✓	✓	75[3]	94[4]	1.04	1.02
Fiber, g	✓	✓	✓	25	35	1.33	1.64
Vitamin A, retinol equivalents	✓	✓	✓	700	900	0.84	1.11
Vitamin C, mg	✓	✓	✓	75	75	0.78	0.81
Vitamin E, mg	✓	✓	✓	8	10	0.68	0.76
Calcium, mg	✓	✓	✓	800	800	0.98	0.85
Iron, mg	✓	✓	✓	9[5]/15[6]	9	1.58[7]/0.95[8]	0.78
Potassium, g	✓	✓	✓	3.1	3.5	1.07	1.03
Magnesium, mg	✓	✓	✓	280	350	0.92	0.96
Vitamin D, µg		✓	✓	10	10	1.56	1.32
Folate, µg		✓	✓	300[5]/400[6]	300	1.58[7]/1.19[8]	1.13
Thiamin, mg			✓	1.1	1.4	1.00	1.00
Riboflavin, mg			✓	1.3	1.7	0.93	1.00
Omega-3 fatty acids, g			✓	2[9]	3[10]	0.89	0.96
Niacin, niacin equivalents			✓	15	18	0.45	0.44
Vitamin B-6, mg			✓	1.2	1.5	0.67	0.65
Vitamin B-12, µg			✓	2	2	0.40	0.33
Phosphorus, mg			✓	600	600	0.48	0.39
Iodine, µg			✓	150	150	1.00[11]	1.00[11]
Selenium, µg			✓	50	60	1.19	1.20
Zinc, mg			✓	7	9	0.74	0.73
Disqualitative nutrients							
Saturated fat, g	✓	✓	✓	22[12]	28[13]	1.19	1.22
Added sugars, g	✓	✓	✓	50[12]	63[13]	1.00	1.00
Sodium, g	✓	✓	✓	2.4	2.4	1.50	1.14

[1] DRI and MRI values are from the Nordic Nutrition Recommendations 2012 (1). Mean intakes of the Swedish population were taken from the national food survey in Sweden from 2010–2011 (Riksmaten 2010–11). WFs for qualitative nutrients were calculated by DRI of nutrient/mean intake of nutrient and for disqualitative nutrients by mean intake of nutrient/MRI of nutrient. E%, energy percent; MRI, Maximum Recommended Intake; NRF index, Nutrient Rich Foods index; WF, weighting factor.

[2] DRI values for qualitative nutrients; MRI values for disqualitative nutrients.

[3] Based on 15 E% of an energy intake of 2000 kcal, the mean of the recommended 10–20 E%.

[4] Based on 15 E% of an energy intake of 2500 kcal, the mean of the recommended 10–20 E%.

[5] Recommendation for women of reproductive age.

[6] Recommendation for women postmenopause.

[7] Based on the dietary reference value for women of reproductive age.

[8] Based on the dietary reference value for women postmenopause.

[9] Based on 1 E% of an energy intake of 2000 kcal.

[10] Based on 1 E% of an energy intake of 2500 kcal.

[11] No mean intake could be found in Riksmaten 2010–11, so the DRI acted as a replacement in the calculation of the WF.

[12] Based on 10 E% of an energy intake of 2000 kcal.

[13] Based on 10 E% of an energy intake of 2500 kcal.

of low intake in the Swedish population (yielding NRF11.3); and *3*) an NRF index based on most nutrients specified in NNR2012 (1) yielding NRF21.3. **Table 1** presents the nutrients included in NRF9.3, NRF11.3, and NRF21.3. The 5 versions of each NRFn.3 index that were compared were as follows: neither capped nor weighted; only capped; only weighted; first capped and thereafter weighted; and vice versa. Capping, or limiting an intake of a nutrient to a maximum of 100% of the DRI, is used to avoid overstating the impact of diets rich in a few nutrients (23) and was used for qualitative nutrients only. Capping was set at DRI levels, except for fiber and omega-3 fatty acids for which no upper limits are defined in NNR2012 (1). Weighting is used to give different weight to nutrients depending on how average nutritional intake levels in Sweden [based on a national food survey in Sweden in 2010–2011 (31)] correspond to recommended intake levels, by adding additional weight to or withdrawing weight from nutrients that the population eats too little or too much of. Weighting factors (WFs) for qualitative nutrients were calculated by dividing the DRI of the nutrient by the mean intake of the nutrient, and for disqualitative nutrients WFs were calculated by dividing the mean intake of the nutrient by the MRI of the nutrient. No weighting was applied for disqualitative nutrients where the population mean intakes were below the MRI. Table 1 presents the DRIs, MRIs, and WFs for each nutrient.

Assessment of total mortality

Information on total mortality was obtained by linking the "Cause of death" registers at the National Board of Health and Welfare in Sweden (https://www.socialstyrelsen.se/statist

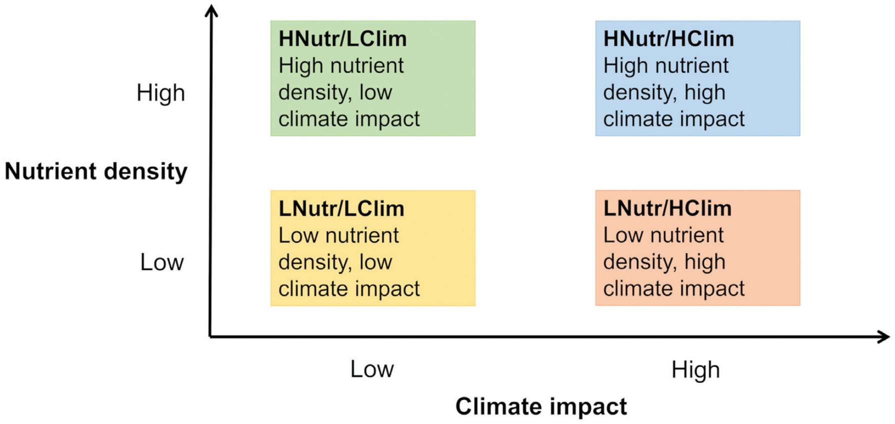


FIGURE 1 Categorization of 4 groups based on the nutrient density and dietary climate impact of the study participants' diets in the Västerbotten Intervention Programme 1990–2016.

ik-och-data/register/) to the VIP participants using personal identification numbers.

Estimation of dietary climate impact

Life cycle assessment (LCA) data from the Research Institutes of Sweden (RISE) Food Climate Database (32, 33) were used to estimate GHGEs for all food items in the VIP FFQ. Most climate data in the database are based on LCA studies from the literature that were harmonized in their key methodological choices, such as system boundaries. For foods lacking or with inadequate LCA data, climate data have been either estimated, modeled, or calculated by RISE personnel. System boundaries were defined as primary production up to and including the raw materials' possible processing in the industry, hence including emissions from primary production, processing, and transportation up to the industry gate, but excluding emissions from packaging. Climate impact was expressed as kg carbon dioxide equivalents (CO_2e) per kg edible food product (e.g., meat without bones). Climate impact of foods consumed in prepared form was expressed per cooked weight, including weight changes due to hydration (e.g., for rice and beans) and dehydration (e.g., for meat and fish). The climate data in the RISE Food Climate Database are intended to be representative of Swedish consumption. In this study GHGEs for meat and dairy products referred to Swedish production. Some questions in the FFQ represent clustered categories of foods. To capture variations in GHGEs due to type of food (e.g., between game, lamb, pork, and beef in the subgroup "Meat" and between different fat contents in the subgroup "Cream, crème fraiche, and sour cream"), emission values were calculated from consumption-weighted averages based on national consumption

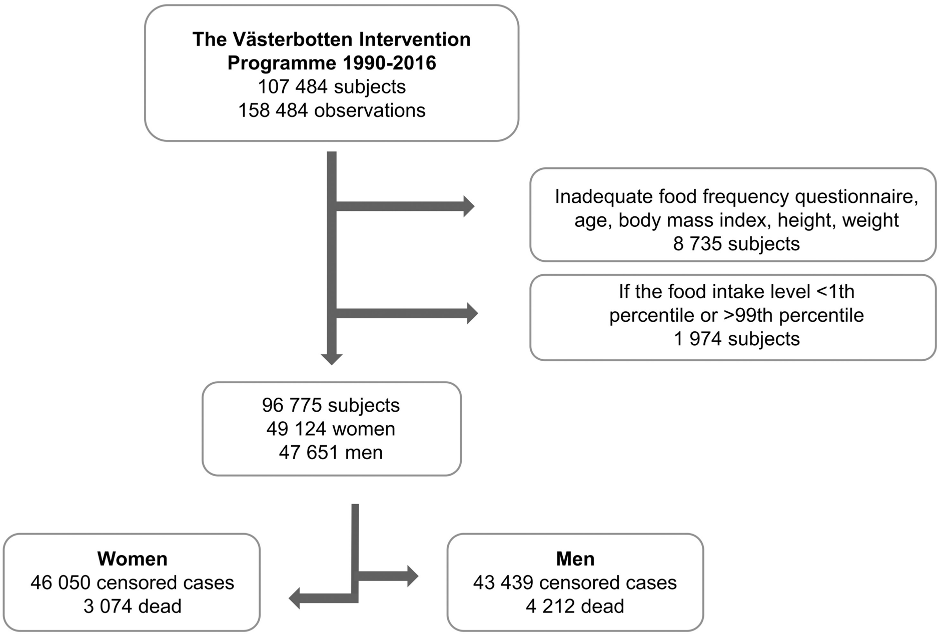


FIGURE 2 Flowchart from inclusion of participants into the Västerbotten Intervention Programme during 1990–2016 to the final study groups.

TABLE 2 Baseline characteristics of women and men participating in the Västerbotten Intervention Programme during 1990–2016[1]

Variable	Women ($n = 49{,}124$) Noncases ($n = 46{,}050$)	Women Cases ($n = 3074$)	Men ($n = 47{,}651$) Noncases ($n = 43{,}439$)	Men Cases ($n = 4212$)
Age,[2] y	47.4 ± 7.9	54.1 ± 6.8	47.4 ± 7.8	54.2 ± 6.7
Systolic blood pressure,[2] mm Hg	123.5 ± 17.6	127.0 ± 20.3	128.2 ± 15.9	132.0 ± 18.9
Diastolic blood pressure,[2] mm Hg	76.9 ± 10.5	78.4 ± 10.7	80.7 ± 10.5	82.6 ± 11.1
Serum cholesterol,[2] mmol/L	5.5 ± 1.1	5.4 ± 1.3	5.6 ± 1.1	5.6 ± 1.2
Fasting blood glucose (capillary),[2] mmol/L	5.4 ± 0.9	5.5 ± 1.3	5.5 ± 1.0	5.7 ± 1.6
2-h blood glucose,[2] mmol/L	6.8 ± 1.5	7.0 ± 2.1	6.4 ± 1.7	6.4 ± 2.2
BMI,[2] kg/m^2	25.6 ± 4.6	26.1 ± 5.0	26.5 ± 3.8	27.0 ± 3.9
Underweight, <18.5	1.0	1.6	0.3	0.5
Normal, 18.5–25.0	52.2	43.0	36.7	33.9
Overweight, >25.0–30.0	31.5	34.9	47.9	48.5
Obese, >30.0	15.2	20.4	15.1	17.2
Physical activity				
Inactive	17.4	21.5	18.2	21.2
Moderately inactive	30.3	35.9	29.7	35.7
Moderately active	27.8	26.5	28.8	27.9
Active	24.2	14.8	23.0	14.4
Missing value	0.4	1.2	0.3	0.9
Level of education				
Basic level, 9 y	33.2	70.0	37.0	70.1
High school	30.1	13.1	35.7	15.0
University	36.1	15.3	26.8	13.8
Missing value	0.7	1.6	0.5	1.1
Smoking				
Currently smoking	19.7	33.5	17.6	31.2
Have smoked	29.0	24.4	30.7	34.6
Do not smoke	50.4	41.0	50.3	32.5
Missing value	0.9	1.1	1.5	1.7

[1] $n = 96{,}775$. Values are means ± SDs or percentages.

[2] Adjusted for age and year of study participation.

shares (34–36) and other sources (37) reflecting the average Swedish consumption. GHGEs for red meat were calculated taking into consideration changes in consumption over the 26-y study period (1990–2016) (36). GHGEs from the complete diet were calculated for all study participants and expressed in kg CO_2e/d. The GHGEs from diets were thereafter adjusted to an energy intake of 2000 kcal for women and 2500 kcal for men.

Monitoring of nondietary variables

Information about age, systolic and diastolic blood pressures, serum cholesterol, fasting and 2-h blood glucose, BMI, physical activity, level of education, and smoking was collected during the standardized health screening and through the diet-and-lifestyle questionnaire. The participants were asked to come to the health screening after an ≥4-h fast. Systolic and diastolic blood pressures were measured after a 5-min rest. A benchtop analyzer was used to analyze blood glucose concentrations. In the earlier years total cholesterol in serum samples was analyzed at health centers using a Reflotron benchtop analyzer (Boehringer Mannheim GmbH, Diagnostica), whereas after 1 September 2009, an enzymatic routine method was used at the Clinical Chemistry Department at the nearest local hospital. An algorithm from a calibration set was used to perform harmonization (24). BMI was examined both as a continuous and as a categorical variable. Physical activity was measured using the validated Cambridge index of physical activity (38), which is based on questions regarding physical activity during both working hours and leisure time. Missing values for any of the 2 physical activity questions were replaced with the lowest intensity level for that variable. The 4 categories used for analysis were inactive, moderately inactive, moderately active, and active. Smoking status was originally divided into 5 categories: smoker; ex-smoker; never-smoker; occasional smoker; and previous occasional smoker. For the present analysis, the 5 categories were merged into 3 categories: current smoker; ex-smoker; and never-smoker. Furthermore, for education 3 categories were used for the analysis: basic level of 9 y; high school; and university. The category "basic level of 9 y" was created by merging 2 categories in the original variable: 1 reflecting the current educational system and 1 reflecting an older educational system.

Sample selection

VIP participants who had completed either the long or the short version of the FFQ were included in the study. If a participant had several visits, only the first visit was included. Participants under the age of 35 y and over the age of 65 y at enrollment, with a height of <130 cm or >210 cm, a body weight <35 kg, or BMI (in kg/m^2) <15.0 or missing, were excluded. Participants were also excluded if the food intake level (FIL) was below the 1st percentile or over the 99th percentile calculated separately for

TABLE 3 HRs and 95% CIs for total mortality of women participating in the Västerbotten Intervention Programme during 1990–2016 classified into quintiles according to diet quality calculated by various versions of the nutrient density score NRF index[1]

	Women ($n = 49{,}124$)					
	NRF9.3[2]	*P*	NRF11.3[2]	*P*	NRF21.3[2]	*P*
Neither capped nor weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.91 (0.81, 1.03)	0.136	0.89 (0.79, 1.00)	0.057	0.99 (0.88, 1.11)	0.873
Capped						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.86 (0.76, 0.97)	0.015	0.83 (0.73, 0.93)	0.002	0.89 (0.79, 1.01)	0.070
Weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.91 (0.81, 1.02)	0.116	0.90 (0.80, 1.02)	0.097	0.95 (0.85, 1.07)	0.405
Capped and weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.84 (0.75, 0.95)	0.006	0.87 (0.77, 0.97)	0.018	0.86 (0.76, 0.97)	0.012
Weighted and capped						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.85 (0.75, 0.96)	0.008	0.82 (0.73, 0.93)	0.002	0.87 (0.77, 0.98)	0.020

[1] HRs, 95% CIs, and *P* values estimated by Cox proportional hazards regression. NRF9.3 includes 9 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, and magnesium) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. NRF11.3 includes 11 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, magnesium, vitamin D, and folate) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. NRF21.3 includes 21 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, magnesium, vitamin D, folate, thiamin, riboflavin, omega-3 fatty acids, niacin, vitamin B-6, vitamin B-12, phosphorus, iodine, selenium, and zinc) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. Ranking into quintiles was adjusted by age groups. Q1 is the lowest quintile and Q5 the highest quintile. Q1 is the reference category. NRF index, Nutrient Rich Foods index; Q, quintile.

[2] Adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

women and men. FIL was calculated as the estimated total energy intake divided by basal metabolic rate according to Schofield's equation (39). In addition, if >10% of the answers from the FFQ were missing, and/or if any of the 3 questions indicating portion size were not filled out, individuals were excluded. The exclusion criteria are in line with previous publications from VIP-based studies.

Data processing and statistical analyses

Normally distributed variables are expressed as mean ± SD. Nonnormally distributed variables are expressed as median [IQR].

To evaluate and select a suitable diet quality index, women and men were ranked separately into quintiles by age group at enrollment (35–44 y, 45–54 y, and 55–65 y), according to the 3 variants (NRF9.3, NRF11.3, and NRF21.3) and each version thereof (neither capped nor weighted, only capped, only weighted, first capped and thereafter weighted, and first weighted and thereafter capped), i.e., 15 alternatives in total. Quintile 5 was the group with the highest and quintile 1 the group with the lowest nutrient density. Trend consistency of risk of total mortality (i.e., the higher the nutrient density, the lower the total mortality risk), statistical significances, as well as patterns of background and sociodemographic factors were evaluated across the quintiles among the 15 diet quality index alternatives to find the NRF variant that best predicted the total mortality risk. Relative risk of total mortality during the follow-up period was examined by Cox proportional hazards regression and HRs with 95% CIs. The time (mo) between the health screening and death or end of the study period (31 December, 2016), whichever occurred first, was used as the time scale. Quintile 1 was the reference category. The basic models included age, age squared, and the quintiles of the NRF indexes. Adjusted models in addition included BMI, educational level, physical activity, smoking status, and screening year, based on variables usually included as covariates in similar analyses.

Thereafter, women and men were ranked by age group into 4 groups, respectively, based on their diet quality as captured by the selected nutrient density index and dietary climate impact (see **Figure 1**):

HNutr/LClim: higher nutrient density and lower climate impact
HNutr/HClim: higher nutrient density and higher climate impact
LNutr/LClim: lower nutrient density and lower climate impact
LNutr/HClim: lower nutrient density and higher climate impact

The median values within each group of women and men were used as cutoffs to dichotomize diet quality and dietary climate impact, respectively (**Supplemental Figure 1**). The HR for total mortality during the follow-up period was calculated for the 4 groups. LNutr/HClim, characterized by a diet with lower nutrient density and higher climate impact, was the reference category in these analyses. The basic and the adjusted models were modeled as aforementioned. The proportional hazards assumption was ensured by a combined evaluation consisting of 2 parts. Initially, the partial residuals of all covariates in the adjusted model were evaluated graphically for time trends. Thereafter, the proportional hazards assumption was tested by evaluating the correlation between the partial residuals of all covariates in the adjusted model and the ranked survival time.

TABLE 4 HRs and 95% CIs for total mortality of men participating in the Västerbotten Intervention Programme during 1990–2016 classified into quintiles according to diet quality calculated by various versions of the nutrient density score NRF index[1]

	Men ($n = 47,651$)					
	NRF9.3[2]	*P*	NRF11.3[2]	*P*	NRF21.3[2]	*P*
Neither capped nor weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	1.00 (0.91, 1.11)	0.944	0.97 (0.88, 1.08)	0.592	1.04 (0.95, 1.15)	0.409
Capped						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.84 (0.76, 0.93)	0.001	0.86 (0.77, 0.94)	0.002	0.89 (0.81, 0.99)	0.028
Weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.93 (0.84, 1.03)	0.166	0.94 (0.85, 1.04)	0.234	1.00 (0.90, 1.10)	0.974
Capped and weighted						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.84 (0.76, 0.93)	0.001	0.84 (0.76, 0.92)	<0.001	0.88 (0.79, 0.97)	0.012
Weighted and capped						
Q1	1.00		1.00		1.00	
Q5, HR mortality (95% CI)	0.87 (0.79, 0.96)	0.005	0.87 (0.79, 0.96)	0.007	0.95 (0.86, 1.05)	0.302

[1] HRs, 95% CIs, and *P* values estimated by Cox proportional hazards regression. NRF9.3 includes 9 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, and magnesium) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. NRF11.3 includes 11 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, magnesium, vitamin D, and folate) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. NRF21.3 includes 21 qualitative nutrients (protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, potassium, magnesium, vitamin D, folate, thiamin, riboflavin, omega-3 fatty acids, niacin, vitamin B-6, vitamin B-12, phosphorus, iodine, selenium, and zinc) and 3 disqualitative nutrients (sodium, added sugars, and saturated fat) in the score. Ranking into quintiles was adjusted by age groups. Q1 is the lowest quintile and Q5 the highest quintile. Q1 is the reference category. NRF index, Nutrient Rich Foods index; Q, quintile.

[2] Adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

Covariates that expressed a time trend (age and age squared) were treated as time-dependent covariates in all models. All Cox regression analyses were run separately for women and men and in sensitivity analyses also for separate age groups. Background and sociodemographic differences between the 4 groups were tested using 1-factor ANOVA, the Kruskal–Wallis test, and the chi-square test. Differences in reported food intake of 19 food groups (see **Supplemental Table 2** for the food groups and associated food items) were characterized by descriptive statistics and depicted in Circos plots for both genders. The size of the reported intake is proportional to the width of the respective line in the Circos plots. For statistical analyses, SPSS versions 25 and 26 (IBM SPSS Statistics) were used. Statistical significance was set to $P < 0.05$.

Results

Study subjects

In total, 54,620 women and 52,864 men participated in the VIP during 1990–2016. After exclusion criteria were applied, 49,124 women and 47,651 men remained (**Figure 2**). Among women, 35% reported having attained a university degree and the mean BMI was 25.6. The corresponding numbers for men were 26% and 26.6. Approximately 50% of both women and men had been smokers earlier in life or were current smokers. Median dietary climate impact for women was 3.0 kg CO_2e/d and 2000 kcal, and for men 3.7 kg CO_2e/d and 2500 kcal. **Table 2** provides background information for the included participants.

Selection of a suitable diet quality index

Tables 3 and **4** summarize HRs for the 15 alternative versions of the NRF indexes and **Supplemental Tables 3–8** provide the full description. For men none of the various NRF versions proved better than the other, whereas for women NRF11.3 was identified as the version with the best HR trend consistency. Applying capping to NRF11.3 improved HR and *P* values for both women and men. Applying weighting to NRF11.3, or applying weighting after capping, only improved the results marginally for men, and had no effect on the results for women (see Supplemental Tables 5, 6). No consistent patterns for background and sociodemographic factors across quintiles were identified for any of the 15 index versions. Based on these results, NRF11.3 with capping, and without weighting, was identified as the diet quality index best predicting total mortality in the population, and was the method used in analyses on combined effects of diet quality and climate impact on mortality. The distributions of the NRF11.3 scores as well as the GHGE scores were similar among women and men and mainly normally distributed (Supplemental Figure 1).

Effects of diet quality and climate impact on total mortality

In women, the median and maximum follow-up times were 16.0 y and 25.9 y, respectively, and 3074 (6.3%) women died during follow-up. Statistically significantly lower hazards for total mortality were found in the full models for the 2 groups characterized by higher diet quality, i.e., HNutr/LClim (HR: 0.87; 95% CI: 0.79, 0.96; $P = 0.008$) and HNutr/HClim (HR: 0.87; 95% CI: 0.78, 0.97; $P = 0.011$), than for the

TABLE 5 HRs and 95% CIs for total mortality, and characteristics, of women participating in the Västerbotten Intervention Programme during 1990–2016, classified into 4 groups according to their diet quality calculated by the nutrient density score NRF11.3 and climate impact[1]

	Women ($n = 49{,}124$)						
	HNutr/LClim (n total = 12,997; n cases = 865)	P	HNutr/HClim (n total = 11,566; n cases = 570)	P	LNutr/LClim (n total = 11,564; n cases = 895)	P	LNutr/HClim, reference group (n total = 12,997; n cases = 744)
HR mortality[2] (95% CI), basic model	0.81 (0.73, 0.89)	<0.001	0.81 (0.72, 0.90)	<0.001	0.92 (0.84, 1.02)	0.096	1.00
HR mortality[3] (95% CI), model 1	0.88 (0.80, 0.97)	0.013	0.87 (0.78, 0.97)	0.012	0.97 (0.88, 1.07)	0.541	1.00
HR mortality[4] (95% CI), model 2	0.87 (0.79, 0.96)	0.008	0.87 (0.78, 0.97)	0.011	0.96 (0.87, 1.06)	0.439	1.00
Age,[5] y	47.2 ± 8.0		48.3 ± 8.0		47.7 ± 8.0		48.3 ± 8.0
Systolic blood pressure,[5] mm Hg	123.8 ± 18.1		123.9 ± 17.6		123.2 ± 18.4		123.9 ± 18.0
Diastolic blood pressure,[5] mm Hg	76.9 ± 10.4		77.1 ± 10.3		76.6 ± 10.7		77.3 ± 10.7
Serum cholesterol,[5] mmol/L	5.5 ± 1.2		5.4 ± 1.1		5.5 ± 1.2		5.5 ± 1.2
Fasting blood glucose (capillary),[5] mmol/L	5.4 ± 0.9		5.4 ± 0.9		5.4 ± 0.8		5.4 ± 0.9
2-h blood glucose,[5] mmol/L	6.8 ± 1.5		6.9 ± 1.5		6.8 ± 1.5		6.9 ± 1.5
BMI,[5] kg/m^2	25.5 ± 4.4		26.1 ± 4.7		25.1 ± 4.6		25.8 ± 4.9
Underweight, <18.5	1.0		0.7		1.5		1.1
Normal, 18.5–25.0	53.8		46.4		57.3		49.2
Overweight, >25.0–30.0	31.3		34.8		28.4		32.3
Obese, >30.0	13.8		18.2		12.8		17.5
Physical activity							
Inactive	14.8		16.2		19.6		19.9
Moderately inactive	31.4		28.4		32.7		30.1
Moderately active	27.8		26.5		28.0		28.4
Active	25.6		28.5		19.2		21.1
Level of education							
Basic level, 9 y	37.3		30.5		42.2		32.2
High school	26.1		28.5		28.3		32.9
University	35.8		40.3		28.7		34.1
Smoking							
Currently smoking	17.7		18.6		22.7		23.3
Have smoked	29.6		31.7		25.6		28.1
Never smoked	51.9		48.9		50.7		47.8
Climate impact per day and 2000 kcal, kg CO_2e	2.6 [2.3–2.8]		3.5 [3.2–3.9]		2.6 [2.3–2.8]		3.5 [3.2–4.1]
Energy-adjusted climate impact per year, tonnes CO_2e	0.9 [0.8–1.0]		1.3 [1.2–1.4]		0.9 [0.9–1.0]		1.3 [1.2–1.5]
Nutrient density score per day and 2000 kcal[6]	7.7 [7.3–8.2]		7.7 [7.2–8.1]		6.3 [5.8–6.7]		6.2 [5.7–6.6]

[1] Values are means ± SDs, medians [IQRs], or percentages unless otherwise indicated. HRs, 95% CIs, and P values estimated by Cox proportional hazards regression. NRF11.3 is based on the NRF index. Qualitative nutrients in NRF11.3 are protein, fiber, iron, potassium, calcium, magnesium, vitamin A, vitamin C, vitamin E, vitamin D, and folate, and disqualitative nutrients are sodium, saturated fat, and added sugars. All qualitative nutrients in NRF11.3 are capped at the DRI, except for fiber which has no recommended upper limits. All group differences were $P < 0.05$ and mostly $P < 0.001$, except for 2-h blood glucose ($P = 0.111$), tested using 1-factor ANOVA, the Kruskal–Wallis test, and chi-square test. CO_2e, carbon dioxide equivalents; HNutr/HClim, higher nutrient density/higher climate impact; HNutr/LClim, higher nutrient density/lower climate impact; LNutr/HClim, lower nutrient density/higher climate impact; LNutr/LClim, lower nutrient density/lower climate impact; NRF index, Nutrient Rich Foods index.

[2] Basic model adjusted for age and age squared.

[3] Model 1 adjusted for age, age squared, BMI, physical activity, educational level, and smoking status.

[4] Model 2 adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

[5] Adjusted for age and year of study participation.

[6] Calculated by NRF11.3 with capping.

reference LNutr/HClim. The hazard for LNutr/LClim did not differ statistically significantly from that of the reference group (**Table 5**). Age-stratified analyses (**Table 6**) demonstrated that women 45–54 and 55–65 y old in HNutr/LClim had a statistically significantly lower risk of total mortality than had the reference group, the HRs being 0.82 (95% CI: 0.68, 0.99; $P = 0.039$), and 0.86 (95% CI: 0.75, 0.98; $P = 0.021$), respectively. The age-stratified analyses also revealed that women 35–44 y old in LNutr/LClim had a statistically significantly higher risk of total mortality than had the reference group LNutr/HClim (HR: 1.52; 95% CI: 1.08, 2.15; $P = 0.017$).

In men, the median and maximum follow-up times were 14.7 y and 26.8 y, respectively, and 4212 (8.8%) men died during follow-up. A statistically significantly higher hazard for total mortality was found in LNutr/LClim than in the reference group LNutr/HClim (HR: 1.10; 95% CI: 1.01, 1.21; $P = 0.033$). For HNutr/LClim and HNutr/HClim the risk of total mortality did not differ statistically significantly from that of the reference group LNutr/HClim (**Table 7**). Age-stratified analyses (**Table 8**) revealed that men 45–54 y in both HNutr/LClim and LNutr/LClim had a statistically significantly higher risk of total mortality than had the reference group, the HRs being 1.21 (95% CI: 1.03, 1.43; $P = 0.021$) and 1.21 (95% CI: 1.02, 1.43; $P = 0.028$), respectively.

Background and sociodemographic characteristics by diet quality and climate impact groups

Women with higher diet quality exhibited a higher percentage of physical activity than did women with lower diet quality. Further, women with lower dietary climate impact had a lower BMI than had women with higher dietary climate impact. The women with lower diet quality and lower climate impact included the highest percentage of women with a basic level of education, whereas those with higher diet quality and higher climate impact included the highest percentage with a university degree. Table 5 presents further characteristics.

Similarly, men with higher diet quality exhibited a higher percentage of physical activity than did men with lower diet quality. Also similarly to the women, men with a lower dietary climate impact had a lower BMI than had men with higher dietary climate impact. The men with higher diet quality contained the lowest percentage of smokers. For further characteristics, see Table 7.

Differences in reported food intake by diet quality and climate impact groups

The reported food intake patterns in the 4 diet quality and climate impact groups were similar for women and men (**Figure 3**). Importantly, women and men with higher diet quality had a higher reported intake of vegetables, fruits, and berries, as well as high-fiber cereal products and low-fat dairy products, than had those with lower diet quality. The women and men with lower diet quality instead had a higher reported intake of sugar sweetened drinks and food products and high-fat dairy products, compared with those with higher diet quality. The 2 groups with higher dietary climate impact had a higher reported intake of red

TABLE 6 HRs and 95% CIs for total mortality of women participating in the Västerbotten Intervention Programme during 1990–2016, in age strata by the 4 groups of nutrient density, calculated by the nutrient density score NRF11.3, and climate impact[1]

		Women ($n = 49{,}124$)						
	Age groups, y	HNutr/LClim ($n = 12{,}997$)	P	HNutr/HClim ($n = 11{,}566$)	P	LNutr/LClim ($n = 11{,}564$)	P	LNutr/HClim, reference group ($n = 12{,}997$)
HR mortality[2] (95% CI), basic model	35–44[3]	1.09 (0.78, 1.50)	0.623	0.87 (0.59, 1.27)	0.456	1.38 (0.99, 1.92)	0.058	1.00
	45–54[4]	0.74 (0.61, 0.89)	0.001	0.78 (0.64, 0.95)	0.012	0.83 (0.69, 1.00)	0.054	1.00
	55–65[5]	0.81 (0.71, 0.91)	0.001	0.82 (0.71, 0.94)	0.005	0.91 (0.80, 1.03)	0.118	1.00
HR mortality[6] (95% CI), model 1	35–44[3]	1.21 (0.87, 1.70)	0.262	0.98 (0.66, 1.45)	0.918	1.53 (1.08, 2.15)	0.015	1.00
	45–54[4]	0.84 (0.69, 1.01)	0.063	0.84 (0.68, 1.02)	0.081	0.86 (0.71, 1.04)	0.128	1.00
	55–65[5]	0.86 (0.76, 0.98)	0.025	0.88 (0.76, 1.02)	0.080	0.96 (0.85, 1.09)	0.503	1.00
HR mortality[7] (95% CI), model 2	35–44[3]	1.21 (0.86, 1.70)	0.283	0.98 (0.66, 1.45)	0.907	1.52 (1.08, 2.15)	0.017	1.00
	45–54[4]	0.82 (0.68, 0.99)	0.039	0.83 (0.68, 1.01)	0.066	0.85 (0.70, 1.03)	0.099	1.00
	55–65[5]	0.86 (0.75, 0.98)	0.021	0.88 (0.76, 1.02)	0.083	0.95 (0.84, 1.08)	0.455	1.00

[1] HRs, 95% CIs, and P values estimated by Cox proportional hazards regression. NRF11.3 was based on the NRF index and energy adjusted by 2000 kcal. The qualitative nutrients included in NRF11.3 are protein, fiber, iron, potassium, calcium, magnesium, vitamin A, vitamin C, vitamin E, vitamin D, and folate. Disqualitative nutrients included are sodium, saturated fat, and added sugars. All qualitative nutrients in NRF11.3 are capped at the DRI, except for fiber which has no recommended upper limits. HNutr/HClim, higher nutrient density/higher climate impact; HNutr/LClim, higher nutrient density/lower climate impact; LNutr/HClim, lower nutrient density/higher climate impact; LNutr/LClim, lower nutrient density/lower climate impact; NRF index, Nutrient Rich Foods index.

[2] Adjusted for age and age squared.

[3] HNutr/LClim n total = 6080, n cases = 118, HNutr/HClim n total = 5192, n cases = 53, LNutr/LClim n total = 5191, n cases = 103, LNutr/HClim n total = 6080, n cases = 54.

[4] HNutr/LClim n total = 3896, n cases = 230, HNutr/HClim n total = 3543, n cases = 176, LNutr/LClim n total = 3542, n cases = 222, LNutr/HClim n total = 3896, n cases = 220.

[5] HNutr/LClim n total = 3021, n cases = 517, HNutr/HClim n total = 2831, n cases = 341, LNutr/LClim n total = 2831, n cases = 570, LNutr/HClim n total = 3021, n cases = 470.

[6] Adjusted for age, age squared, BMI, physical activity, educational level, and smoking status.

[7] Adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

TABLE 7 HRs and 95% CIs for total mortality, and characteristics, of men participating in the Västerbotten Intervention Programme during 1990–2016, classified into 4 groups according to their diet quality calculated by the nutrient density index NRF11.3 and climate impact[1]

	Men ($n = 47{,}651$)						
	HNutr/LClim (n total = 12,719; n cases = 1305)	P	HNutr/HClim (n total = 11,108; n cases = 789)	P	LNutr/LClim (n total = 11,105; n cases = 1244)	P	LNutr/HClim, reference group (n total = 12,719; n cases = 874)
HR mortality[2] (95% CI), basic model	0.96 (0.88, 1.04)	0.307	0.87 (0.79, 0.96)	0.004	1.09 (1.00, 1.19)	0.051	1.00
HR mortality[3] (95% CI), model 1	1.05 (0.96, 1.14)	0.320	0.92 (0.84, 1.02)	0.106	1.13 (1.03, 1.23)	0.009	1.00
HR mortality[4] (95% CI), model 2	1.01 (0.93, 1.11)	0.765	0.91 (0.83, 1.01)	0.072	1.10 (1.01, 1.21)	0.033	1.00
Age,[5] y	47.3 ± 7.9		48.4 ± 8.1		48.1 ± 8.1		48.2 ± 7.9
Systolic blood pressure,[5] mm Hg	128.8 ± 16.4		128.6 ± 16.3		128.3 ± 16.7		128.5 ± 16.1
Diastolic blood pressure,[5] mm Hg	80.7 ± 10.5		80.7 ± 10.5		80.7 ± 10.7		81.2 ± 10.7
Serum cholesterol,[5] mmol/L	5.5 ± 1.2		5.6 ± 1.1		5.6 ± 1.2		5.7 ± 1.1
Fasting blood glucose (capillary),[5] mmol/L	5.5 ± 1.1		5.6 ± 1.2		5.5 ± 1.0		5.5 ± 1.1
2-h blood glucose,[5] mmol/L	6.4 ± 1.7		6.4 ± 1.7		6.4 ± 1.7		6.4 ± 1.8
BMI,[5] kg/m^2	26.4 ± 3.6		26.9 ± 3.8		26.1 ± 3.7		26.8 ± 4.0
Underweight, <18.5	0.2		0.2		0.5		0.3
Normal, 18.5–25.0	39.6		31.4		41.8		33.1
Overweight, >25.0–30.0	47.6		50.2		45.5		48.4
Obese, >30.0	12.5		18.2		12.2		18.3
Physical activity							
Inactive	17.2		18.2		18.7		19.8
Moderately inactive	30.7		29.7		31.0		29.5
Moderately active	27.4		27.2		30.8		29.6
Active	24.4		24.6		19.1		20.8
Level of education							
Basic level, 9 y	41.1		34.6		46.9		37.3
High school	31.3		32.7		33.0		38.1
University	27.1		32.2		19.4		24.1
Smoking							
Currently smoking	15.8		15.9		21.6		21.8
Have smoked	31.9		32.5		29.3		30.4
Never smoked	51.0		50.3		47.4		46.2
Climate impact per day and 2500 kcal, kg CO$_2$e	3.1 [2.8–3.5]		4.3 [3.9–4.9]		3.1 [2.8–3.5]		4.4 [4.0–5.1]
Energy-adjusted climate impact per year, tonnes CO$_2$e	1.1 [1.0–1.3]		1.6 [1.4–1.8]		1.1 [1.0–1.3]		1.6 [1.5–1.9]
Nutrient density score per day and 2500 kcal[6]	7.1 [6.8–7.5]		7.1 [6.8–7.4]		5.9 [5.3–6.2]		5.9 [5.3–6.2]

[1] Values are means ± SDs, medians [IQRs], or percentages, unless otherwise indicated. HRs, 95% CIs, and P values estimated by Cox proportional hazards regression. NRF11.3 is based on the NRF index. Qualitative nutrients in NRF11.3 are protein, fiber, iron, potassium, calcium, magnesium, vitamin A, vitamin C, vitamin E, vitamin D, and folate, and disqualitative nutrients are sodium, saturated fat, and added sugars. All qualitative nutrients in NRF11.3 are capped at the DRI except for fiber, which has no recommended upper limits. All group differences were $P < 0.05$ and mostly $P < 0.001$, except for systolic blood pressure ($P = 0.194$) and 2-h blood glucose ($P = 0.323$), tested using 1-factor ANOVA, the Kruskal–Wallis test, and chi-square test. CO$_2$e, carbon dioxide equivalents; HNutr/HClim, higher nutrient density/higher climate impact; HNutr/LClim, higher nutrient density/lower climate impact; LNutr/HClim, lower nutrient density/higher climate impact; LNutr/LClim, lower nutrient density/lower climate impact; NRF index, Nutrient Rich Foods index.

[2] Basic model adjusted for age and age squared.

[3] Model 1 adjusted for age, age squared, BMI, physical activity, educational level, and smoking status.

[4] Model 2 adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

[5] Adjusted for age and year of study participation.

[6] Calculated by NRF11.3 with capping.

TABLE 8 HRs and 95% CIs for total mortality of men participating in the Västerbotten Intervention Programme during 1990–2016, in age strata by the 4 groups of nutrient density, calculated by the nutrient density score NRF11.3, and climate impact[1]

		Men ($n = 47,651$)						
	Age groups, y	HNutr/LClim ($n = 12,719$)	P	HNutr/HClim ($n = 11,108$)	P	LNutr/LClim ($n = 11,105$)	P	LNutr/HClim, reference group ($n = 12,719$)
HR mortality[2] (95% CI), basic model	35–44[3]	0.97 (0.74, 1.26)	0.798	0.94 (0.70, 1.26)	0.684	1.16 (0.87, 1.54)	0.308	1.00
	45–54[4]	1.15 (0.98, 1.35)	0.087	0.91 (0.76, 1.10)	0.331	1.20 (1.02, 1.42)	0.027	1.00
	55–65[5]	0.87 (0.78, 0.97)	0.014	0.84 (0.74, 0.95)	0.004	1.03 (0.92, 1.15)	0.600	1.00
HR mortality[6] (95% CI), model 1	35–44[3]	1.07 (0.81, 1.41)	0.627	1.02 (0.76, 1.37)	0.902	1.22 (0.92, 1.64)	0.173	1.00
	45–54[4]	1.22 (1.04, 1.44)	0.014	0.95 (0.80, 1.15)	0.614	1.21 (1.03, 1.43)	0.023	1.00
	55–65[5]	0.96 (0.85, 1.07)	0.449	0.89 (0.79, 1.01)	0.081	1.07 (0.95, 1.19)	0.260	1.00
HR mortality[7] (95% CI), model 2	35–44[3]	1.02 (0.77, 1.35)	0.901	0.97 (0.72, 1.31)	0.844	1.21 (0.90, 1.62)	0.203	1.00
	45–54[4]	1.21 (1.03, 1.43)	0.021	0.95 (0.79, 1.14)	0.575	1.21 (1.02, 1.43)	0.028	1.00
	55–65[5]	0.92 (0.82, 1.04)	0.174	0.89 (0.78, 1.01)	0.076	1.04 (0.93, 1.16)	0.525	1.00

[1] HRs, 95% CIs, and P values estimated by Cox proportional hazards regression. NRF11.3 was based on the NRF index and energy adjusted by 2500 kcal. The qualitative nutrients included in NRF11.3 are protein, fiber, iron, potassium, calcium, magnesium, vitamin A, vitamin C, vitamin E, vitamin D, and folate. Disqualitative nutrients included are sodium, saturated fat, and added sugars. All qualitative nutrients in NRF11.3 are capped at the DRI, except for fiber which has no recommended upper limits. HNutr/HClim, higher nutrient density/higher climate impact; HNutr/LClim, higher nutrient density/lower climate impact; LNutr/HClim, lower nutrient density/higher climate impact; LNutr/LClim, lower nutrient density/lower climate impact; NRF index, Nutrient Rich Foods index.

[2] Adjusted for age and age squared.

[3] HNutr/LClim n total = 5865, n cases = 138, HNutr/HClim n total = 4856, n cases = 96, LNutr/LClim n total = 4855, n cases = 109, LNutr/HClim n total = 5865, n cases = 87.

[4] HNutr/LClim n total = 3955, n cases = 433, HNutr/HClim n total = 3422, n cases = 231, LNutr/LClim n total = 3421, n cases = 345, LNutr/HClim n total = 3955, n cases = 240.

[5] HNutr/LClim n total = 2899, n cases = 734, HNutr/HClim n total = 2830, n cases = 462, LNutr/LClim n total = 2829, n cases = 790, LNutr/HClim n total = 2899, n cases = 547.

[6] Adjusted for age, age squared, BMI, physical activity, educational level, and smoking status.

[7] Adjusted for age, age squared, BMI, physical activity, educational level, smoking status, and year of participation.

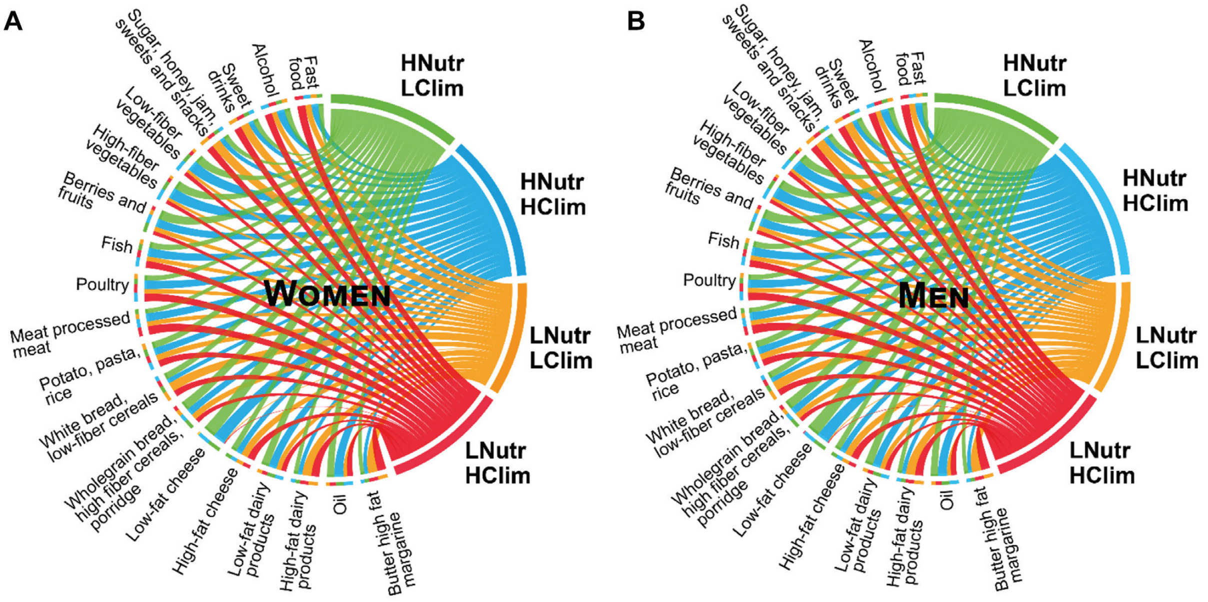
and processed meat, fish, and poultry than had the groups with lower dietary climate impact.

Discussion

The effects of diets varying in nutrient density and climate impact on total mortality were examined in a population-based prospective cohort of women and men in northern Sweden. The results demonstrated the usefulness of nutrient density indexes for predicting total mortality of diets, and that diets benefiting both health and climate are feasible and associated with lower mortality among women. The results also showed that diets with low climate impact may have either a positive or a negative impact on health, depending on the diet quality.

In the evaluation of different nutrient density indexes, NRF11.3 with capping was identified as the diet quality index best predicting total mortality in the study population. The fact that the Sweden-adapted index here turned out superior over the original NRF9.3 adapted for a US population suggests that nutrient density indexes should be adapted to the specific population of study (23). Here, when examining the effect of diet quality irrespective of that of dietary climate impact, our results demonstrated an association between higher diet quality and lower mortality for both women and men, in line with other studies using various indexes for diet quality (40). In sum, our results suggest that nutrient density indexes are valid to predict risk of total mortality in general, including the specific NRF11.3 variant used here for the Swedish population.

Next, whether a more nutritious diet with lower dietary climate impact also would be considered beneficial for human health was examined. The results indicated that women with a diet of higher quality, no matter whether combined with higher or lower dietary climate impact, had a statistically significantly lower risk of total mortality than had the reference group with a diet of lower quality and higher dietary climate impact. Surprisingly, for men none of the groups with a diet of higher quality showed a lower risk of total mortality than the reference group. More narrow ranges in reported intake of various foods among men than among women in the VIP cohort have been shown in the earlier years of the study period (41), although in the later years more similar variances in reported intake among both sexes have been found (42). Consequently, our study may have had less ability to detect statistically significant differences in intake between subgroups of men. Further, the diet variations most influential for total mortality risk in men may not have been captured by the 19 created food groups. Finally, unmeasured lifestyle factors may have confounded the associations differently for the 2 sexes. Nevertheless, men with *lower* diet quality and *lower* climate impact exhibited statistically significantly *higher* mortality risk (∼10% higher) than the reference group of lower diet quality and higher dietary climate impact. The same risk increase was found among women aged 35–44 y (∼50% higher). In addition, men aged 45–54 y with *higher* diet quality and *lower* climate impact exhibited statistically significantly *higher* mortality risk (∼20% higher). This was unexpected, and may be due to residual confounding. Further research regarding this seemingly negative effect of lower dietary climate impact on mortality risk for men is needed. In summary, the results indicate that dietary patterns with lower climate impact may affect the total mortality risk either



	WOMEN				MEN			
FOOD GROUPS (g/day)	**HNutr/LClim** (n=12 997)	**HNutr/HClim** (n=11 566)	**LNutr/LClim** (n=11 564)	**LNutr/HClim** (n=12 997)	**HNutr/LClim** (n=12 719)	**HNutr/HClim** (n=11 108)	**LNutr/LClim** (n=11 105)	**LNutr/HClim** (n=12 719)
Fast food (g/day)	16 (1;27)	20 (2;32)	18 (1;29)	25 (12;38)	33 (3;47)	41 (16;57)	36 (12;51)	47 (26;66)
Alcoholic drinks (g/day)	36 (3;81)	48 (17;101)	30 (2;77)	43 (4;102)	111 (47;199)	148 (73;252)	96 (33;187)	132 (58;242)
Sweet drinks (g/day)	35 (17;72)	31 (13;57)	55 (27;133)	46 (24;113)	57 (31;117)	54 (31;103)	89 (41;202)	78 (39;176)
Sugar, honey, jam, sweets and snacks	25 (16;36)	23 (15;33)	42 (27;61)	34 (22;50)	33 (21;50)	30 (19;44)	54 (33;83)	41 (26;63)
Low-fiber vegetables (g/day)	56 (28;97)	76 (42;123)	26 (10;48)	34 (15;59)	30 (13; 55)	39 (18;69)	11 (4;27)	14 (5;33)
High-fiber vegetables (g/day)	100 (49;175)	123 (66;207)	38 (16;75)	48 (21;86)	40 (17;81)	52 (23;97)	14 (6;34)	18 (7;42)
Berries and fruits (g/day)	259 (166;400)	253 (165;391)	145 (85;219)	136 (77;207)	157 (95;246)	145 (86;225)	81 (40;139)	68 (37;121)
Fish (g/day)	22 (14;31)	31 (21;44)	18 (11;27)	26 (16;38)	24 (15;34)	34 (22;49)	18 (10;28)	27 (15;41)
Poultry (g/day)	13 (9;18)	21 (15;32)	12 (7;17)	20 (13;30)	15 (10;21)	23 (16;36)	14 (8;20)	23 (14;35)
Red meat, processed meat (g/day)	60 (46;74)	104 (84;129)	62 (48;77)	109 (87;138)	78 (60;97)	135 (109;168)	80 (61;100)	142 (112;183)
Potato, pasta, rice	239 (174;318)	229 (163;306)	216 (157;285)	220 (158;289)	263 (190;352)	278 (206;360)	225 (160;302)	253 (182; 333)
White bread, low-fiber cereals	27 (13;47)	19 (10;34)	43 (23;67)	28 (14;48)	43 (22;69)	31 (16;52)	56 (32;89)	39 (21;63)
Wholegrain bread, high-fiber cereals, porridge	141 (94;211)	112 (76;165)	102 (63;160)	82 (48;125)	155 (106;231)	121 (82;175)	102 (61;158)	78 (44;121)
Low-fat cheese	2 (0;14)	2 (0;11)	0 (0;6)	0 (0;4)	2 (0;10)	2 (0;9)	1 (0;5)	0 (0;4)
High-fat cheese	8 (2;19)	8 (2;18)	13 (3;22)	13 (4;22)	11 (2;22)	11 (3; 22)	12 (3;22)	13 (4;24)
Low-fat dairy products	292 (160;465)	325 (180;514)	203 (52;366)	218 (65;406)	338 (184;568)	353 (190;598)	212 (42;411)	220 (48;429)
High-fat dairy products	56 (19;177)	49 (13;158)	144 (43;276)	136 (44;286)	79 (32;239)	73 (31;219)	152 (45;337)	137 (47;335)
Oil (g/day)	6 (2;14)	7 (3;14)	4 (1;10)	5 (1;11)	7 (2;17)	9 (3;19)	4 (0;12)	6 (2;15)
Butter, high-fat margarine (g/day)	3 (0;15)	3 (0;13)	17 (3;26)	15 (3;25)	13 (1;30)	11 (1;26)	31 (16;45)	28 (13;42)

FIGURE 3 Circos plots of the reported intake per day of 19 food groups of 4 groups of women ($n = 49{,}124$; A) and men ($n = 47{,}651$; B) participating in the Västerbotten Intervention Programme during 1990–2016. Reported intakes are presented as median [IQR] values in grams and energy adjusted to 2000 kcal for women and 2500 kcal for men. The size of the reported intake is proportional to the width of the respective line in the Circos plots. HNutr/HClim, higher nutrient density/higher climate impact; HNutr/LClim, higher nutrient density/lower climate impact; LNutr/HClim, lower nutrient density/higher climate impact; LNutr/LClim, lower nutrient density/lower climate impact.

positively or negatively, and both dietary climate impact and diet quality should be jointly accounted for (43).

To define higher and lower dietary climate impact, the population-specific median was used as cutoff. For women this was 3.0 kg CO_2e/d and for men 3.7 kg CO_2e/d when expressed for an intake of 2000 kcal/d for women and 2500 kcal/d for men, yielding 1.1 and 1.4 tonnes CO_2e/y, respectively. Slightly higher values have been reported based on repeated 24-h recalls from a Swedish population-based national food survey (31), with energy-adjusted median GHGEs for women being 1.7

tonnes CO_2e/y and for men 1.8 tonnes CO_2e/y (17). The World Wide Fund for Nature (WWF) has suggested a sustainable limit of climate impact of ∼0.59 tonnes CO_2e/y and person from food (44)—well below the median of our studied population. The WWF limit was thus unfeasible for our analyses because too few participants would be categorized as consuming diets both nutritious and having a low climate impact. The EAT–*Lancet* Commission proposed a universal healthy reference diet from a sustainable food system (45). Our results and previous results (17) demonstrate that the Swedish population is far from such a diet and that strategies for making people shift their diet toward more sustainable options are acutely needed. The observed variation in climate impact between individuals in the studied population nevertheless suggests that adoption of diets consumed by a large proportion of the Swedish population entails a substantial potential for reduced GHGEs. Still, to reach the WWF sustainable limit of climate impact, improvements in climate impact efficiency in the food production systems are also needed (9).

Strengths and weaknesses of both VIP and LCA data have been reviewed before (46). Importantly, the large and population-based sample of study participants in the VIP is a main strength. Additional strengths of the VIP include standardized, validated, and consistent methods of dietary and lifestyle assessment and medical examination, although the well-known problem of underreporting concomitant with all reported dietary data should not be disregarded. Also LCA climate data comprise several uncertainties (47). To reduce the effect of these on the climate analyses, updated LCA data were harmonized in key methodological aspects, such as system boundaries. Both the nutritional intake and the dietary climate impact data were energy adjusted to 2000 kcal for women and 2500 kcal for men, to partly compensate for the expected underreporting of total dietary intake and to focus on diet quality rather than quantity. Because the FFQ consists of only 84 or 64 food items and has not been updated with novel foods since the 1980s, it most likely does not depict the full dietary habits of the participants in their broadness. The FFQ was also not adapted to apprehend differences in GHGEs within food groups that are of importance for the climate impact of the diet, as for example the distribution of meat consumption among game, lamb, pork, and beef meat and the production methods of meat. By making assumptions based on national consumption statistics, attempts were made to correct for this. Further, it must be stressed that climate change is only one of several major environmental consequences of food production, with other examples being freshwater use, land use change, biodiversity loss, and pollution (45). Even though climate impact may be used as a proxy for several other environmental impacts (48, 49), further studies need to include additional environmental consequences beyond climate impact, which may potentially affect the results. Other values of relevance for facilitating the transition into a sustainable diet include cultural acceptance, affordability, and animal welfare, which should be kept in mind when conducting studies regarding how to achieve the UN Sustainable Development Goals and the Paris Climate Agreement while still having public health in mind (45, 50–52).

In conclusion, the present results suggest that measuring nutrient density with NRF11.3 with capping is suitable to evaluate the quality of Swedish diets, but population adaptation is likely needed in other contexts, and that diet quality per se is a predictor of total mortality for both women and men. When combined with dietary climate impact, women with higher diet quality and either a higher or a lower climate impact had a lower risk of total mortality, suggesting that a diet benefiting both health and climate is possible. The same conclusion could not be reached for men. This advocates further studies of how men can transition into more climate-sustainable and healthy diets. Among men and the younger group of women, a diet of lower diet quality and lower climate impact was associated with higher mortality than was a diet of lower diet quality and higher climate impact, highlighting that dietary patterns with lower climate impact can have either a positive or a negative impact on risk of total mortality depending on diet quality. A more comprehensive evaluation regarding the environmental sustainability of nutritionally adequate diets is, however, sought after, and should be included in further studies.

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The authors' responsibilities were as follows—AW, IJ, US, EH, and MB: designed the research; IJ and BL: provided data from the Västerbotten Intervention Programme; IJ: created the diet database in the Västerbotten Intervention Programme; AS: performed the statistical analyses, analyzed the data under supervision from AW and IJ, wrote the paper, and had primary responsibility for the final content; and all authors: read and approved the final manuscript. The authors report no conflicts of interest.

Data availability

Data described in the article, codebook, and analytic code will not be made available owing to legal restrictions.

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