Elevated Atmospheric CO_2 Levels and Effects on Plant Nutrition and Health of Indigenous Peoples; a Review of Current Research

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ABSTRACT

The extent to which current academic research has investigated the possibility that elevated levels of atmospheric carbon-based gases are affecting the health of indigenous peoples is a pressing issue. As described in the paper 'Traditional Foods and Medicines and Mounting Chronic Disease for Indigenous Peoples Worldwide', prior meta-analyses of extant literature have noted that "elevated CO_2 and other greenhouse gases in the atmosphere have negatively affected cultivars of various commercial crop species resulting in serious chronic disease consequences for human beings". This paper notes that there is a "dearth of information on the changing nutrition (protein, micronutrients, bioavailability) of wild plants and animals, which constitute from 40% to 80% of Fourth World peoples' diet and sources of medicine" which "suggests the need for further research". The effects of elevated carbon-based gases in the atmosphere may impact on the nutritional value of consumable plants and animals and consequently directly affect the health of indigenous peoples and other peoples in the world dependent on commercially cultivated foods and medicines.

As part of this call for further research, this paper seeks to investigate the extent to which current academic literature has investigated the possibility that elevated levels of atmospheric carbon-based gases are affecting the health of indigenous peoples. Gaining a clear picture of the state of such research will help to determine the particular vulnerabilities of distinct peoples from these changes, develop strategies tailored to assist indigenous peoples in mitigating any effects and determine any insights their káhlaculture based lifeways may present for adaptation to the effects of increasing atmospheric CO_2 levels for humanity generally.

A mixed methods analysis of relevant literature was conducted for this investigation, providing an overview of findings on the large scale social and ecological effects of increasing atmospheric carbon dioxide levels and reviewing the extent to which current academic research has investigated the possibility that elevated levels of atmospheric carbon-based gases are affecting the health of indigenous peoples specifically. In order to review current findings from research about this, a mixed

methods analysis of relevant literature was undertaken, providing a holistic overview of findings and the effects of elevated atmospheric carbon-based gas levels on indigenous communities. The findings from this provide an overview of the wider ecological and human health effects of rising atmospheric carbon-based gases and insights into where further research is required to address current gaps in the literature.

Key words: kálhaculture, Fourth World peoples, nutrition, chronic disease

"Kálhaculture" *A term derived from two words; the first is an Oneida word for "forest or woods", the second is from the Latin meaning "worshiping Earth" or tending to the earth. It succinctly describes the concept of the balanced use of nature that indigenous peoples carry out every day; producing foods and medicines from the natural world, whilst balancing the reciprocal needs of humans, plants, animals and the Earth's capacity to restore life.*

Are Fourth World Peoples [Indigenous peoples] "stewards" of the natural world?

This argument is often put forward in popular literature to romanticise the actual pragmatic relationship between Fourth World peoples and the natural world. Dependence on the natural world requires a practical commitment to sustain that world for personal nourishment and renewal. Long evolved cultural practices aimed at balancing human needs against maintaining the capacity of the earth's biosphere to provide for them in a sustainable fashion are a practical necessity for realistic prospects of continued survival. Sustaining the diversity of the biological world in turn means that indigenous peoples themselves are sustained. Some nations of course do not follow this maxim, but rather pursue an expansionist paradigm with wide scale unsustainable resource use contributing to excessive waste production including climate altering gases such as carbon dioxide [CO_2] into the atmosphere and oceans; the effect of this being to dramatically affect the natural balance of ecosystems and compromise the ability of life supporting plants and animals to survive.

There are more than 5000 distinct nations of indigenous cultures spread across the planet, reflecting the ingenious and successful adaptations human beings have made to the greatly varied ecosystems that support life. Indigenous nations inhabit almost every environment type on this planet from some of the richest and most fertile lands in the world, such as the region between the Tigris and Euphrates rivers in eastern Syria and Northern Iraq, to the most arid regions including the Sahara Desert. The cultural adjustments made by each successful community and its descendants in order to prosper in different ecosystems, as well as to varied climate conditions, is testament to the power of culture and enduring flexibility

of peoples. The very richness and diversity of life in the natural world is reflected in human diversity; cultural responses to the environment as demonstrated in the practice of Kálhaculture.

While the cultural variation present between societies is immense, one common theme can be said to unite indigenous peoples around the globe; that they predominantly respect the natural environment and exploit it only to the extent that the earth can replenish, they all practice kálhaculture[1] to some degree. This of course stands in direct contrast to the practices of metropolitan societies and the large-scale waste streams produced by industrialised nations, such as the emission of greenhouse gases that are altering the earth's biosphere on a global scale.

Elevated levels of Greenhouse Gases in the Atmosphere

Atmospheric levels of carbon dioxide have risen from 280 parts per million [ppm] in the preindustrial period (NASA 2020), to 415ppm at present, looking set to rise up to 750ppm at the end of this century (Marland and Boden 2002). It has been documented in a range of studies that rising CO_2 levels have effects on plants; namely that higher levels enable plants to grow more quickly, but what is often less noted is that higher levels of carbon dioxide have often been documented to have negative impacts on plant nutrition. The scale of the change in atmospheric CO_2 means that in addition to leading to rapid climate change, the increasing levels of the gas itself may have significant effects on human health globally as well as wider ecological effects. As such this phenomenon merits further investigation.

Whilst elevated atmospheric greenhouse gases will have an effect on the world population as a whole there are of course substantial disparities in wealth globally and diversity of life ways, which all affect the nature of people's diets. One noted risk from elevated CO_2 levels is many plants producing less protein (Conroy 1992, 445) and having reduced levels of certain micro and macronutrients (Dong, et al. 2018, 1). Such effects are most likely easiest to mitigate in the world's wealthy industrialized nations where higher levels of animal protein consumption in people's diets and the availability of multivitamins and a range of store-bought crops mean for a great deal of choice to maintain a balanced diet.

The majority of the world's population does not have the luxury of mitigating the adverse effects of elevated CO_2 levels, with economically impoverished people in urban areas and rural populations generally relying more on plant-based proteins in their diets (Solomons 2000, 41). In many parts of the world where these people predominantly rely on the industrial food system they also have access to a limited range of plant species for the majority of their caloric needs and only a few select cultivars of those species (FAO 2020). The homogeneity of such diets with their dependence on a limited range of plant species place such populations at heightened risk of inadequate nutrition from increasing CO_2 levels negatively impacting on the nutritional qualities of plants.

[1] The word Kálhaculture is derived from two words. The first is an Oneida word for "forest or woods" and the second word is from the Latin meaning "worshiping Earth" or tending to the earth. This word has been employed to provide a clear explanatory term for the concept of balanced use of nature that indigenous peoples carry out on a daily basis.

These two generalized groups, of course, omit a great deal of diversity within and between countries but provide a useful framework when reviewing the effects of rising CO_2 levels on the largest scale globally. Overlooked in such broad scale research and overview is the world's Fourth World [indigenous] peoples. While these different peoples predominantly reside in the global south or often live as marginalized communities in industrialized nations they often have a distinct nuance in their lifeways that provide invaluable insights. Namely, that though many of these groups often consume predominantly plant-based diets complimented by fish and wild caught animal protein sources, they typically eat a much broader range of species and many more varieties of more widely consumed crop plants of which only a few cultivars are grown commercially (Swiderska and Ryan 2020).

The genetic narrowing from most agricultural production leads to greater vulnerability of crops to ecological change, in addition to impacts from climate change (Swiderska and Ryan 2020). If the limited number of varieties of a few crops that are used to produce the majority of global calories are nutritionally affected by rising carbon dioxide levels there is relatively little scope within the system for any dynamic adaptation to a change in conditions. Traditional agricultural and horticultural methods with their greater genetic diversity, and dynamic cultivation practices that are responsive and adaptable to changing conditions are likely to have a greater capacity to maintain adequate nutrition in the face of change, especially for those living on a primarily plant-based diet (Swiderska and Ryan 2020).

Many Fourth World peoples employ Kálhaculture[2] methods to obtain sustenance from a much broader range of plant species than people in industrialized nations or many of the urban poor in the majority world. Alongside gathering, horticultural methods employed as part of such lifeways are arguably more biodiverse than mechanized agricultural practices; localized production and consumption means for much greater heterogeneity of plant breeds within even relatively small geographical areas. This diversity, combined with a more labour-intensive, relational system of food production means for much greater levels of plant diversity. There are, for example, a rich diversity of varieties of mahiz [Taino for the Spanish maize] in countries such as México (O'Leary 2016) , as opposed to a handful of varieties grown throughout the majority of the United States (Hwang 2017).

As described in the paper 'Traditional Foods and Medicines and Mounting Chronic Disease for Indigenous Peoples Worldwide', prior meta-analyses of extant literature have noted that "elevated CO_2 and other greenhouse gases in the atmosphere have negatively affected cultivars of various commercial crop species resulting in serious chronic disease consequences for human beings" (Rÿser 2019, 13).

[2] "Kálhaculture" is a word that means the production of foods and medicines from natural world, while balancing the reciprocal needs of humans, animals and the Earth's capacity to restore life. This term accurately refers to the methods employed by Fourth World nations emphasizing the reciprocal relationship between human beings and natural life support foods and medicines.

This paper notes that there is a "dearth of information on the changing nutrition (protein, micronutrients, bioavailability) of wild plants and animals, which constitute from 40% to 80% of Fourth World peoples' diet and sources of medicine" which "suggests the need for further research" (Rÿser 2019, 13). The effects of elevated CO_2 gases in the atmosphere may produce effects on the nutritional value of consumable plants and animals and consequently directly affect the health of indigenous peoples and other peoples in the world dependent on commercially cultivated foods and medicines

As part of this call for further research, this paper seeks to investigate the extent to which current academic research has investigated the possibility that elevated levels of atmospheric carbon-based gases are affecting the health of indigenous peoples. In order to gain a clear picture of current findings from research about this crucial issue, a mixed methods analysis of relevant literature was conducted for this paper, providing an overview of findings on the large scale social and ecological effects of increasing atmospheric carbon dioxide levels and reviewing the extent to which current academic research has investigated the possibility that elevated levels of atmospheric carbon-based gases are affecting the health of indigenous peoples specifically.

Gaining a clear picture of the state of such research will help to determine the particular vulnerabilities of distinct peoples from these changes, develop strategies tailored to assist indigenous peoples in mitigating any effects and determine any insights their káhlaculture based lifeways may present for adaptation to the effects of increasing atmospheric CO_2 levels for humanity generally. Furthermore, such research may provide deeper insights into the elevated CO_2 measures and the health and nutrition of all peoples.

Methodology

- Guided searches were conducted on Google and in the Center for World Indigenous Studies archive, with studies focused on changes in atmospheric carbon gases in relation to plants and/or animals within the last 30 years considered appropriate for analysis. Papers were selected randomly from this cohort to provide a representative sample of available literature for analysis.

- More than 100 individual studies and meta studies were selected and reviewed, with details noted for each paper according to pre-specified categories, selected to ensure information regarding each facet under evaluation could be noted. This was in order to evaluate where possible the relationship between geographic location, CO_2 levels, plant and animal characteristics and uses, changes in nutritional or medicinal values and indigenous nations. Details were also noted of author, copyright, publisher and funding of papers to review any potential author bias.

• Categories noting the relevant details from each paper selected according to the above criteria were;

Geo-location	CO_2 Levels referenced	Plant families referenced
Animal families referenced	Methodology of paper	Nutritional changes observed
Medical changes observed	Fourth World nation referenced	Reviewer Comments

• Those papers lacking robust methodological rigour or clear partisan bias were discounted as a first stage of analysis. Publications flagged up as such were reviewed by another investigation team member and any cases where there was disagreement over the status was put out to a third researcher to decide upon.

• In order to provide an overview summary of findings from reviewed papers with regards to the effects of the rise of atmospheric CO_2 levels since the Industrial Revolution, findings from papers were sub-categorised into 'wider ecological effects, general effects on crops and humanity globally' and the specific effects on changes in the nutritional quality of crop plant species on large-scale human demographic groups globally, 'industrialised nations', 'the majority world urban poor' and 'indigenous peoples and majority world rural poor' [see infographic 1]. These categories were selected to provide a holistic overview of background factors and large-scale demographic groups as described in the introduction.

• The overall set of papers was then analysed for their relevance to elevated atmospheric carbon-based gas levels and indigenous community health responses, with those prior identified as having clear methodological issues or political bias or funding issues excluded.

• The relationship between nutrition and consumption of plants and animals is directly associated with the health levels of human populations. With some indigenous communities wholly or partially reliant on non-commercial, non-cultivated foods, any difference in their health compared to the wider population who primarily subsist on domesticated crops in the context of globally increasing CO_2 levels is of note.

• Since indigenous peoples also rely heavily on plants and animals for medicinal support it is equally important to evaluate any changes in the beneficial effects from these sources owing to elevated CO_2.

• The health of indigenous peoples (in so far as chronic diseases are concerned) may be inferred from gas levels, plant types or animal types, nutritional changes in these sources of nutrition and any medicinal changes. Such factors may mean it can be concluded that there is a relationship between elevated atmospheric carbon-based gas levels and indigenous community health responses.

• In order to evaluate the extent to which current academic research has investigated this possibility, the below categories from reviewed

papers were selected and the extent to which they have noteworthy relevance to elevated atmospheric carbon-based gas levels and their effect on indigenous communities assessed.

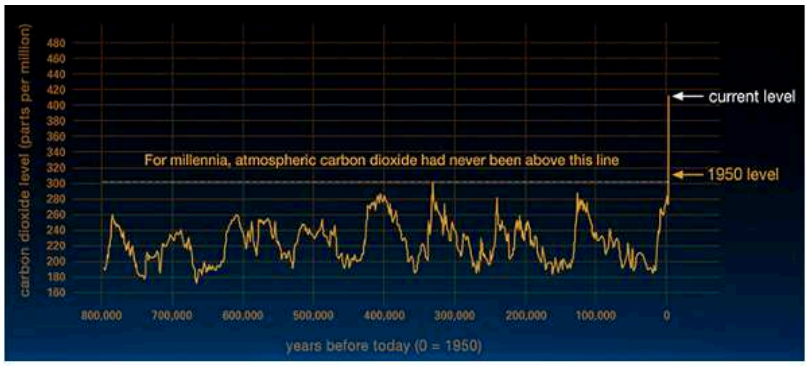
CO_2 Levels referenced	Plant families referenced	Animal families referenced
Nutritional changes observed	Medical changes observed	Fourth World nation referenced

● The details recorded in each category for each paper were rated from 0=not relevant, 1=possible relevance, 2=relevant to 3= highly relevant. Combined scores of values less than nine were deemed unsupportive or unrelated. Combined scores of 9 or greater were deemed as supportive. Papers were analysed and categorised independently by two researchers and any cases where there was disagreement over the status it was put out to a third researcher to decide upon.

● The selected papers reviewed as having noteworthy relevance to elevated atmospheric carbon-based gas levels and their effect on indigenous community health responses are reviewed below in conjunction with the wider background information summarised in infographic 1. This mixed methods approach providing a holistic overview of findings from relevant literature.

- Ocean acidification will negatively impact the productivity of marine ecosystems.
- Decline in biodiversity and biomass of wild plants and animals caused by wider background anthropogenic factors may be exacerbated by increasing CO_2 levels causing knock on ecological effects on terrestrial and marine ecosystems.
- Potential decline in metabolic health for humanity with increasing CO_2 levels, with rising levels of obesity.
- Protein and mineral concentration in plants will generally decrease, compounding other negative impacts on crop yields from anthropogenic climate change.

Image ref: (NASA 2020)



Effects on Industrialised nations	– Increase in carbohydrate content of crops and decrease in protein levels, combined with expected declines in micronutrient content of crops. – Increase in prevalence of toxic chemicals produced by moulds that grow on crops prior to harvest and during storage; increasing temperatures and drought making crops more susceptible to mould. – Expected increase in pesticide use would lead to greater levels of food toxicity.
Effects on Majority World Urban Poor	– With a rapid shift from a subsistence to an industrialised economy there have been notable dietary changes and declines in levels of physical activity that have led to rising obesity levels. The effects of elevated CO_2 on plant and human metabolic health may further exacerbate this trend. – Rising CO_2 generally reduces the nutritional value of C3 food crops. – Risks of health issues such as iron deficiency on a mainly plant based diet.
Effects on Indigenous Peoples and Majority World Rural Poor	– Indigenous peoples often have background issues of poor nutrition due to marginalisation which may be further exacerbated by climate change. – Changes in diet away from traditional sources are also causing health problems for many groups of indigenous people and the majority world rural poor. – Increasing ocean acidification affects an important food source for many indigenous peoples. – Many indigenous peoples source their protein from animals which may offer them more buffering to reduced nutrition in plant protein sources that others depend on. – They may however be adversely affected in terms of herbal medicine; there may be complex phytochemical changes that impinge on their traditional health systems and the availability of particular plant species with climate change. – There is also the issue of indigenous peoples' knowledge not being taken seriously; humanity as a whole all risk missing out on indigenous peoples' insights of the effects of climate change and potential solutions.

Infographic 1

Results & Analysis - Elevated atmospheric carbon-based gas levels and their effect on indigenous community health responses

Only a relatively small proportion of the papers in this study were deemed as highly relevant in the criteria, 22 papers out of 112, indicative of the need for further research in this area. These papers can broadly be distinguished into three themes; wider impacts on ecology from changes in plant physiology due to increasing levels of atmospheric carbon gases, the effects of this on human health generally and on indigenous peoples specifically.

For instance, (Williams 2010) describes that plants generally have lower protein levels in higher CO_2 concentrations, this has wider ecological effects on ecosystems but means humans have to eat more to obtain the same amount of protein from plants and for the majority of the world population eating a primarily plant-based diet this will present issues. In terms of ecosystems, lower protein nutritional quality of leaves may mean forest ecosystems can no longer support animals such as koala, possums and sugar gliders. Lower nutritional content of plants more broadly with higher plant toxicity loads also present issues for animals such as insects and affect general ecosystem health. This paper discussed issues presented by this phenomenon in the wider context of increasing food output globally whilst reducing inputs in the context of ecosystem degradation. Specific mention was also made of increased cyanide toxicity in plants such as cassava, which whilst concentrated in the peel of this plant still reduces its nutritive benefits. Findings corroborated by (Gleadow, et al. 2009).

Plants may gain some benefits from increasing CO_2 levels with plants having enhanced carbon uptake, general reduced water use, increased photosynthetic nitrogen use efficiency in C_3 plants, with legumes having the potential to respond maximally, and can also benefit non-legumes growing alongside them (Andres, et al. 2009). "C_4 photosynthesis is not directly stimulated by elevated [CO_2]. Nevertheless, there is significant potential for increased growth of C_4 plants at elevated [CO_2] to decrease water use and reduce drought stress, leading via this indirect mechanism to greater photosynthesis and yield" (Andres, et al. 2009, 2869). Such findings are also corroborated in (Conroy, Influence of Elevated Atmospheric CO_2 Concentrations on Plant Nutrition 1992).

There are also crop specific effects with regards to protein level changes grown at elevated [540–958 ppm] compared with ambient [315–400 ppm] CO_2, as described in (Taub, Miller and Allen 2007) for "wheat, barley and rice, the reduction in grain protein concentration was-10–15% of the value at ambient CO_2. For potato, the reduction in tuber protein concentration was 14%. For soybean, there was a much smaller, although statistically significant reduction of protein concentration of 1.4%" (Taub, Miller and Allen 2007, 565).

Changes in plant nutrition was not purely restricted to human food crops, perennial ryegrass and white clover showed rising atmospheric CO_2 levels from 380-670ppm increased the dry-matter yield of white clover/ryegrass also likely impacting upon its nutritive value which may have implications for grassland management (Schenk, Jäger and Weigel 1997).

Wider points were noted with regards to the effects of CO_2 on plant health, including potentially unforeseen effects on insects (Barbehenn, Karowe and Chen 2004) and important observations such as though the nutritional quality of C_3 plants will decline more under elevated atmospheric CO_2 than will the nutritional quality of C_4 plants, herbivorous insects did not increase their feeding rate on C_3 plants or increase their predation levels on currently less favoured C_4 plants due to their "lower nutrient levels, higher fiber levels, and greater toughness" (Barbehenn, Karowe and Spickard 2004, 86).

'Elevated CO_2 *effects on plant carbon, nitrogen and water relations: six important lessons from FACE'* also notes the limitations of such experiments; the [CO_2] 'fertilization' effect in FACE studies on crop plants is less than expected, "data from laboratory and chamber experiments systematically overestimate the yields of the major food crops, yet may underestimate the biomass production of trees" (Andres, et al. 2009, 2870). The potential limitations of lab-based field studies, complexity of interactions between different ecosystem components and the variation of effects on individual crop species as outlined above illustrates the need for further research.

The changes in plant's growth and composition due to elevated atmospheric CO_2 levels will likely have a range of effects on human nutrition beyond the lower protein levels detailed above as well as wider ecological effects. Staple crops that provide dietary iron and zinc for a large proportion of the global population are likely to have significantly reduced levels of these elements by mid 21st century anticipated atmospheric CO_2 levels, as detailed in (Dietterich, et al. 2015). This finding is corroborated in (Loladze 2014) and *'Food Safety, Nutrition and Distribution'* which notes that "rising CO_2 levels are very likely to lower the concentrations of essential micro and microelements such as iron, zinc, calcium, magnesium, copper, sulphur, phosphorus, and nitrogen in most plants (including major cereals and staple crops" (Ziska, Crimmins, et al. 2016, 197). In addition to such changes it notes increasing carbohydrate and decreasing proportional protein content are expected in many crops and that "an increase in dietary carbohydrates-to-protein ratio can have unhealthy effects on human metabolism and body mass" (Ziska, Crimmins, et al. 2016, 197).

The potential knock on effects of this are set out in *'Canaries in the coal mine: a cross-species analysis of the plurality of obesity epidemics'* which states that alongside the observed increase in obesity in humans, analogous increases in average mid-life body weights have been observed among primates and rodents living in research colonies as well as among feral rodents and domestic cats and dogs (Klimentidis, et al. 2010, 1626). This is evidenced by multigenerational assessments of animals with data from the 1970s & 80s to the present, during which time atmospheric CO_2 levels have increased from e.g. circa 340ppm in 1980 and <400ppm today. Findings also corroborated in (Hersoug, Sjödin and Astrup 2012).

Insights from research such as the above noting the effects on human health of changes to plant physiology due to increasing levels of atmospheric CO_2 also offer potential insights for methods of adaptation, maize for example may be able to maintain growth under higher CO_2 and mild drought (Yu-zheng and Zhou-ping 2016, 2775) making it a crop that may have better resilience growing in the face of climate change. Some crops also appear to maintain current mineral concentrations in elevated CO_2 concentrations, notably sorghum and potatoes showing no significant change in iron content (Smith, Golden and Myers 2017, 250). Such knowledge can inform selection of crops to grow for maximal nutrition in addition to growth resilience to changed conditions.

With regards to health effects on indigenous people specifically some papers noted general trends with regards to the effects on indigenous peoples, *'Northwest African and Middle Eastern food and dietary change of indigenous peoples'* noting there was good data on a regional level to demonstrate changing food patterns but less evidence regarding different peoples in the region and indigenous peoples' dietary changes (Kuhnlein and Johns 2003, 348-349). Likewise, *Indigenous Foods and Nutrition Security in India: A Case Study* regarding the Bhil people of India only discusses nutritional composition of plants with current CO_2 levels given rather than a future elevated scenario (Bhattacharjee, et al. 2009). Though it does provide recommendations for strengthening and promoted integrated home gardening through increased production and consumption of nutritious foods (indigenous leafy vegetables, fruits, herbs spices and other foods) with an emphasis on foods rich in micronutrients (Bhattacharjee, et al. 2009, 228).

Other papers have described wider ecological impacts of climate change and their effects in indigenous peoples' lifeways and food security. For example, *'The Impacts of climate change on tribal traditional foods'* notes that tribal harvesters for example, have noticed shifts in the harvesting times of traditional foods, climate change impacting on ecosystems and lifecycle processes in complex ways and that "if the timing of flowering plants and the presence of pollinators, such as birds and insects, become less synchronized, impacts can ripple throughout the food webs" (Lynn, et al. 2013, 546). Impacts on marine ecosystems and changes in the fruiting of berry plants as having substantial effects on traditional health practices were also observed (Lynn, et al. 2013, 548) . It also notes that "Tribes are experiencing declines in health that accompany traditional food use declines. Obesity, diabetes and cancer, rare in communities living on a traditional diet, are now increasing health problems in tribes across the U.S." (Lynn, et al. 2013, 547). Changes in local traditional food harvests were also observed in (Guyot, et al. 2006).

'Populations of concern' provides a detailed overview of the factors affecting demographic groups in the United States who will be negatively impacted by Climate Change (Gamble, et al. 2016). The various indigenous peoples of the country are mentioned as part of this, with specific case study examples provided for

particular groups. With regards to food security it notes climate change is projected to reduce the nutrient and protein content of some crops, like wheat and rice which will disproportionately affect marginalised groups;

"Examples of how climate changes can affect the health of Indigenous peoples include changes in the abundance and nutrient content of certain foodstuffs, such as berries for Alaska Native communities; declining moose populations in Minnesota, which are significant to many Ojibwe peoples and an important source of dietary protein;, rising temperatures and lack of available water for farming among Navajo people; and declines in traditional rice harvests among the Ojibwe in the Upper Great Lakes region. Traditional foods and livelihoods are embedded in Indigenous cultural beliefs and subsistence practices", "Climate impacts on traditional foods may result in poor nutrition and increased obesity and diabetes." (Gamble, et al. 2016, 253-254)

"In addition, oceans are becoming more acidic as they absorb some of the carbon dioxide (CO_2) added to the atmosphere by fossil fuel burning and other sources, and this change in acidity can lower shellfish survival. This affects Indigenous peoples on the West and Gulf Coasts and Alaska Natives whose livelihoods depend on shellfish harvests. Rising sea levels will also destroy fresh and saltwater habitats that some Indigenous peoples located along the Gulf Coast rely upon for subsistence food." (Gamble, et al. 2016, 254).

Changes in indigenous peoples' diet and the health effects were detailed, without specific allusions to elevated atmospheric carbon levels metabolic effects, in *'Arctic Indigenous Peoples Experience the Nutrition Transition with changing Dietary Patterns and Obesity'* (Kuhnlein, et al. 2004). Similar conclusions are drawn in *'Climate Change and health in Nunavik and Labrador: Lessons from Inuit knowledge'* (Furgal, Martin and Gosselin 2002).

In addition to these points, it can also be noted that there is a likely relationship between increased levels of chronic disease and reliance on commercially produced foods and lower levels of nutritive value in wild plant foods. As highlighted in Infographic 1, majority world urban poor populations have had notable dietary changes with increasing reliance on commercially produced foods contributing to rising obesity levels in the context of a rapid shift from a subsistence to an industrialised economy (Popkin 2004, 141-142). Changes in diet away from traditional sources are also causing health problems for many groups of indigenous people (Gordon and Oddo 2012, 9). This is in addition to elevated CO_2 potentially causing complex phytochemical changes in wild plant foods which may negatively affect their nutritive value (Wand, et al. 1999) and effectiveness when used in a medicinal context (Ziska, Emche, et al. 2005). In conjunction with this, wider effects of climate change have been noted to have effects on medicinal plant composition (Gairola , et al. 2010, 1826).

Conclusions and recommendations for further research

An overall picture of the ecological effects of rising atmospheric CO_2 levels can be drawn from current literature with regards to wider ecological effects, general effects on crops and humanity globally, with impacts on major demographic groups drawn out. Though limitations were noted such as those of lab-based field studies overlooking the complexity of interactions between different ecosystem components and the variation of effects on individual crop species which limits what can be concluded from such research methods.

Up to 80% of the world's 1.9 billion indigenous people either wholly or mainly depend on naturally produced foods and medicines or foods produced through kálhacultural practices. Traditional foods and medicines are essential to the diets of these many different peoples, yet evidence is building to indicate that as a result of unrestricted development pressures, elevate CO_2 in the atmosphere and forced removals of peoples from their territories indigenous peoples have become more reliant on commercially produced and distributed foods and medicines. And through studies conducted by the Center for World Indigenous Studies, Centre for Indigenous Peoples' Nutrition and Environment, Center for Traditional Medicine, the International Development Research Centre and the United Nations Food and Agriculture Organization evidence is growing to indicate that indigenous peoples in North America, parts of South America and Central Africa as well as Europe show dramatic trends toward higher levels of chronic disease—particularly diabetes, heart disease, kidney disease and cancers. Elevated levels of CO_2 and the consequent changes in nutritional content in plants may contribute significantly to these health changes combined with the increased dependence of indigenous peoples on commercially produced foods that contain higher levels of sugars and processed ingredients.

Only a relatively small proportion of the selected papers reviewed were deemed as having noteworthy relevance to the specific effects of elevated atmospheric carbon-based gas levels on indigenous community health responses. Whilst the effect of rising atmospheric CO_2 was mentioned in terms of its effect on ecosystems and indigenous people's wellbeing, relatively little mention was made of the specific impacts of its effect on reducing nutrition from plants and the implications for indigenous peoples' health in most selected papers. While the selected studies considered in this analysis did not directly focus on food and medicine by indigenous peoples' consumption other notable studies concerned with indigenous peoples' nutrition and health strongly suggest a connection between changes in atmospheric carbon gases and changes in plant nutritional value. As noted above researchers associate elevated CO_2 and other greenhouse gases in the atmosphere with adversely affecting cultivars of various commercial crop species resulting in increased incidents of chronic disease (Dietterich et al., 2015a; Loladze, 2014; Thompson & Cohen, 2012). Hence, indigenous peoples dependent on agriculture and shifting away from kálhaculture are particularly

vulnerable to the effects of elevated carbon gases in the atmosphere adversely affecting the nutritional values on plant-based and animal-based foods.

Interdisciplinary research addressing these factors will provide more comprehensive insights into and potential solutions for the issue and address the gaps in current research literature. Such new research may focus specifically on any changes in nutritional content in foods obtained through kálhaculture and health changes in subject populations.

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