Food Inequality, Injustice, and Rights

PAOLO D'ODORICO, JOEL A. CARR, KYLE F. DAVIS, JAMPEL DELL'ANGELO, AND DAVID A. SEEKELL

As humanity continues to grow in size, questions related to human rights and the existing unequal distribution of food resources have taken on greater urgency. Is inequality in food access unjust or a regrettable consequence of the geographic distribution of biophysical resources? To what extent are there obligations to redress inequalities in access to food? We draw from a human rights perspective to identify obligations associated with access to food and develop a quantitative framework to evaluate the fulfillment of the human right to food. We discuss the capacity of socioeconomic development to reduce inequalities in per capita food availability with respect to the distribution of biophysical resources among countries. Although, at the country level, international trade shows the capacity to reduce human rights deficits by increasing food availability in countries with limited food production, whether it actually improves the fulfillment of the right to food will depend on within-country inequality.

Keywords: food security, human rights, international trade, inequality, agriculture

Equality and inequality are fundamental ethical, moral, philosophical, and political concepts that have been largely discussed in history, shaping the understanding of what human beings ontologically are and how they relate to each other. The concept of equality is determined by the multiple manifestations of human diversity, and it is one of the central principles in the debate on the different visions of social organization (Sen 1992). Starting from the universally recognized value that all "humans are born equal," a variety of economic and political considerations diverge in theorizing the role and importance of equality and, conversely, of inequality. Sen (1992), in order to discuss inequality's ethical and societal tenets, began from two interdependent questions: "why equality?" and "equality of what?" Equality, Sen (1992) argued, is often discussed in terms of incomes, opportunities, wealth, achievements, rights, or other factors. These are some of the several dimensions that influence the variety of normative theories of social arrangements (Sen 1999). The multidimensional nature, and the complexity of defining and measuring inequalities, is also stressed by Atkinson (2015) who, in line with Sen (1992), details how inequality can be measured on multiple scales of analysis, depending on the space in which different individuals, households or countries, are to be compared.

In the present article, we specifically focus on food inequality. The relationship between inequality and food, is, we believe, a fundamental one, which has a strong moral and societal value. Our analysis is based on a precise universal ethical foundation: The human right to food. In fact, this right is considered as a universal value and accepted as an international ethical standard (Sen 2004).

Under article 11 of the International Covenant on Economic, Social, and Cultural Rights (UN 1966), every state has the obligation to ensure that all its people have access to a minimum amount of nutritionally adequate and safe food to be free from hunger (De Schutter 2009). Article 25 of the Universal Declaration of Human Rights (UN 1948) specifies that "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing, and medical care and necessary social services." Nevertheless, we live in a world with worrying levels of malnourishment, in which food is unevenly distributed and food security is affected by patterns of socioeconomic development, international trade, and the availability and appropriation of natural resources (e.g., D'Odorico et al. 2014, MacDonald et al. 2015, D'Odorico et al. 2018, Dell'Angelo et al. 2018a).

Inequality in the access to food is a direct result of the distribution of populations, natural resources, and the productivity of their use but can be modified by human action—for example, through patterns of agricultural development, international trade, and dietary choices (Seekell et al. 2011). Regarding the justice of unequal distributions, Rawls (1999) noted, "a natural distribution is neither just nor unjust.… These are simply natural facts. What is just and unjust is the way that institutions deal with these facts."

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We argue that questions on food distribution and the relationship between inequality and injustice should consider the causes of inequality (i.e., anthropogenic or existing in nature), whether those who are left with fewer resources have enough food to meet their vital human needs, and whether failure to meet these needs constitutes a violation of human rights that must be redressed by the international community.

In the present article, we conduct a cross-country assessment to investigate two types of inequality. First, we focus on the distribution of natural resources available for agriculture, which we define as "biophysical endowment inequality" and evaluate on the basis of the potential of each country to produce food. Second, we characterize the distribution of the actual food availability, which results from different production characteristics, economic capacities, and trade patterns and is determined by a variety of socioeconomic drivers. The corresponding inequality in actually available food, or "available food inequality," is evaluated on the basis of the geographic distribution of actual rates of food production and trade across countries.

To analyze the fulfillment of the human right to food we identify quantitative thresholds in caloric intake (Carr et al. 2015) and develop a framework based on the notions of positive and negative rights (Fried 1978) that allows us to determine which inequalities the international community is obliged to redress with directed food transfers and which inequalities the international community should monitor but is not obliged to redress.

From a theory of rights toward a quantitative analysis of food inequality and injustice

In 1948, the United Nations recognized the right to food as a human right (UN 1948). Human rights are held by all just by virtue of being human; therefore, they cannot be alienated, sold, or traded (Narula 2013), but food can be. Therefore, it is important to evaluate the implications of agricultural development and trade on the human right to food. We draw from Fried's (1978) classification of positive and negative rights, which provides a normative framework to identify whether and to what extent the recognition of the right to food as a human right implies that societies and governments are morally obliged to act.

This approach allows us to propose a framework to assess whether inequalities are unjust—and therefore need to be redressed—or simply regrettable. According to Fried (1978), a person can enjoy a negative right (e.g., civil liberties) if nobody acts against it (e.g., Dasgupta 1993, 2010). Conversely positive rights (e.g., a child's right to education, shelter, or health care) require action; someone (e.g., in this case, either the parents or an organization of the state) is responsible to ensure that adequate conditions are in place for the enjoyment of this positive right. Most civil and political rights are negative because they do not oblige action (indeed, they oblige inaction), whereas positive rights typically involve the allocation of a share of resources that are available in a finite amount (Dasgupta 1993).

Although it is always feasible to recognize and honor negative rights, there might be economic and natural constraints on the ability of a society to honor positive rights (Dasgupta 2010). Such constraints are posed both by the availability of specific material goods and economic resources and the willingness to share them by modifying their current distribution (Dasgupta 1993). It is on this point that the discussion on the right to food intersects with the discourse on inequality. Therefore, the analysis of inequality is relevant to the study of human rights, including the right to food, which is acknowledged by the international community (UN 1948, 1966). As the associated (positive) obligations have been recognized (Ziegler et al. 2011), the right to a minimum necessary amount of food is a positive right. Its fulfillment should be evaluated by ensuring that everyone in the society has reliable access to adequate and nutritious food. In this regard, the United Nations have also clarified that the right to food is not exactly a right to be fed but a requirement for governments to create favorable conditions for people to be able to provide food for themselves (UN fact Sheet No. 34). Indeed, violations of human rights are often used as criteria to recognize failing governments (e.g., Golay and Biglino 2013).

To link ethical theory to quantitative analysis and data, we first need to define and identify situations in which the (positive) right to food is violated, and then we need to evaluate whether enough resources would exist to honor this right worldwide or not. In addition, we can consider the possible extension of the right to food beyond the notion of a positive right to be free from hunger (UN 1966) and define also a negative right to well-being, corresponding to levels of nourishment above those defining freedom from hunger. In this regard, we have identified two reference levels of food access, F_{fh}, and F_{wb}, expressed on a food calories per capita basis. These thresholds demarcate a spectrum of food access (figure 1). The lower threshold, F_{fh}, corresponds to the minimum food access per capita required to meet vital human nutritional needs (i.e., being free from hunger; UN 1966). We recognize, however, that, when higher levels of food supply are accessible, individuals and entire societies might have the right to enjoy better diets than the minimum requirements to be free from hunger. Levels of food supply above the undernourishment threshold (but without the "excess" of overnourishment) may permit a more balanced diet, thereby improving health and well-being with respect to survival levels. Therefore, we suggest that being able to maintain higher levels of nutrition within the well-being domain (figure 1) should also constitute a human right, which is presently not explicitly recognized by the United Nations. We also argue that the ability to enjoy well-being conditions would be a negative right, with no obligations on institutional organizations or more affluent societies. Moreover, the enjoyment of this negative right to food could be subordinated to the need to meet the positive food rights of societies that are not free from hunger. The upper level,

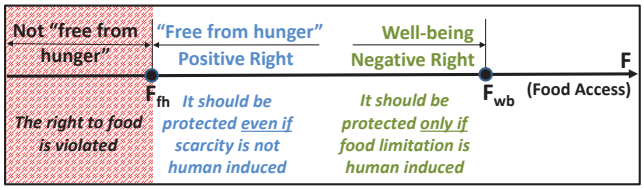

Figure 1. Positive and negative right to food. Below a minimal level of food availability (F_{fh}) people are not free from hunger and positive rights to food are violated. A positive obligation exists regardless of whether food insufficiency is due to natural or man induced factors. Below the well-being level, F_{wb} (but above F_{fh}) negative food rights exist. They entail a negative obligation not to deprive people of their well-being but there is no positive obligation to provide it.

F_{wb}, here termed the *well-being threshold*, represents the level of supply above which food is either not consumed, wasted, or consumed at rates that are detrimental to human health (i.e., overnourishment; Patel 2007).

We acknowledge the complexity and multidimensionality of diets and nutritional needs and that their characterization requires a variety of metrics, but we intentionally characterize them through these two sharp thresholds for the sake of this specific assessment. Although the notion of well-being introduced above should be better explored considering a bundle of economic, cultural, nutritional, and environmental factors that control human diets and their viability, we rely on calories as the simplest metric suitable for quantitative analyses (FAO 2011, FAO et al. 2013, Schanbacher 2010). However, the framework proposed in this study can be easily reformulated using other metrics. Even though well-being likely involves a more complex "parameter space," what figure 1 highlights is that the well-being state may constitute a negative right, and therefore, it should not be taken away from anyone (as human rights should not be alienated). Following this logic, however, the state of well-being (figure 1) does not raise a moral obligation to provide additional external resources. The focus in the present article is about the importance of not violating the conditions that guarantee well-being (negative food right) in addition to the obligation of an external intervention to guarantee that the basic nutritional needs to be free from hunger are satisfied (positive food right).

Following the application of this framework, inequality in the distribution of natural resources (i.e., the *biophysical endowment inequality*, expressed in terms of maximum potential crop production) is unjust when individuals or entire groups are left in conditions of chronic hunger (i.e., positive food rights are violated). The second type of inequality, the *available food inequality* (i.e., inequality in food availability resulting from the global patterns of agricultural production and trade), instead, is not unjust but regrettable once hunger is eradicated but not everyone can access diets that guarantee well-being. In other words, whether inequality is unjust depends both on its causes and implications. Although biophysical endowment inequality is unjust only if it violates positive human rights, the second type of inequality, induced by patterns of agricultural development and trade, can be considered unjust even if it only erodes the negative rights to well-being, while respecting the positive right to be free from hunger. This well-being component of food rights is a novel aspect of the right to food that to date has remained for the most part unexplored.

Cross-country food inequality

We evaluate inequalities in biophysical endowments (i.e., in the potential to produce food) and actual food availability by looking at the distribution of agricultural resources among countries in three different scenarios: a world with no trade and with all the land suitable for agriculture cultivated for food production at its maximum potential, a world with trade and with current distribution of cultivated land, crops, and crop yields, and a world with no trade and with current distribution of cultivated land, crops, and crop yields. The first scenario allows us to evaluate inequality in the global distribution of natural resources suitable for food production (biophysical endowment inequality) and highlights the differences in natural resource endowments for agriculture relative to the population of each country, independent of the economic, political, and institutional factors that determine differences in agricultural development and trade reliance among countries. The ability of a country or region to produce food depends in general both on the biophysical endowments (i.e., agricultural land and water resources) and access to fertilizers, energy, technology and other inputs, which results from institutional and socioeconomic conditions (Motesharrei et al. 2014, 2016). In this analysis of potential productivity, we focus only on differences in the distribution of biophysical resources for agriculture and assume that the other inputs that are related to economic development and institutional capacity are not limiting crop production.

In the second scenario, instead, we evaluate inequality in the actual distribution of food (available food inequality) among countries. This is where the socioeconomic conditions play out. In this second scenario we add to the biophysical dimensions the socioeconomic one, which is represented by the global patterns of actual agricultural production and involvement in international trade.

The comparison between these two scenarios allows us to evaluate the extent to which the economic activity represented by trade and agricultural development, contributes to cross-country inequality in the distribution of food. The third scenario highlights the effect of trade alone on inequality. Using the Gini coefficient (Gini 1936) as a measure of inequality in the distribution of both biophysical endowments (i.e., food production potential) and actual availability of food crops, we find that the biophysical endowment inequality is relatively high, with Gini coefficients slowly

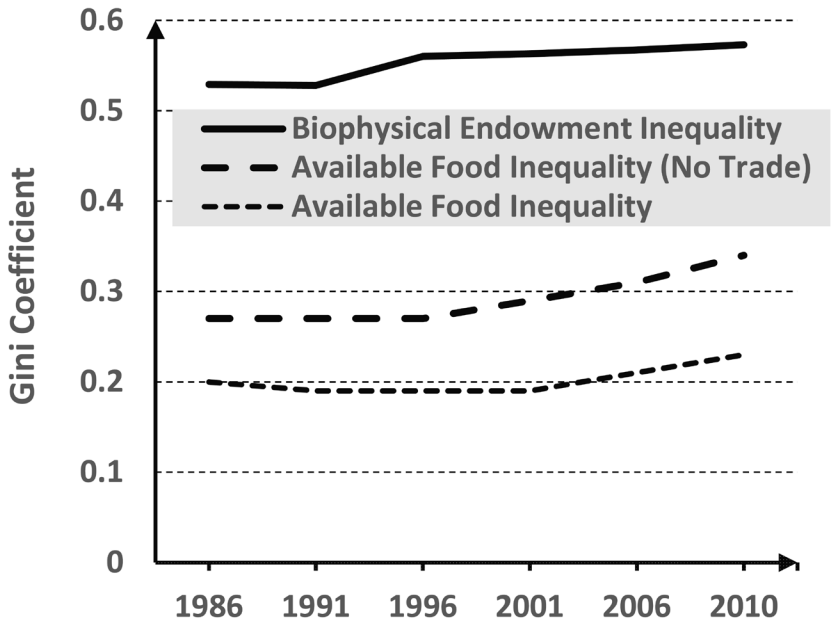

Figure 2. Inequality in the distribution of biophysical resources for agriculture and in food availability distribution modified by socioeconomic patterns of food production (with or without trade).

growing from 0.53 and 0.57 between 1986 and 2010 (where 0 represents no inequality and 1 represents complete inequality; figure 2). In this analysis the potential agricultural resources are assumed to be constant in time and do not account for land degradation. The slight increase in inequality is due to population growth occurring faster in countries that have relatively less biophysical resources useful for agriculture. The actual inequalities in available food, however, are much smaller, with Gini coefficients varying between 0.19 and 0.23. This reduction in inequality relative to the distribution of biophysical resources (e.g., land and water) is due to an uneven development of those resources that partly offsets the biophysical endowment inequality (scenario a). The lower inequality in the available food distribution is also contributed by trade dependencies. Indeed, trade reduces inequality in actual food availability among countries, from 0.27–0.34 (scenario c) to 0.19–0.23 (scenario b, with actual production and trade patterns).

Globally, these results indicate that trade has the overall effect of moving food from countries with higher per capita food availability to countries with lower per capita food availability—though there are several trade links that exhibit flows in the opposite direction and therefore increase inequality (Carr et al. 2016).

It should be stressed, however, that the effect of agricultural development and trade on the available food inequality is hard to evaluate separately because the current patterns of production are often the result of trade policies (Stevens et al. 2003). Trade affects each country's production either by pushing exporting countries to sustain higher levels of production than their domestic demand or by decreasing production in importing countries in which local farmers are outcompeted by their international counterparts. Of note is the case of developing countries and their reliance on cheaper subsidized agricultural surpluses from North America (e.g., Friedman 1993, Narula 2011). Therefore, it could be argued that, whereas the direct effect of trade is to reduce country-level inequality, it might have indirectly contributed to the emergence of those inequalities in food availability in the first place. It is clear from our results, however, that strong inequalities exist in the distribution of biophysical natural resources necessary for agriculture, independently of trade and other socioeconomic factors. The finding, that trade and socioeconomic drivers of agricultural development are associated with reduced inequalities in food availability among countries with respect to the baseline of biophysical endowment inequality (i.e., inequality in the potential to produce food), is an interesting one. This result should be considered in the light of the complex relationship between globalization, economic growth, technological change, and income inequality within and across countries, which is at the center of heated scientific and political debates (e.g., Polanyi 1944, Rawls et al. 1987, Gallino 2000, Sen 1999, Vercelli and Borghesi 2005, Sachs 2015, Weber 2015, Kohler et al. 2017). Moreover, this result is consistent with the income global inequality trend described by Atkinson (2015), that illustrates how in the recent history there has been a transition from a moment in which inequality within rich countries was declining while inequality between countries was rising to the current pattern in which inequality between countries is narrowing, but inequality within is on the raise.

What is particularly problematic and raises critical reflections, is that despite the potentially positive effects of international trade in food availability distribution among countries, when we zoom in at the within-country level of analysis, there are several dynamics associated with globalization that threaten the livelihoods and food security of poor and more vulnerable population groups. For example, the case of land and water grabbing associated with transnational large-scale land investments represents a fundamental threat to the sustainability and food security of smallholders, traditional users of natural resources, and indigenous people (De Schutter 2011, Rulli et al. 2013, Rulli and D'Odorico 2014, Dell'Angelo et al. 2017a, 2017b, D'Odorico et al. 2017). In that case, it is clear how agricultural financial investments implemented for trade and international export in regions of the world with high levels

of water scarcity and malnourishment, raise strong ethical questions on the global economic patterns associated with the trends of neoliberal globalization, which are often related to dynamics of ecological unequal exchange and socioenvironmental cost shifting (Dell'Angelo et al. 2018a, 2018b).

Trade, food availability, and the right to food

This study takes a first step toward evaluating the direct effect of trade on country-scale food availability (table 1), which is a prerequisite for adequate food access and well-being. We then look at within-country access to food through an analysis of the ability of the least affluent people to afford sufficient and adequate food. Indirect effects associated with the impact of trade policies on patterns of agricultural development, crop production, and yields are not investigated in this study.

Using country averages to investigate recent trends in food availability, we find that, as global population has increased, so too has the number of countries that are on average below the malnourishment threshold (i.e., not free from hunger); however, their fraction of the global population has remained roughly constant (table 1). We reconstructed the global network of food trade and analyzed crop production and trade data for 1986–2010 (D'Odorico et al. 2014). Interestingly, by redistributing food crops, trade significantly reduces the number of countries in which the average per capita food availability is below malnourishment levels (figure 3). Throughout the study period, large parts of Africa, the Middle East, and Japan underproduced food calories for their population. Therefore, with the observed levels of production in these regions it would not be possible to meet the positive right to food in the absence of trade (figure 3).

Moreover, during this 25-year study period, trade rarely reduced the average food availability below malnourishment levels. The two exceptions to this trend are Swaziland from 1997–2006 and Zambia from 2007–2009, both of which were net exporters of calories despite their populace being on average below undernourishment thresholds. These countries are the exception. Between 1986 and 2010, food availability was, on average, improved by trade for approximately 75% countries, collectively accounting for a population of 3.9–5.4 billion people, whereas trade reduced food availability for approximately 25% of the countries. The majority of these countries with trade-reduced food availability remained above well-being thresholds (table 1). These results depend on the food waste fraction, which is, in the present article, assumed to be 24% (Kummu et al. 2012). A sensitivity analysis with respect to this parameter (supplemental figure S1) shows a near-linear relationship whereby the fraction of countries in conditions of hunger increases in proportion to the food waste fraction. All of the other results (i.e., the 1986–2010 increase in the number of countries in a well-being state, and the effect of trade) are independent of the waste fraction.

In countries in which average levels of food availability are below the malnourishment threshold, a large fraction of the population is without a doubt affected by hunger. In these cases, additional analyses are not needed to document the existence of malnourishment but to evaluate how widespread it is. Conversely, for countries that were able to maintain relatively high levels of per capita food availability, doing so does not guarantee that portions of their populations experience limitations to their food availability and access. We found that between 1986 and 2010 about 53 to 67 countries—accounting for approximately 16% of the global population—would have been on average below the malnourishment threshold in the absence of trade (i.e., with less than 2407 kilocalories (kcal) per capita per day; see the "Data and methods" section). Trade redistributes food calories with the potential to decrease inequality (figure 2), at the cost of increasing the dependence of resource-limited nations (Porkka et al. 2013, D'Odorico et al. 2014, MacDonald et al. 2015). Overall, despite the increasing reliance on trade, (actual) food inequality among countries has remained almost constant over time (figure 2).

If we do not account for trade (i.e., considering domestic production only), we find that the disparities between calorie-rich and calorie-poor nations become enhanced, as is evidenced by elevated global inequality in country-average food availability (figure 2). Trade plays an important role in rectifying these inequalities in food availability (figure 2), although such patterns of per capita food production can also be partly the result of trade policies (i.e., the indirect effect of trade mentioned earlier).

The results presented so far refer to food availability at a country level. In any given country, droughts, floods, and other extreme events may have substantial impacts on crop production and food supply. However, famines and starvation are typically not a problem of supply or physical availability but, rather, of economic access (e.g., in periods of escalating food prices) and institutional failures (Sen 1981, Devereux 2001). Therefore, simply checking the average levels of food availability at the national level is not sufficient to fully assess the equitable distribution of food, and it is vital to ascertain whether the most vulnerable people within a society (typically the poor, especially in periods of escalating food prices) have access to adequate and safe food (FAO 2002). In fact, the analysis presented in figure 2 deals with food inequalities among countries but not within them. Therefore, this analysis does not allow us to conclusively assess the impact of human action on the fulfillment of the right to food because it uses country-level data, whereas human rights are ultimately defined at the scale of single individuals (i.e., rights that every individual has by the fact of being human). The fact that in one country there is on average enough food to feed everyone does not necessarily mean that every person in that country will have physical and economic access to that food. In fact, great inequalities exist within each country, and we were unable to evaluate how within-country inequalities translate into levels of malnourishment and human right deficits with respect to the right to food. Although the existence of country-average

Table 1. Effects of trade on the number of countries and the percentage of the global population not free from hunger ($F<F_{fh}$), free from hunger but with no well-being ($F_{fh} < F < F_{wb}$), and in a well-being state ($F > F_{wb}$), for select years in the study period.

	Access to food	1986		1991		1996		2001		2006		2010	
State after trade	**Reduced by trade percentage)**	**Number of countries**	**Percentage of global population**	**Number**	**Percentage**	**Number**	**Percentage**	**Number**	**Percentage**	**Number**	**Percentage**	**Number**	**Percentage**
Countries not free from hunger $F < F_{fh}$	from not free from hunger ($F<F_{fh}$)	0	0.00	1	0.08	2	0.29	1	0.20	2	1.34	3	0.25
	from free from hunger ($F_{fh}<F<F_{wb}$)	0	0.00	1	0.20	0	0.00	1	0.14	0	0.00	0	0.00
	from well-being (i.e., $F>F_{wb}$)	0	0.00	2	0.10	1	0.02	2	0.04	2	0.04	1	0.59
	Improved by trade	21	3.65	26	4.66	34	8.12	26	5.48	18	3.35	24	5.95
	Total	21	3.65	30	5.04	37	8.42	30	5.86	22	4.72	28	6.79
Countries free from hunger but with no well-being $F_{fh}<F<F_{wb}$	Reduced by trade												
	from free from hunger ($F_{fh}<F<F_{wb}$)	3	0.42	3	17.03	5	17.92	1	0.19	1	0.20	2	0.71
	from well-being (i.e., $F>F_{wb}$)	2	0.27	0	0.00	1	0.13	2	1.01	2	0.42	4	0.60
	Improved by trade												
	from free from hunger ($F>F_{fh}$)	15	7.41	13	5.15	10	3.55	15	4.93	12	4.55	10	4.26
	from not free from hunger ($F<F_{fh}$)	13	20.78	13	4.65	14	2.87	13	21.58	8	19.90	7	19.89
	Total	33	28.88	29	26.82	30	24.47	31	27.71	23	25.07	23	25.46
Countries in well-being state $F>F_{wb}$	Reduced by trade	23	18.64	22	19.90	21	14.46	25	17.98	26	17.32	24	18.84
	Improved by trade												
	from well-being (i.e., $F>F_{wb}$)	26	39.31	24	36.77	38	41.33	39	39.03	40	40.57	44	37.27
	from not free from hunger ($F<F_{fh}$)	16	4.32	13	5.46	11	6.42	8	3.48	19	6.50	11	6.08
	from free from hunger ($F_{fh}<F<F_{wb}$)	14	5.20	16	6.01	18	4.91	22	5.95	24	5.82	24	5.56
	Total	79	67.47	75	68.14	88	67.10	94	66.44	109	70.21	103	67.75
Global	Population billions	4.84		5.36		5.77		6.16		6.54		6.85	
	Reduced by trade	28	19.33	29	37.31	30	32.81	32	19.56	33	19.32	34	20.98
	Improved by trade	105	80.67	105	62.69	125	67.19	123	80.44	121	80.68	120	79.02

Note: Within each of these categories we show the number of countries and the percentage of the global population whose situation is improved by trade, eroded by trade, and shifted from a different category. Globally, trade is improving the per capita calories available, but inequality is not decreasing (see figure 2). The majority of countries—and their associated populations—"adversely" affected by trade remain above the well-being threshold.

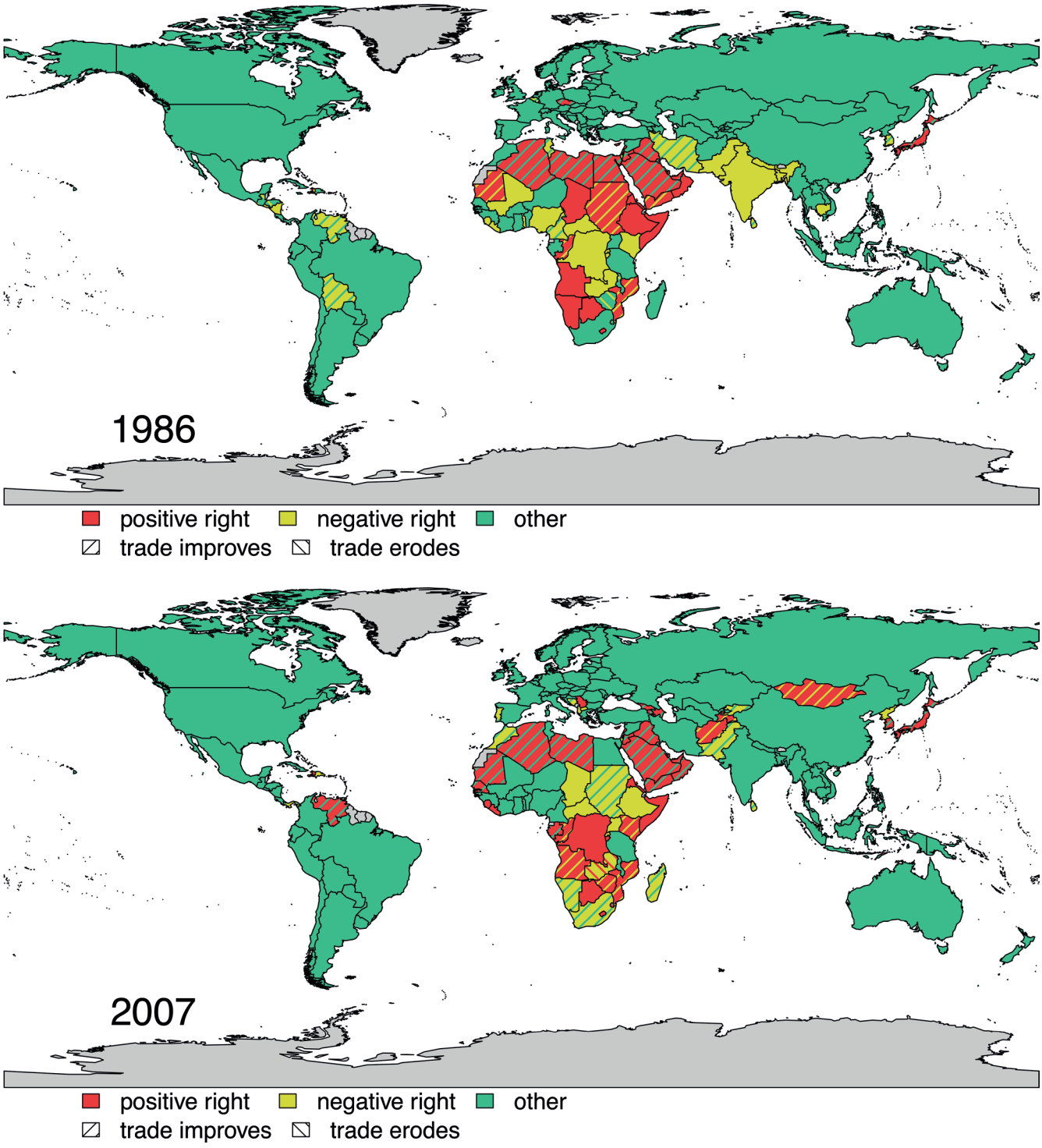

Figure 3. Positive and negative rights (based on country averages) as affected by trade. Note that most countries improve with trade, and only in few cases trade erodes positive or negative food rights (e.g., in Zimbabwe in 1986).

food availability above the malnourishment level is an important prerequisite for food security, within-country inequalities may still prevent part of the populace from having adequate access to food.

To address the issue of within-country access we verify to what extent the per capita income of the poor is sufficient to afford to buy adequate food. To that end, we look at the income of the lowest quintile of the population of each country and compare it to the average cost of food through an index, SE, defined (Seekell et al. 2017) as the ratio between these two variables (SE is the income of the lowest quintile; the second variable is the average cost of food per capita,

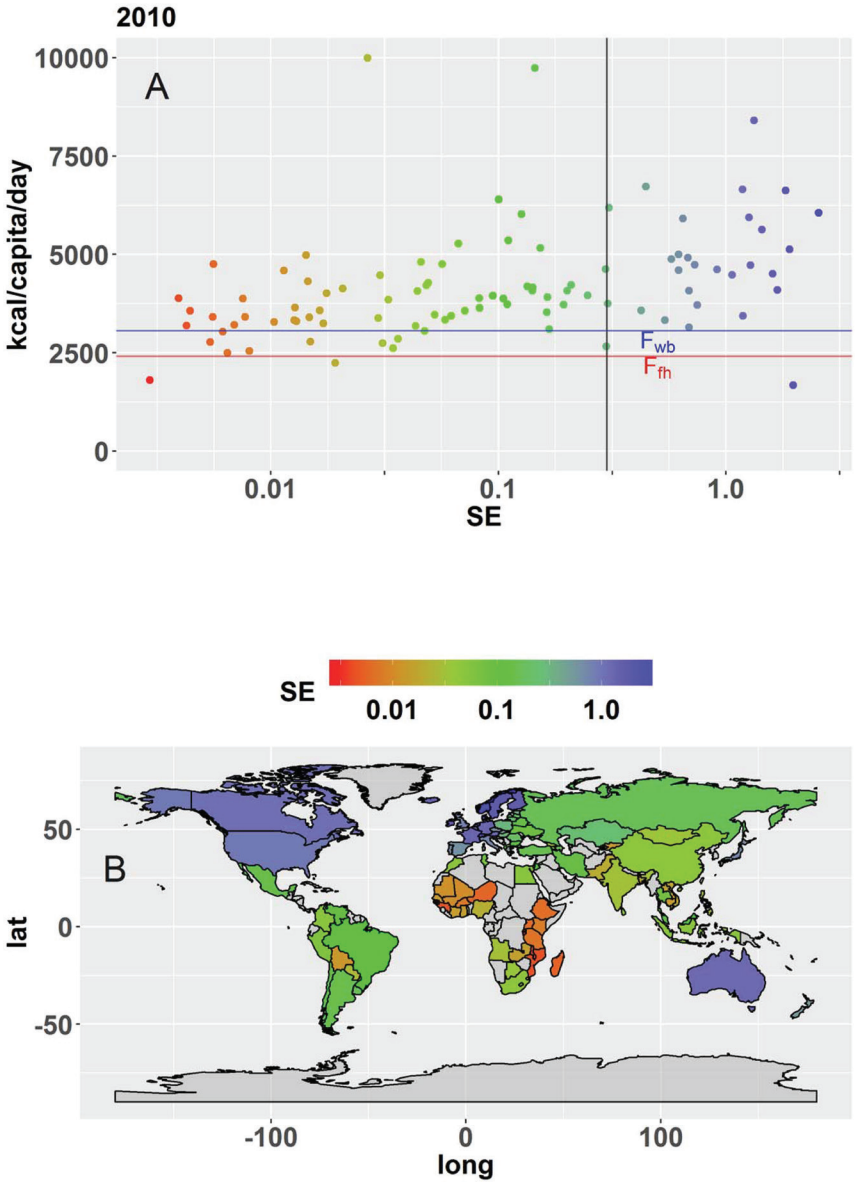

Figure 4. Access to food based on the SE index defined as the ratio between the income of the lowest quintile of the population of each country and country-specific average food cost in 2010 (see Seekell et al. 2017). For panel (a), each of the 104 countries for which the SE index is available is represented by different dot in a plot showing country-average food availability (vertical axis) and food access by the "poor" (expressed by the SE index on the horizontal axis). The two horizontal lines represent two threshold values of food availability corresponding to "free from hunger value" (F_{fh}), calculated as the minimum daily energy requirement (F_{fh} = 2407 kcal per capita per day) and the "well-being value" (F_{wb}), calculated as the average daily energy requirement (F_{wb} = 3062 kcal per capita per day). Dots in the top right quadrat of this plot correspond to countries with no malnourishment because in these countries there is both adequate availability and (on the vertical axis) and economic access. Dots in all the other quadrats correspond to countries with either no sufficient availability of or not sufficient economic access to food, or both.

and both variables are country-specific and expressed in the same units). More details on this index and how it has been calculated can be found in Seekell and colleagues (2017). In theory, values of SE smaller than 1 would indicate the existence of malnourishment due to lack of economic access to food. Because the food cost used in this analysis is a country-specific average, we expect that our estimates of SE are conservative and that people with lower incomes and close to undernourishment levels will consume a diet made of cheaper (albeit possibly less nutritious) food products. Indeed, big differences exist in the cost of food within each country (e.g., between urban and rural areas) and therefore the average food cost is likely much higher than the average food cost paid by the poor. As a result, lack of economic access to food likely corresponds to values of SE that are smaller than 1. In the present article, we follow Seekell and colleagues (2017) and choose a threshold value of 0.3. Using this SE metric therefore allows us to develop a more complete country-specific analysis of the fulfillment of the right to food (figure 4a). Interestingly, although in most cases trade may ensure the attainment of adequate availability at the national level, lower socioeconomic groups appear to be denied food access in a large number of countries around the world (figure 4).

Conclusions

This calorie-based analysis offers only a limited perspective on well-being and nourishment because access to calories alone does not fully characterize the nutritional status of an individual (FAO 2011, FAO et al. 2013). Regardless, this analysis provides a framework that connects ethical questions centered on human rights to a quantitative assessment of inequality in food availability and agricultural production. This quantitative approach is explicitly based on the normative premises that there are both positive and negative rights to food. This rights-based interpretation is built on the recognition of two tiers of

food-related needs: those that make life possible by allowing human beings to be free from hunger and those that make life enjoyable (Dasgupta 1993). Only the former needs, however, constitute a positive right in that they require a redistribution of resources. Obligations arise when a positive right to be free from hunger is violated. In principle, there might not be enough resources to fulfill these positive rights; in that case, an absolute right to a "fair share" of the existing resources should still be recognized (Dasgupta 1993). However, our results, as well as those of other studies (e.g., Cassidy et al. 2013, Davis et al. 2014, Carr et al. 2015), have shown that the planet currently produces enough food to fulfill everyone's positive food rights.

Obligations also emerge from negative rights in the event they are violated. Even though individuals in a society might not be willing to deprive others of their right to food, they can indirectly contribute to human rights deficits through their participation in a global system that allows for those rights to remain unfulfilled in some countries or shares of the society. Therefore, because we contribute to (and often benefit from) such a global process, some compensatory obligations could be considered with respect to both positive and negative rights to food (Pogge 2008). These aspects of the fulfillment of the right to food are not accounted for in the analyses presented in this study. We notice, however, that such obligations are even stronger in the case of *avoidable* human rights deficits because in those cases it would be possible to potentially devise alternative institutional arrangements capable of fulfilling everyone's rights to food (Pogge 2008). Our analysis has was shown that deficits in the right to food are avoidable and only relatively small changes in global food trade would be needed to eliminate the country-scale deficit in positive food rights existing around the world (Carr et al. 2015).

But, what is the magnitude of these deficits? It could be argued that—once trade is accounted for—country-scale food availability remains insufficient only in a handful of countries. The analysis presented in figure 3, however, is based on country-specific average rates of food supply and consumption, and it does not account for strong within-country inequalities. As such, it underestimates the number of malnourished people whose positive rights are violated, a number reported to be roughly 900 million (FAO et al. 2013). However, the analysis of food affordability in low income populations within each country (expressed through the SE indicator) shows that conditions of limited economic access are widespread across Africa, South and Southeast Asia, and Latin America (figure 4).

By better ensuring that food production reaches places of consumption, international food trade serves as an essential first step in redressing unequal food availability. This is not to say (and we do not claim) that trade necessarily arises from institutional arrangements that are just. In fact, such arrangements contribute to a complex global interdependent system that affects the distribution of populations, resources, economic development, income, and fulfillment of human rights. Even though, *on average*, more people might be able to be free from hunger because of trade, the current patterns of food globalization could hardly be considered just if they produce conditions that allow the violation of positive human rights to persist. Moreover, as was noted earlier, current production patterns are often the result of trade policies and their impact on local farming and agrobusiness (e.g., Friedmann 1993). Therefore, an interconnection exists between patterns of agricultural production and trade. It is for this reason that we provided a comparison between inequality in the distribution of biophysical resources potentially available for agriculture and the distribution of actual food availability that results from patterns of socioeconomic development and trade (figure 2). This analysis shows the potential of human action to substantially decrease both inequality and human rights deficits.

In conclusion, our study provides new criteria for studying the link between country-level inequality and human rights violations in the distributions of biophysical resources and food availability. Future work is needed in order to fully understand these dynamics and to begin developing interventions that may actively address issues of inequality in food access. For one, it will be important to incorporate a variety of socioeconomic factors that influence within-country access to food. Closer examinations of how trade policies influence patterns of agricultural development, crop production, and yields will also be essential.

Data and methods

To be free from hunger, a minimum daily energy requirement (F_{fh}) of 1829 kcal per capita per day must be met (FAO 2014). For well-being, we argue that an individual must be at or above an average daily energy requirement, F_{wb}, estimated at 2327 kcal per capita per day (FAO 2014). Assuming that about a quarter (24%) of food production is (unavoidably) lost or wasted (Kummu et al. 2012), these two threshold values were upscaled to F_{fh} = 2407 and F_{wb} = 3062 kcal per capita per day, respectively. We combined these values with annual population data (UN 2015) to calculate country-specific calorie requirements, which were then compared to country-specific levels of food calories either from internal production alone, or internal production and international trade together. We calculated country-specific food calorie supply on the basis of bulk country-specific food production data combined with food balance sheets to acquire country- and commodity-specific values of production (metric tons) for 1986 through 2010 (FAOSTAT 2017). We also used food balance sheets to acquire country-specific estimates of crops used for feed, seed and other uses, as well as stock variation. To avoid double accounting (i.e., crops not available for human consumption because of their use as animal feed or in derived commodities such as bread), the available commodity list of 266 commodities was partitioned into 145 primary goods that were used in determining production values (FAOSTAT 2017). Detailed trade of all 266 primary and secondary commodities was

obtained from FAOSTAT (2017). Both production and trade data were converted from tonnes to kilocalories following methods in (D'Odorico et al. 2014) and politically rectified following Carr and colleagues (2013) to account for the timing of country formation or dissolution. Our analysis was limited to countries with populations exceeding 1 million people throughout the 25-year period. Production for scenario (a) was estimated in two parts. First, on currently cultivated lands, maximum production was estimated using maps of high input potential production capacity (tonne per hectare) and harvested area (in hectares) for the current extent of 16 major crop groups—groundnut, maize, millets, other cereals, oil palm, pulses, rapeseed, rice, roots, sorghum, soybean, sugarbeet, sugarcane, sunflower, tubers, and wheat—from the International Institute for Applied Systems Analysis's Global Agro-Ecological Zones database (IIASA and FAO 2012). These crops account for more than three-quarters of global crop production, and their production was converted into calories using calorie conversion factors (kcal per tonne) derived from the the Food and Agriculture Organisation of the United Nations' Food Balance Sheets (FAOSTAT 2017). Second, in areas that are not currently cultivated but are suitable for agriculture, we converted maps of high input total production capacity for those same crops (IIASA and FAO 2012) into calories (kcal per hectare). For each pixel outside of current croplands, we then chose the crop with the highest caloric total production capacity value and multiplied this by the area of the pixel to calculate the total maximum calorie production of that pixel. Finally, maximum calorie production on current croplands and on lands that are not currently cultivated (but suitable for agriculture) was then summed for each country.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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Paolo D'Odorico (paolododo@berkeley.edu) and Jampel Dell'Angelo are affiliated with the Department of Environmental Science Policy and Management at the University of California, Berkeley. Joel Carr is affiliated with the Department of Environmental Sciences at the University of Virginia, Charlottesville. Kyle F. Davis is affiliated with the Earth Institute, at Columbia University, in New York, New York. Kyle F. Davis is affiliated with the Data Science Institute, at Columbia University, in New York, New York. Jampel Dell'Angelo is affiliated with the Department of Environmental Policy Analysis, Institute for Environmental Studies, at Vrije Universiteit Amsterdam, in the Netherlands. David A. Seekell is affiliated with the Department of Ecology and Environmental Science at Umeå University, in Umeå, Sweden.