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## Science meets Comics

Proceedings of the Symposium on  
Communicating and Designing the Future of Food  
in the Anthropocene

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Toni Meier

# Planetary Boundaries of Agriculture and Nutrition – an Anthropocene Approach

## Introduction

Human-induced environmental change represents one of the major challenges of current and future generations. To evaluate the anthropogenic impacts on the biosphere, the concept of Planetary Boundaries (Rockström et al. 2009, Steffen et al. 2015) was developed, indicating that in case of four out of nine environmental indicators a transgression of corresponding boundaries has already taken place: Biodiversity loss, climate change, land-system change, and biogeochemical flows (N, P). Further, paleoclimate research has shown that the earth's environment has been relatively stable for the last 12,000 years (Walker et al. 2009, IPCC 2014). Researchers assume that this, in geological terms, very short period – called Holocene – is now already again replaced by a new geological era: the Anthropocene, due to the tremendous impacts humans had on earth (Crutzen 2002, Steffen et al. 2007, Steffen et al. 2011, Zalasiewicz et al. 2011). However, different views concerning the starting point of the Anthropocene exist – ranging from 50,000-10,000 BP with the first human-induced mega-fauna extinction to 1950, when, for the first time, persistent chemicals were produced globally in large scale (Lewis/Maslin 2015). A recently published article by Waters et al. (2016) provides new insights as stratigraphically distinct sediments were identified in drilling cores, supporting the hypothesis that the Anthropocene started in the middle of the twentieth century. The stratigraphically relevant substances identified by Waters et al. (2016), are mainly persistent chemicals and radionuclides.

However, to derive sector-specific political recommendations both concepts, Planetary Boundaries and Anthropocene, are too general. Therefore, we quantified the corresponding attributable fractions of the considered indicators in Rockström et al. (2009) and Steffen et al. (2015) related to agriculture and nutrition. Moreover, as the indicator atmospheric aerosol loading has not been quantified yet, we propose here a possible representation in the concept of the Planetary Boundaries. We focus here on the agricultural and nutritional sectors, as these are held to be responsible for major relevance affecting global environment change and degradation (Herrero et al. 2015, Kahiluoto et al. 2014, Lamb et al. 2016, Rosin et al. 2012, Smith et al. 2016). On the other side, shifts in agricultural and nutritional practices play a potential role to resolve current

problems (Foley et al. 2011, Meier/Christen 2012, Meier/Christen 2013, Nemecek et al. 2016, Tilman/Clark 2014, Vermeulen et al. 2012).

## **Method and Scope**

For eight indicators covered in Rockström et al. (2009) and Steffen et al. (2015), we identified here corresponding attributable fractions related to agriculture and nutrition. Applying this sector-specific approach, we differentiate between agricultural production (agriculture), food processing and food trade (food processing/trade), and food consumption referring to household and gastronomy activities related to food preparation (food consumption).

### Climate change

To account for the Planetary Boundary (PB) of climate change related to agriculture and nutrition, we used data from Bajzelj et al. (2013) and followed the approach of Rockström et al. (2009) and Steffen et al. (2015) considering solely CO<sub>2</sub>-emissions. Emissions of CH<sub>4</sub> were omitted in this study. According to Rockström et al. (2009), emissions of N<sub>2</sub>O are accounted for in the Planetary Boundary of the N cycle.

### Biodiversity loss: Genetic diversity, extinction rate

To derive extinction rates (E/MSY) related to agriculture and nutrition, we used meta data from Hoffmann et al. (2011) indicating that 11% of all endangered species (possibly extinct) are attributed to agriculture and aquaculture, whereas 40% is attributed to hunting/trapping. Although we cannot exclude that endangered species are hunted also for nutritional purposes, the before mentioned 11% was used as a conservative proxy to derive the impact of agriculture on global species extinction. The impacts of agriculture and nutrition on Functional diversity / Biodiversity Intactness Index (BII) were omitted in this study.

### Ocean acidification

As ocean acidification is mainly caused by the entry of atmospheric CO<sub>2</sub> into the sea, we applied as a proxy the corresponding share related to agriculture and nutrition identified by Bajzelj et al. (2013) for climate change. Hereby a linear correlation was assumed.

### Biogeochemical flows (N, P)

Concerning the contribution of agricultural phosphorous use (P) to the global P cycle, we used data proposed by Steffen et al. (2015), who accounted globally for 14.2 Tg P yr<sup>-1</sup> which are applied via fertilizers to cropland – based on MacDonald et al. (2011) and Bouwman et al. (2013). The proposed regional agriculture-specific

P boundary of 6.2 Tg P yr<sup>-1</sup> was not considered in this study, as the overall impact should be analysed. Hence, the global boundary of 11 Tg P yr<sup>-1</sup> was used. P used in food processing was omitted from the study. With regards to nitrogen (N), we used the boundary proposed by De Vries et al. (2013) (62 Tg N yr<sup>-1</sup>) and data from Kahilouto et al. (2014), which accounted for an N-uptake of 139 Tg N yr<sup>-1</sup> in agrifood systems.

#### Freshwater use

Using data from FAO Aqua Stat (2016), we identified a higher total blue water withdrawal of 3,721 km<sup>3</sup> than Steffen et al. (2015) (2,600 km<sup>3</sup>) for the year 2005. Hence, assuming the same Planetary Boundary as Steffen et al. (2015) of 4,000 km<sup>3</sup>, the transgression of the boundary is far more within reach. Data from FAO Aqua Stat (2016) was also used to derive the amount of water withdrawal for agricultural and nutritional purposes (2,570 km<sup>3</sup>) related to the total water use – equaling a share of 68.9%.

#### Land-system change

Regarding the share of deforestation related to agriculture and nutrition, we used data taken from the comprehensive analysis of Hosonuma et al. (2012). They conclude that, overall, agriculture reflects 80% of deforestation worldwide.

#### Atmospheric aerosol loading

Using the global average concentration of particulate matter (PM<sub>2.5</sub> with a diameter less than 2.5, PM<sub>10</sub> less than 10 microns, respectively), according to Apte et al. (2015) and WHO (2014), as well as corresponding WHO air quality guidelines (WHO 2006) as a proxy, we substantiate here, for the first time, this planetary boundary with robust data. Whereas Apte et al. (2015) used data from Brauer et al. (2012) referring to the year 2005, WHO (2014) builds upon data of the Ambient Air Pollution Database referring to the years 2008-2012. As planetary boundary, the WHO guidelines for the atmospheric concentration of particulate matter (WHO 2006) were used with an upper limit of 10 µg m<sup>-3</sup> for PM<sub>2.5</sub> and 20 µg m<sup>-3</sup> for PM<sub>10</sub>, respectively. With regards to the attributable fraction caused by agriculture, we used data from CEIP (2016) for the EU27, as data on global level was not available. In the EU27 in the year 2013, 12.7% of all PM<sub>10</sub> emissions and 3.3% of all PM<sub>2.5</sub> emissions were due to agricultural activities.

## Results

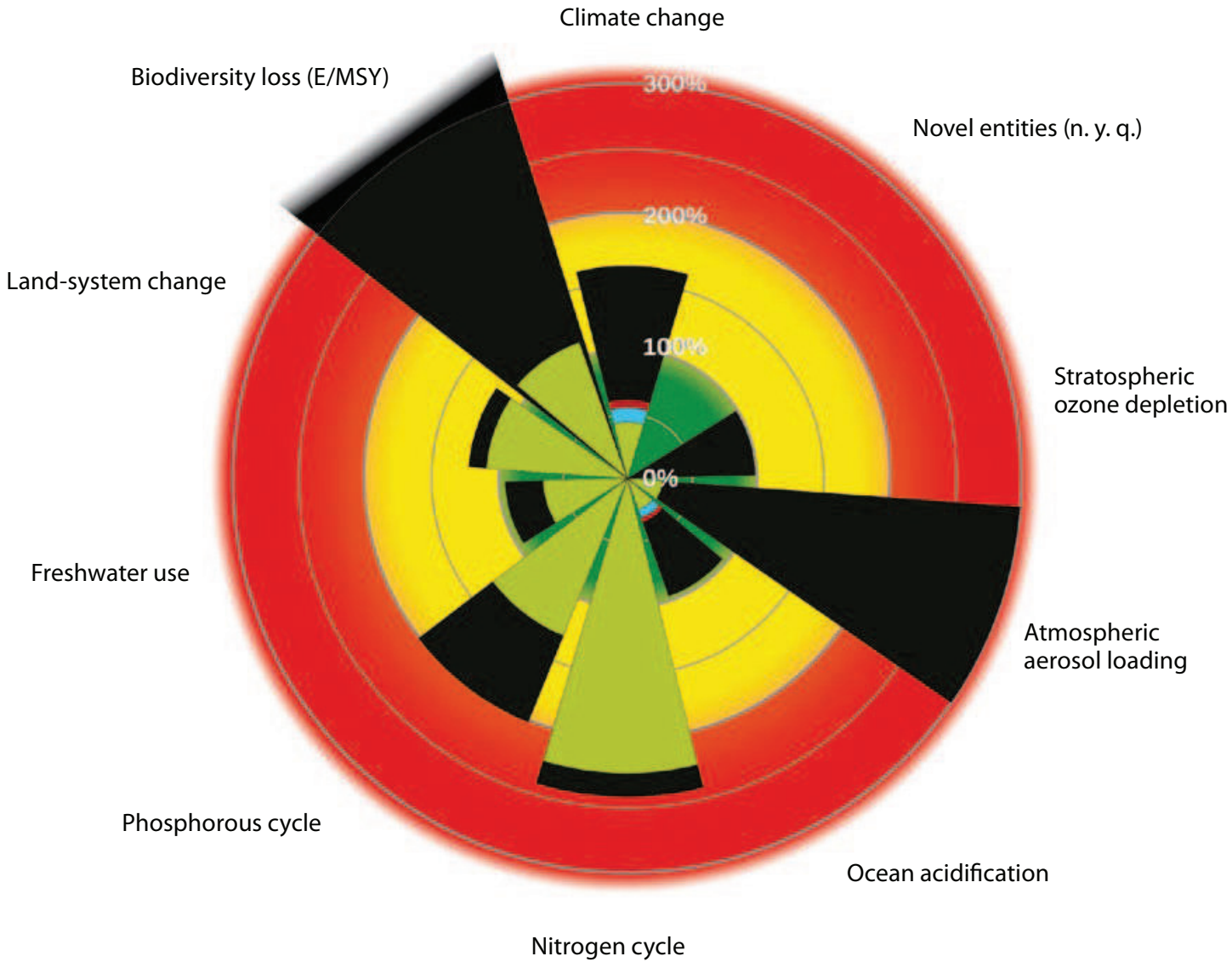
As presented in Tab. 1 and Fig. 1 current agricultural and nutritional activities contribute itself to the transgression of three planetary boundaries: the loss of biodiversity, biogeochemical flows (P, N), and land-system change. Whereas in the case of biodiversity loss, P cycle and land-system change, the transgression is in the zone of uncertainty – indicating an increasing risk (yellow marked fields in Tab. 1), the N boundary related to agriculture is more than 200% transgressed – indicating a high risk (red marked field in Tab. 1).

Agricultural and nutritional activities related to climate change and atmospheric aerosol loading alone do not lead to the transgression of the corresponding boundaries, but contribute indirectly to the transgression, whereas for climate change the relative impact is higher (37% compared to 8.9% in the case of atmospheric aerosol loading).

Although the indicators ocean acidification and freshwater use were close to 100%, the boundaries were crossed in neither case. Whereas for freshwater use with a total withdrawal of  $3,71 \text{ km}^3 \text{ yr}^{-1}$  the attributable fraction of 69% related to agriculture is substantial ( $2,567 \text{ km}^3 \text{ yr}^{-1}$ ), for ocean acidification the fraction had the same magnitude than for climate change (37%).

Due to missing data for food processing/trade and food consumption, no corresponding global impacts were calculated in this study for the following indicators: biodiversity loss, N and P biogeochemical flows, land system change, freshwater use, and atmospheric aerosol loading.

Impacts from food processing/trade and food consumption were solely considered for climate change and ocean acidification (see Fig. 1 and Tab. 1). Due to a lack of data in the case of stratospheric ozone depletion and novel entities, neither the impacts stemming from agriculture nor from food processing/trade and food consumption, were considered here.



n.y.q. = not yet quantified

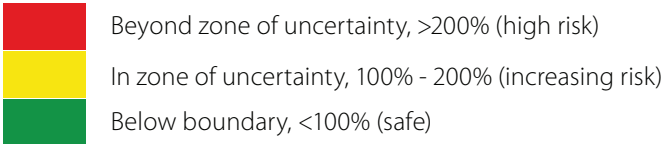





Fig. 1: **Fraction of agriculture and nutrition attributable to the total environmental burden and corresponding planetary boundaries.** The inner circle (green, <100%) represents the safe operating space for the planetary systems. The middle circle (yellow, 100-200%) represents the zone of uncertainty (increasing risk), whereas the outer circle (red, >200%) represents the zone with high environmental damage (high risk).

**Tab. 1: Fraction of agriculture and nutrition attributable to the total environmental burden and corresponding planetary boundaries**

earth system process / indicators	Parameters	Proposed boundary (zone of uncertainty)	Current status (total) <small>data source</small>	Current status (agriculture) <small>data source</small>	Current status (food processing, trade) <small>data source</small>	Current status (food consumption) <small>data source</small>	Pre-industrial level
Climate change	Energy imbalance at top of atmosphere ( $\text{W m}^{-2}$ )	1 (1.0 - 1.5)	2.3 (1.1 - 3.3) 1)				0
	Atmospheric $\text{CO}_2$ concentration (ppm $\text{CO}_2$ )	350 (350 - 450)	396.5 1)				280
	$\text{CO}_2$ emissions ( $\text{Gt yr}^{-1}$ )	21,626	35,000 2)	9,283 3)	2,399 3)	1,316 3)	1,500
Biodiversity loss	Extinction rate, extinctions per million species per year (E/MSY)	<10 (10 - 100)	>100 1)	11 4)	?	?	0.1 - 1
Ocean acidification	Global mean saturation state of aragonite in surface sea water ( $\Omega$ arag)	2.75	2.90 5)	0.77 3)	0.20 3)	0.11 3)	3.44
Stratospheric ozone depletion	Stratospheric ozone Depletion in Dobsen Unit (DU)	276	283 1)	?	?	?	290
Biogeochemical flows	P cycle: P flow from freshwater systems into the ocean ( $\text{Tg P yr}^{-1}$ )	11 (11 - 100)	~22 1)	14 1)	?	?	-1
	N cycle: industrial and intentional biological fixation of N ( $\text{Tg N yr}^{-1}$ )	62 (62 - 82)	~150 1)	139 6)	?	?	0
Land-system change	Area of forested land as % of original forest cover	75 (75 - 54)	62 1)	70 7)	?	?	100
Freshwater use	Maximum amount of consumptive blue water use ( $\text{km}^3 \text{ yr}^{-1}$ )	4,000 (4,000 - 6,000)	3,721 8)	2,567 8)	?	?	415
Atmospheric aerosol loading	Particulate matter (PM 2.5) concentration in atmosphere ( $\mu\text{g m}^{-3}$ )	10	20 9)	0.7 11)	?	?	?
	Particulate matter (PM 10) concentration in atmosphere ( $\mu\text{g m}^{-3}$ )	20	71 10)	9.0 11)	?	?	?
Introduction of novel entities	No control variable currently defined	No boundary currently identified	?	?	?	?	?



	Beyond zone of uncertainty (high risk)
	In zone of uncertainty (increasing risk)
	Below boundary (safe)

- 1) According to Steffen et al. (2015)
- 2) Calculated by linear regression using data from Steffen et al. (2015)
- 3) Based on Bajzelj et al. (2013) (reference year: 2010), without N<sub>2</sub>O emissions, as these emissions are accounted for in the N cycle
- 4) According to Hoffmann et al. (2011), related to endangered species (possibly extinct) due to agri- and aquaculture (reference year: 2008)
- 5) According to Rockström et al. (2009)
- 6) According to Kahiluoto et al. (2014)
- 7) According to Hosonuma et al. (2012)
- 8) According to FAO Aqua Stat (2016) for the year 2005
- 9) According to Apte et al. (2015), lognormal distribution, geometric mean of PM2.5
- 10) According to WHO (2014) for the period 2008 - 2012
- 11) According to WHO (2006)

## Discussion

The originality of our study is based upon the consistent integration of agriculture and nutrition-related environmental pressures into the concept of Planetary Boundaries. With the exception of stratospheric ozone depletion, the corresponding attributable fractions were identified and included. To the best of our knowledge, a similar approach was solely applied by Kahiluoto et al. (2014) considering the impact of agriculture and nutrition on global N and P cycles. In comparison to Kahiluoto et al. (2014), different results were identified for the agriculture-related share of the P cycle. Whereas Kahiluoto et al. (2014) based their assessment on data from Seitzinger et al. (2010), we used here data from Steffen et al. (2015). Further, it has to be mentioned that in case of uncertain attributable fractions (biodiversity loss) the most conservative value was chosen to be implemented in our analysis. In case of biodiversity loss, therefore, the attributable fraction related to agriculture might be even higher.

## Conclusion

Taking the production, processing and trade of food, as well as food consumption into account (here referred to as agriculture and nutrition), we could show that in case of three out of four critical indicators (biodiversity loss, biogeochemical flows (P, N), and land-system change) the latter are predominantly affected by agricultural activities. The strongest contribution to a transgression of a planetary boundary at all, was caused by the excessive application of nitrogen (N) as fertilizer in agriculture. Moreover, as the application of N is related to other critical indicators indirectly – via the emissions of  $N_2O$  to climate change and via eutrophication to biodiversity loss (Storkey et al. 2015, Tilman/Isbell 2015) – the ban of an excessive usage of N should be prioritized in agricultural policy agendas.

Further, additional efforts should be made to quantify the current status as well as the planetary boundary concerning the release of novel entities – by Rockström et al. (2009) described as chemical pollution. Although both concepts, the one of the Planetary Boundaries and the one of the Anthropocene, are closely interwoven, this parameter, which represents the core rationale behind the concept of the Anthropocen (see introduction), is currently not substantiated with robust data in the concept of the planetary boundaries. Moreover, further studies should focus on the data gaps identified related to food processing/trade and food consumption (see results) and implement this data properly in the framework of the planetary boundaries.

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# Table of contents

05	<b>Introduction to the Symposium Proceedings</b> Reinhold Leinfelder, Alexandra Hamann, Jens Kirstein, Marc Schleunitz, Theresa Habermann
13	<b>Beyond Illustration</b> Nick Sousanis
19	<b>How Factual are Factual Comics? Parasitic Imaginations in Referential Cartoons</b> Stephan Packard
29	<b>Comics and Truth – Why Non-Fiction Comics need Rules</b> Lukas Plank
41	<b>Manga meets Science: Going beyond the Education- Entertainment Divide</b> Jaqueline Berndt
61	<b>Understanding Science through Comics</b> Veronika Mischitz & Helmholtz-Gemeinschaft
67	<b>Planetary Boundaries of Agriculture and Nutrition – an Anthropocene Approach</b> Toni Meier
79	<b>Insects, the New Food?</b> Arnold van Huis
89	<b>Food Production in the Anthropocene: The Role of AgTech in Urban Spaces</b> Anne-Kathrin Kuhlemann
97	<b>Interview with Katerina Teaiwa by Teresia K. Teaiwa for Microwomen</b> Katerina Teaiwa
109	<b>Epilogue: Eating Anthropocene – Merging Science and Comics</b> Reinhold Leinfelder, Alexandra Hamann, Jens Kirstein, Marc Schleunitz