Environmental Impacts of Crop production

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Post-workshop summary of impacts

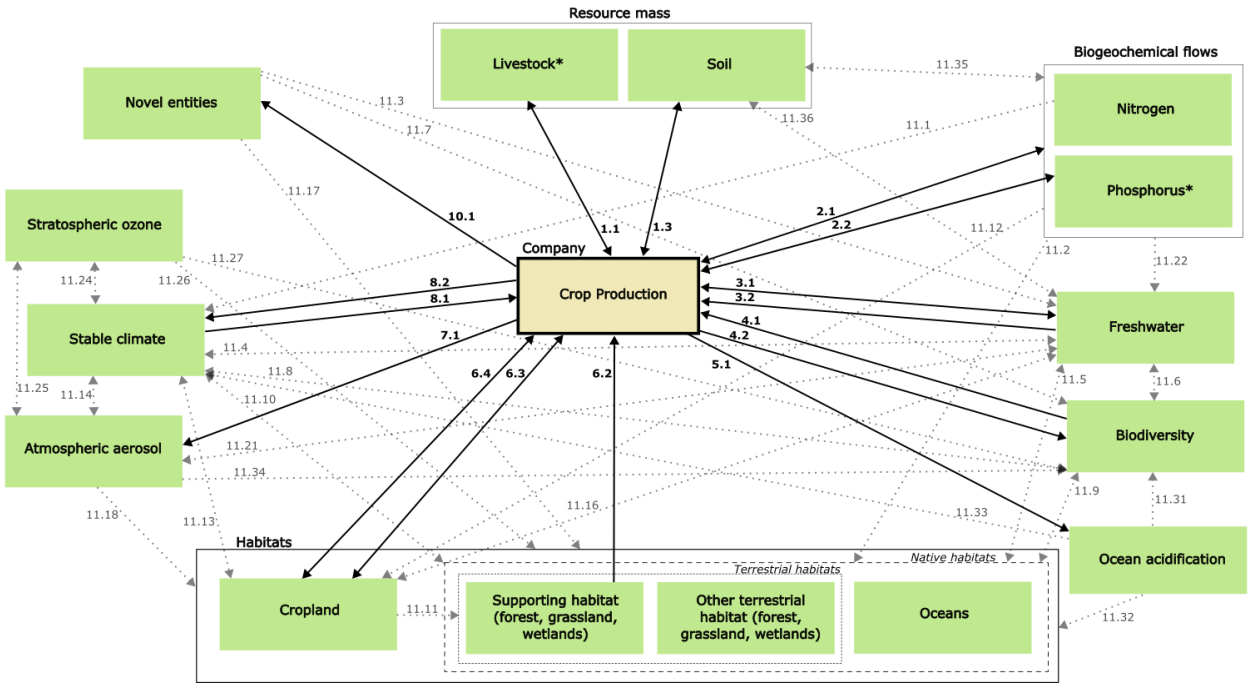

Figure 1. Conceptual systems diagram showing potential interactions between a company (yellow box) and various environmental dimensions. Dimensions are based on processes captured by the planetary boundaries framework, with the addition of natural resources. Solid lines represent direct impacts and/or dependencies of the company on various environmental dimensions. Dashed lines represent interactions between environmental dimensions. Viewed together, solid, and dashed lines represent the indirect impacts and dependencies of the company. Numbers refer to Tables 2 and 3 in this document. Boxes are shaded depending on if mechanistic links (i.e. arrows) are present (green) or not (grey).

Table 1. Direct environmental impacts and dependencies of crop production sector, shown as solid lines in figure 2. Links between a company operating in this industry, and the different environmental dimensions, are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Category	Sub-category	Impact, Dependency or Both	Description of Mechanisms	References
1.1	Resource mass	Living biomass	Both	Dependency on living biomass, e.g. animal-based energy, manure, which also have environmental impacts	1
1.3	Resource mass	-	Both	Dependency on soil, a resource comprising both living and non-living components. Unsustainable practices in crop production cause soil loss and degradation of soil structure. The mechanisms include removing vegetation, which leaves soil exposed, and ploughing practices which remove soil, disrupting processes which build soil structure (decomposition, microbial activity). This leaves soil vulnerable to erosion.	W
2.1	Biogeochemical flows	-	Both	Nitrogen and Phosphorus provide fertilizer input for food production. However, effluent discharge can cause nutrient pollution and disrupt biogeochemical cycles.	2
2.2	Biogeochemical flows	Phosphorus	Both	Phosphorus provides fertilizer input for food production. However, use contributes to P depletion. Approximately 90% of phosphate rock is used for food production (82% for fertilizers).	3, 4
3.1	Freshwater	-	Both	Dependency on freshwater for crop production. However, practices can disturb hydrological flows across blue and green water. Practices include dam building and operation, and type of irrigation. Land conversion and land management affect water retention in the soil, which impact quantities of runoff, affecting blue water flows and evaporation. This impacts precipitation either locally or in distal locations. Intense or excessive groundwater abstraction for irrigation can lead to deterioration of groundwater quality due to saline intrusion, especially in coastal aquifers.	1, 5, W
3.2	Freshwater	-	Dependency	Dependency on good water quality	1

4.1	Biodiversity	-	Dependency	Dependencies on biodiversity, e.g. better soil quality, bioremediation, pollination, pest and disease control, and genetic material	1
4.2	Biodiversity	-	Impact	Impacts on biodiversity, e.g. invasive species, practices like drainage, cultivating monocultures and selective breeding	1, 6
5.1	Ocean acidification	-	Impact	Emissions of CO_2, e.g. due to fuel use by machinery or biomass burning, increase the acidity of surface seawater	7
6.2	Habitats	Supporting habitats	Dependency	Dependencies on supporting habitats, e.g. filtration, buffering and erosion control, and flood and storm protection	1
6.3	Habitats	Appropriated habitats	Both	Dependencies on qualities of appropriated habitats, e.g. soil quality. Impacts on appropriated habitats depends on practices, such as those relating to soil and irrigation management, e.g. with poor management practices, rainfed arable crops can lead to increased soil erosion and decreased soil moisture, but with appropriate soil management, crops can reduce flood severity. Practices like overuse of machinery, intensive cropping, short crop rotations, intensive grazing and inappropriate soil management leads to soil compaction. Poor irrigation practices can lead to soil salinization.	1
6.4	Habitats	Appropriated habitats	Both	Use of space of appropriated habitats. This can lead to land use change, which negatively impacts native habitats.	8
7.1	Atmospheric aerosol	-	Impact	Crop residue burning releases particulate matter, including black Carbon	9
8.1	Stable climate	-	Dependency	Climate regulation, e.g. growing seasons	1
8.2	Stable climate	-	Impact	GHG emissions, e.g. CO2, CH4, N2O, NH3, NOx, SO2. Mechanisms include from soils (inefficient inputs of N fertilizers, cultivation), biomass burning, machinery, rice production, synthetic pesticide production	10
10.1	Novel entities	-	Both	Inputs of novel entities contribute to production, e.g. pesticides and herbicides. However these also cause substantial environmental pollution, including of water and soils. Insecticides kill both target and non-target species. There is a risk of genetic pollution by aggressive genotypes.	1

Table 2. Interactions between environmental processes relevant to crop production sector, shown as dashed lines in figure 1. Links are visually represented in Figure 1. References are numbered, 'W' indicates data from the expert elicitation workshop.

No.	Categories	Description of Mechanisms	References
11.1	Biogeochemical flows (Nitrogen), Stable climate	Production of Nitrogen fertilizer by industrial N fixation (Haber-Bosch process) is energy intensive and currently creates a large amount of GHG emissions	11
11.2	Biogeochemical flows, Habitats (Native)	Nutrient runoff causes eutrophication and/or hypoxia	12
11.3	Freshwater, Novel entities	Release of novel entities causes groundwater contamination e.g. herbicides and pesticides	1
11.4	Freshwater, Stable climate	Interactions between climate and hydrological cycles, e.g. climate change leads to heavier precipitation in some areas and drought in others; with increasing temperature and precipitation fluctuations, water availability and crop production are likely to decrease in the future	13, 14
11.5	Freshwater, Habitats (Native)	Interactions between native habitats and water cycle and quality, e.g. agricultural practices can increase salinity of a basin, changing the physical environment and processes of freshwater ecosystems	15
11.6	Freshwater, Biodiversity	Interactions between hydrological cycle and biodiversity, e.g. in a healthy ecosystem, biodiversity provides clean water and flow regulation, which also supports biodiversity. Increasing salinity in freshwater ecosystems adversely affects many biota.	15
11.7	Biodiversity, Novel entities	Impact of novel entities on biodiversity, e.g. pesticides, comprising insecticides, herbicides, fungicides and others, have lethal affects on many species, including non-target species, thus affecting species diversity.	6
11.8	Biodiversity, Stable climate	Interactions between climate and biodiversity, e.g. climate change causes shifts in species' ranges toward higher latitudes or elevations or alter seasonal timings. This includes pole-ward shifts in crop pests and pathogens, and pollinators like bees, thus influencing crop production.	16
11.9	Biodiversity, Habitats (Native)	Interactions between native habitats and biodiversity, e.g. Habitat destruction is a leading cause of species extinction. Agriculture is a large contributor to biodiversity loss, mainly because it converts natural habitats to intensely managed systems.	17, 18
11.10	Habitats (Native), Stable climate	Interactions between native habitats and climate regulation. Ecosystems regulate the global climate at both local and global scales. e.g. Boreal and subarctic peatlands are large carbon reservoirs, but drainage for agriculture and other uses has turned peatlands into significant sources of GHGs.	19, 20

11.11	Habitats (Appropriated), Habitats (Native terrestrial)	Land use change causes habitat loss and fragmentation in native terrestrial habitats, e.g. deforestation	21
11.12	Habitats (Appropriated), Biogeochemical flows	Excessive utilization of mineral fertilizers contributes to soil degradation, soil erosion due to loss of organic matter, breakdown of soil structure, poor internal drainage, salinization and acidification problems, and loss of soil C stock.	22
11.13	Habitats (Appropriated), Stable climate	Interactions between climate regulation and appropriated habitats. Ecosystems regulate the global climate at both local and global scales, so land use change affects climate regulation. Climate regulation provides favorable conditions for agroecosystems like cropland, so climate change can have adverse impacts e.g. increased frequency and intensity of drought causes large crop losses	20
11.14	Atmospheric aerosol, Stable climate	Aerosols have complex interactions with the climate system. They have both a cooling effect, by reflecting incoming solar radiation, and a warming effect, by absorbing heat radiation and changing surface albedo, but the net impact is a cooling effect. Uncertainty arises from complexity of aerosol absorption and impacts of aerosols on cloud microphysics.	7, 23
11.16	Habitats (Appropriated), Freshwater	Interactions between cropland and hydrological cycle, including interactions between blue and green water (e.g. certain types of crop cover lead to less water retention in the soil and increased runoff)	W
11.17	Habitats, Novel entities	Pesticides pollute habitats, especially agricultural soils	24
11.18	Atmospheric aerosol, Habitats (Native)	Aerosols have harmful impacts on native and appropriated habitats, e.g. exposure to ozone can damage crops and natural ecosystems. Acid precipitation causes acidification of water, soil and forest environments.	25
11.21	Atmospheric aerosol, Freshwater	Aerosols influence the hydrological cycle by altering mechanisms that form precipitation in clouds. Aerosols may substantially influence the Asian monsoon circulation.	26, 27
11.22	Biogeochemical flows, Freshwater	Flows of biogeochemical effluents pollute freshwater resources, degrading water quality, e.g. high use of chemical fertilizers increases fluxes of N and P through watersheds and coastal zones. It also contaminates groundwater in many regions.	28
11.24	Stable climate, Stratospheric ozone	Complex interactions between GHGs and ozone-depleting substances. Nitrous oxide (N_2O) is both a powerful GHG and the dominant ozone-depleting substance emitted in the 21st century, because it decomposes in the stratosphere to form nitrogen oxides (NO_x), which catalyze ozone destruction. However, other GHGs reduce the effectiveness of N_2O in destroying ozone (CO_2, CH_4).	29, 30

11.25	Atmospheric aerosol, Stratospheric ozone	High stratospheric aerosol loading reduces the ozone depletion potential (ODP) of N_2O, because NO_x is converted to HNO_3 on aerosol surfaces. In addition, aerosols affect ozone loss through Cl_y chemistry.	29
11.26	Stratospheric ozone, Habitats	Stratospheric ozone depletion leads to increased solar UVB radiation, causing DNA damage in plants	31
11.27	Stratospheric ozone, Biodiversity	Stratospheric ozone depletion leads to increased solar UVB radiation, causing DNA damage in fauna, such as marine Antarctic organisms.	32
11.31	Ocean acidification, Biodiversity	Many marine organisms are highly sensitive to changes to ocean CO2 chemistry, especially those using carbonate ions to form calcium carbonate shells or structures. Ocean acidification could be deleterious to such organisms, which would constitute a major disturbance to marine ecosystems with highly uncertain impacts. Marine plankton are also vulnerable.	7
11.32	Ocean acidification, Habitats	Ocean acidification may have serious impacts on various marine and coastal habitats.	7
11.33	Ocean acidification, Climate	Oceans remove a large proportion of anthropogenic CO2, but acidification threatens the ability of oceans to continue to function as a carbon sink.	7
11.34	Atmospheric aerosol, Biodiversity	Aerosols have harmful impacts on flora and fauna, e.g. exposure to ozone can kill freshwater fish.	7, 33
11.35	Resource mass, Biogeochemical flows	Soil is connected to biogeochemical flows. Erosion of soil and loss of soil structure leads to more runoff because soil is less able to retain water and nutrients.	W
11.36	Resource mass, Freshwater	Erosion of soil and loss of soil structure leads to more runoff because soil is less able to retain water. This can lead to desertification, with a higher risk in regions already vulnerable to water scarcity and other effects of climate change.	W

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ELICITATION RECORD – Part 1

The Workshop Context

Elicitation title	Essential Environmental Impact Variables
Workshop	Crop Production
Date	7 December, 2022
Part 1 start time	9:00

Attendance and roles	Facilitator, Note taker, Experts 1, 2 and 3
Purpose of elicitation	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. 2. Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
This record	Participants are aware that this elicitation will be conducted using an adapted Sheffield Elicitation Framework, and that this document, including attachments, will form a record of the session.
Orientation and training	Participants received a pre-workshop participant brief.
Participants' expertise	<u>Expert 1</u> *Expertise:* Food systems, looking broadly at food from production to consumption, mostly from Earth systems perspective, water stress. Quite broad understanding. <u>Expert 2</u> *Expertise:* Water and land use, water cycle, a bit on nutrient flows. Mostly global. <u>Expert 3</u> *Expertise:* Broad understanding of global food system. Worked more concretely in agricultural landscapes. Crop and livestock production

	and impacts on biodiversity and ecosystem services. Work on the ground was in Europe – more concrete. More meta level understanding more Global South.
Declarations of interests	No competing interests
Strengths and weaknesses	<u>Expert 1:</u> *Strengths:* Food systems, looking broadly at food from production to consumption, mostly from Earth systems perspective, water stress. Quite broad understanding. *Weaknesses:* The crop level, more global understanding of global food systems. <u>Expert 2:</u> *Strengths:* Water and land use, water cycle, a bit on nutrient flows. Mostly global. *Weaknesses:* local scale <u>Expert 3</u> *Strengths:* Global food systems, land use change, biodiversity, ecosystem services, agricultural landscapes Europe. *Weaknesses:* Water, including freshwater use.
Evidence	*Clarifying question asked:* (Expert 3) About level of detail you would like. How much certainty. *Answer:* (Facilitator) Two parts: check understanding is correct, look at material that is there and see if anything should be removed, changed or added. Second part – what you see as greatest impact. More about reasoning on why, and this could be broad or specific. *Clarifying question asked:* (Expert 1) The categories – the impact categories were mix of PBs and something else. Some boundaries global and some are quite local. *Answer:* (Facilitator) Trying to get a global understanding in the sense we want different types of impacts even if not applicable in every case, to get broad portfolio. Then getting context and examples, e.g. this impact is high in impact in Europe and not somewhere else. Few impacts are same across world, context really matters. But also specify as much as possible in material where context dependent or not.

	Response: Also about how large area are we talking about. *Answer:* It is a problem of scale. The end product is company scale, target is larger impacts. Creates geographical bias, differences between regions on where agriculture is run by corporations. But we are thinking about impacts so even for smaller actors and disclosure is hard. *Question:* (Expert 2) The impacts themselves can be local? *Answer* (Facilitator)*:* Yes. Hence we have asked for greatest impacts, it can be either.
Structuring	The variables were not elaborated or rephrased at this stage.
Definitions	Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured. Assessment of which are the *greatest* impacts on nature, meaning either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.

Part 1 end time	9:24
Attachments	

ELICITATION RECORD – Part 2: Outcome 1

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Crop Production
Date	7 December, 2022
Outcome	1. Assessment of background review: assess the background review of impacts and ensure that all significant and salient impacts from an industry on the environment are captured in the conceptual systems diagram and the associated tables. Specify if any impacts are missed, should be rewritten/rephrased or removed.
Anonymity	Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records). Comment from a fourth expert (Expert 4) were collected before the workshop and brought into the discussion.
Start time	9:50

Definition	Assessment of background review of impacts, ensuring all significant and salient impacts from an industry sector on the environment are captured.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	**Missed –** Expert 2: Add Carbon cycle to Biogeochemical flows Expert 3: Non-living mass. Crop production is dependent on non-living mass - soil really matters. We are losing soil at hyper fast rate globally. Extremely problematic and don't talk a lot about. Both depends on that and is also impacting, with unsustainable practices that lead to soil loss and poor soil structure etc. Note that disturbing the soil leads to erosion and also higher runoff of nutrients due to lack of soil structure to retain water and nutrients, so it is interconnected with biochemical cycles. Expert 1:

	As Expert 3 mentioned, soil impact for non-living mass **Rewritten/Rephrased –** <u>Expert 2:</u> Water use and water scarcity are the terms used – somewhat simplistic, but maybe they have to be. I would prefer more general terms, e.g. flow disturbance, or something that describes change in quantity and timing of freshwater, instead of scarcity. Does not specify timing. Sometimes, too much water can be an issue, not just lack. The use side as well, not just taking water, the fact that we store it in reservoirs which changes flows and the timing of flows. If you just talk about water use the indicator is water withdrawals but that might not be sufficient to represent all the impacts. Minor point, rephrase 9.3 - not just ground but also surface water and also soil water to some extent. I do feel soil moisture was implicitly considered everywhere but not sure whether necessary to add. Feedback no 4, I would add link in 9.4 to the description: Very important in some regions but also interregional impacts can be significant. Has to do what Expert 1 said about moisture recycling. You mention it but buried in indirect. But it is an important part of feedback loop on climate. <u>Expert 3:</u> You have it, could be more explicit, we tend to think about pollution from novel entities, we think about water, but the soil pollution is really important, and it affects the quality of what you eat, health. Direct effect on quality of crops, health wise it is a risk. Studies show it affects nutrient content. **Expert 1:** Expert 2 discussed water – not just water use but broader impacts on water. See recent paper on greenwater PB. It might be beneficial to have soil moisture explicitly, then blue water. Only looking at blue water withdrawals is very narrow. Some impacts are same, some different with green and blue water. It is also linked to soil quality. Blue water, groundwater and soil moisture all interact, e.g. irrigate land, blue water being used but green water increases. Interactions between storages, e.g. climate change might impact precipitation, temperature increases which increases evaporation, and that impacts different systems. Seasonal changes might be important, for example

	hydropower operation. Filtration to groundwater. Some good articles this year on issue. Habitat and what Expert 3 said, on 'other terrestrial', from resilience point of view. Moisture recycling, crop changes might impact other habitats. Radical changes in Amazon might impact precipitation quite far away. I would put impacts to other terrestrial habitats. Might be very far away from cropland. Novel entities, in figure arrow from crops to Novel Entities, but table is both directions – not in line. It is both directions. Consider referring to recent papers on planetary interactions – Lade 2019, Chrysafi 2022. Most important PBs for food production **Removed –** Expert 2**:** None Expert 3**:** Suggestion to simplify it and not have as many Expert 1**:** None
Matches/ Mismatches	There was a lot of agreement and support for each others' comments.
Group discussion	**Soil** <u>Expert 2</u>: Not really disagreeing, but I would interested to hear more about soil loss aspects Expert 3 mentioned, not sure I fully understood it all. There are more vulnerable regions where a lot of impacts collide and are connected. I wonder if we can identify them, or if they should be identified. Sahel region comes to mind. Soil quality, loss, water, climate change to make it worse. Tropics mentioned. Didn't really disagree with anyone. <u>Expert 3</u>: Shall I clarify? [Facilitator: Yes] Soil loss is erosion, it happens when big exposure of soil to wind, water… the elements. First, just by removing vegetation, you of course are leaving soil exposed. <u>Expert 2</u>: Just to specify, non-living mass includes organic compounds? <u>Expert 3</u>: Yes, dead leaves and wood, not living anymore but contribute to soil fertility, structure, water retention. When you remove vegetation and when you have ploughing practices to remove

	soil instead of letting it be, and decompose, [activity of] microorganisms. Leaving soil extremely vulnerable to erosion. Combination of deforestation and removal vegetation layer but then also agricultural practices. Agroecology, you do not leave soil bare but cover with leaves, protect from erosion. But mechanical practices, intensive – you remove roots which are important, so everything gets taken away. As we do it often, never build up soil layer, depend on artificial inputs that would be naturally in soil. Expert 2: So in diagram would be connected to water cycle, biogeochemical flows. Expert 3: Could be connected to water cycle, increased erosion leads to more runoff and to desertification. You have less water retention in soil due to no roots, soil structure that contributes to water retention. Expert 2: Doesn't it go both ways, less water leads to more erosion? Expert 3: Yes, in Africa or other drylands where already water scarcity and climate change, the risk is even higher. Combination of both. In diagram it should be connected with non-living biomass Expert 2: Implicitly everywhere Expert 3: Almost want a separate thing just on soil. It is connected to habitat. It is both living and non-living. It would be good to make it explicit. **On water** Expert 3: Point on green water was really important. Facilitator: What kind of practices or activities that create [those] impacts, especially greatest? Expert 2:: Dam building and operation a big one. Even if don't withdraw water, storing it behind dam means it does not flow in as big quantities as free flowing river. Often dams built for hydropower but often also for irrigation. Expert 1 might know better but purely irrigation dams are relatively small? Expert 1: Yes, but there are a lot that are primarily built for irrigation. Expert 2: More on green water, land conversion and land management. As Expert 3 said, management impacts water retention, impacts quantities that runoff and add to blue water flows

	and evaporation flows. Those may impact precipitation either locally or in faraway regions. Facilitator: What do you mean with land management? Expert 2: Obviously irrigation, as Expert 1 mentioned. Don't know if water use or land management, it is both probably. Probably biggest impact on water flows when it comes to land management. Many practices Expert 3 mentioned relating to soil loss also disturb water cycle. Facilitator: Difference between types of water practices? Or just taking out. Expert 3: Huge difference Expert 2: Difference relates to amount of water lost, efficiency Expert 3: Drop irrigation much more efficient than slang. Phased drop irrigation close to soil- the system turns on with certain frequency. Much less evaporation, more efficient. Maybe 30% amount of water, same output. What methods do you use. Simple things – when in the day? Middle of the day, most just evaporates. Slang is one of least efficient ways. Huge difference. Studies with farmers in India comparing when could use solar energy systems for drop irrigation compared to diesel water pumps. Huge, huge difference. Expert 2: Extreme example wasteful irrigation, rice fields are basically flooded, evaporation huge. Facilitator: Can you grow rice in different way? Expert 1: There are varieties, water mostly for pest control. Depending on variety and where grow rice. But no expert. But yes, different types of rice. Abundant water is the traditional and easy way. And pesticides could have other impacts. Expert 2: Probably river deltas if flooded anyway, not bad. But if you have to transfer water to another place could disturb cycle. Expert 3: Of course, the choice of crops. More or less water-intensive crops even within same species. Varieties – different water needs and resistance to water shortage and climate variation. If you choose water intensive crops you have a negative impact on the PBs. Facilitator: How much of a different in terms of varieties? Would you need that level to assess impact? Expert 3: The biggest differences are among species. Rye, which is more resistant to extreme climate variation than wheat. Intensive

	vegetables. Some varieties have been used but don't use anymore due to homogenization of seeds that the industry uses. Before, you had farming in many areas, dry lands, mountains. It was adapted. But with seed market, the same. Facilitator: Also difference between big impacts vs. resilience. You might just need species regarding impacts. Maybe in order to understand resilience the varietal differences key. Expert 3: Potential for change. You could say – stop cultivating tomatoes in Southern Spain, should adapt to dryland conditions. But then within tomatoes, both species and varieties better adapted. Two levels of diversity. The varieties open for not needing to stop producing things in that place, but adapt to be more suitable. Facilitator: Anything else on land management affecting water cycle apart from tillage and what was mentioned? Expert 2: Not my expertise though there is a paper. There are cover crops that reduce evaporation. Thinking whether increases disturbance from natural state. Hard time seeing as bad thing as used in areas with little water. Expert 3: Depends on the landscape composition. When you have different layers of vegetation, less of a problem. Trees help water cycle, better conditions for soil because they have roots. Feed animals. On understory you can plant crops. Mixed vegetation structure. Is that what Expert 1 referred to? Expert 1: One thing Expert 3: Then crops different on how contribute to evapotranspiration. **Biogeochemical flows** Facilitator: Biogeochemical flow impacts and eutrophication. Do these come from same type of practices as mentioned on water flow, cycling. Or are there other practices? Expert 2: Everything that increases erosion increases nutrient runoff. On top of that, biggest impact comes from fertilisation and overuse of fertilizers. Expert 1: Linked to agroforestry. Trees are nutrient pumps. From below ground, provide biomaterial to aboveground vegetation. The overuse of fertilizers for sure.

	Facilitator: Difference between artificial and manure, or is it just the amount? Expert 2: Depends which impacts. Industrial fertilizer adds. Manure recycling. And to do with scale. If you purely look at inputs, if you added same amount N in manure or industrial fertilizer, immediate environment the same, but larger scale… whenever you add to the system it is always worse, when recycling does not occur anymore. Facilitator: Linked – how often, depending on scale, is crop production integrated with animal? Expert 3: Less and less integrated. Most industrial agriculture, not at all. Small scale, more integrated, and recycling. I agree with Expert 2, but we shouldn't neglect methane release from livestock. Huge downside of manure. But agree about recycling part. Livestock one of main sectors that has biggest climate impact. Expert 2: recycling should happen not just with livestock but also humans. Nutrients in wastewater but don't know technologies scaleable, cheap enough Expert 3: Things happening Expert 2: Cheaper to produce new N Expert 3: COP session. Companies working on recycling P from wastewater for ag. Impression a lot has happened and growing, companies interested. Expert 2: Our lab has pilot, for N. Expert 3: The point is, integration is important, but you don't need nutrients from animal sources to have good quality soil. With good recycling of vegetable material you can fertilize soil, need to give it time and feed the soil. Decomposition of dead matter. Studies showing very good results. Expert 2: Does not happen at all in industrial agriculture. Expert 3: Seagrass becoming more spread in industry to fertilize. Mostly artificial inputs or manure. Manure small scale. Facilitator: Most common artificial fertilizer, smaller scale might be integrated, and could do without animals if better practices Expert 3: Absolutely Expert 2: [With] closed loop, could stop using artificial fertilizers. Technically possible.

	Facilitator: Anything else? Expert 3: Crop rotation as well – simple but work – not planting in the same place. Does not exhaust soil of nutrients. Crops use different nutrients. You let soil recover certain nutrients. Decomposing material and fixation. Also, more efficient to plant vertically. Different heights in same plot. Effective use of space and different depths roots and nutrient needs. Different nutrients at different depths. Water storage at different levels. Can adjust to have smarter use of resources. Light too. Optimising crop mixes – best output, less impact. Less water, nutrient inputs. Simple but in industrialization lost. Easier to just add more. Facilitator: This does not happen in industrial? Expert 3: Intensive systems, no not happening. Today several companies think about it. Expert 2: Obviously that's the more ideal way. Thinking about industrial agriculture, the bare minimum is more efficient use inputs, whether water, nutrients/fertilizers. Overused, efficiency [only] considered when resource is scarce. We overuse and leads to larger runoff.
Group elicitation	**Missed –** Impact and dependency on soil **Rewritten/Rephrased –** Water use to hydrological flow disturbances (including differences between blue and green water). Make indirect impacts more prominent (moisture recycling impacts). **Removed –** None
Chosen outcome	See above
Discussion	Expert 3 and Expert 1 had some feedback about cleaning up the structure with the arrows, as it is perhaps too complicated. Also using colours to communicate more in the figure. Expert 3 also highlighted the connection with not only planetary boundaries but also resilience. Some points are more critical for

	resilience than others. Suggestion to highlight feedbacks to bring in resilience angle. Expert 1 had a suggestion to specify direction for the interactions. Overall the workshop went well, followed format nicely. Balanced discussion and good breadth of knowledge. Highlights the benefit when finding experts with sector-specific knowledge but who are used to thinking about sustainability/environmental impacts.

End time	12:00
Attachments	

ELICITATION RECORD – Part 2: Outcome 2

Eliciting Expert Knowledge on Qualitative Outcomes

Elicitation title	Essential Environmental Impact Variables
Workshop	Crop Production
Date	7 December, 2022
Outcome	Assessment of greatest impact: assess which of these impacts have the greatest impact on the environment. By 'greatest' we mean that impacts have either 1) a large globally cumulative impact; or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
Anonymity	Experts are identified as Experts 1, 2 and 3 (aligned across all elicitation records).
Start time	9:50

Definition	Assessment of which are the *greatest* impacts on nature, meaning that impacts have either 1) a large globally cumulative impact, or 2) impacts that are locally incurred but are identified as generally having the largest local effect.
Evidence	A participant brief was provided in advance, containing a background review and evidence.
Individual elicitation	<u>Expert 2:</u> **Impact:** Land use and land cover change / land conversion **Reason:** Impacts biodiversity, climate, water cycling, everything. The change from natural to agricultural land is the biggest change [compared with changes between types of agricultural systems]. Greatest impact is expansion of agriculture. **Impact:** Disturbance of biogeochemical flows, and include the carbon cycle **Reason:** Water quality changes, impacts on biodiversity **Impact:** Water cycle disturbance and water quality disturbance.

	Reason: Habitat change, in aquatic environments. <u>Expert 3:</u> *[Note: The below impacts are ranked]* **Impact:** Land conversion, habitat degradation and loss. **Reason:** That also leads to biodiversity loss. Depends so much on type of practices. You can have high biodiversity on well-managed land. The habitat you don't get back. They are connected, but there is a slight difference. Regional variation: Habitat conversion hugest issue in tropical areas. Tropical forest lost larger impact both climate and biodiversity, so this is more important to distinguish. Also, habitats are critical for resilience. **Impact:** Biodiversity **Reason:** One reason is it is critical for resilience **Impact:** Biogeochemical flows **Reason:** We have crossed that boundary and by far agriculture has the hugest impact **Impact:** Soil loss **Reason:** Important everywhere but gets more critical in places where you have water scarcity. Parts of Africa [suffering from] desertification. It is happening everywhere, global trend, but more critical in some parts, those already affected by climate change with existing problems of water scarcity, becomes more critical. Also, soil health is critical for resilience - mitigating impacts of potential disturbances but also providing ground for crop diversity. <u>Expert 1:</u> **Impact:** Habitats **Reason:** As described by the other experts

	Impact: Biogeochemical flows **Reason:** As described by the other experts **Impact: Water** **Reason:** Crop production is highest sector impacting water, 90% blue and 95% green water is for food production. Quantities, flows, cycle, and quality. In many ways. **Impact:** Climate **Reason:** All agricultural sector is a third greenhouse gas emissions globally (not sure what share crop production, but check recent papers)
Matches/ Mismatches	There was a lot of agreement overall and support for each others' comments.
Group discussion	Facilitator: [Reads the four suggested 'greatest impacts': Land cover/use change, biogeochemical flows, water cycle impacts, and soil loss.] Expert 2: On water, not just user but disturber of cycle including through land use change. By far the biggest sector. Expert 2: Should make carbon cycle more explicit? It is implicit in all four. Facilitator: Make carbon part of BGC flows? Expert 2: Makes sense to me Expert 3: Soil loss – reason is deforestation, unsustainable practices. Facilitator: mention of climate Expert 2: I think it is there implicitly through what is there. Expert 1: Agriculture main actor disturbing biodiversity loss both directly and indirectly. Vote to include. Expert 2: I feel like second level. All four lead to biodiversity loss but they are drivers. Expert 3: All interlinked. Water cycle impacts soil loss. Land cover impacts water. Biodiversity loss should be here. Really important. Land conversion for agriculture still main driver.

	Facilitator: [Reads suggested wording.] Expert 1: Good way of wording. Expert 2: Using same logic should we add climate change? Expert 1: Again, agriculture largest factor contributing to climate change and also suffering. I would. Expert 3: Yes maybe good to have explicit. Hard to say implicit when everything interconnected. Expert 1: For us it is self-evident, but those outside science it is important. Expert 2: Having overlap less issue than ignoring important aspects due to not mentioning explicitly. Facilitator: [Reads suggested wording.] Expert 2: Feedbacks massive because agriculture is dependent on stable climate. Same for biodiversity.
Group elicitation	**Impact:** Land cover/use change **Reason:** Conversion from non-agricultural to agricultural land. **Impact:** Biogeochemical flows **Reason:** PB that is crossed, agriculture is biggest contributor. Make carbon more explicit. **Impact:** Water cycle impacts **Reason:** Agriculture the biggest (by far) user/impact on cycle **Impact:** Soil loss **Reason:** Global problem, deforestation and unsustainable agricultural practices fuel this impact. **Impact:** Biodiversity

	Reason: This comes from changes in the above, but needs to be highlighted explicitly due to the extent of impact. Feedbacks are big (dependencies of agriculture). **Impact:** Climate **Reason:** This comes from changes in the above, but needs to be highlighted explicitly due to the extent of impact. Ag is big contributor to climate impacts. Feedbacks are big (dependencies of agriculture).
Chosen outcome	See above
Discussion	

End time	12:00
Attachments	