Table 3: Summary of the impact of trends in direct driver on nexus elements.

Resource extraction refers to living and non-living materials (i.e. mining) as well as water withdrawals.

Neither land/sea use change, nor direct exploitation/utilization, invasive alien species or pollution are direct drivers of climate, beyond their impacts on climate via climate *change* (which is listed as a direct driver). Therefor 'climate' as a separate Nexus element is not included here.

Direct driver	**Nexus element**						
	Biodiversity	**Water (quantity)**	**Water (quality)**	**Food (quantity)**	**Food (quality)**	**Health (physical)**	**Health (mental)**
Land/ sea use change	The continued land expansion for agriculture and forestry into pristine regions contributes notably to the continued loss of biodiversity (Newbold et al., 2015; Pereira et al., 2010; Pörtner et al., 2023). This includes also direct and indirect pressures arising from competition for land for bioenergy crops. Urban land expansion also reduces habitats, particularly in biodiversity hotspots (McDonald et al., 2020; Seto et al., 2012). Increases in area under marine aquaculture, expansion of port-, and flood- protection infrastructure, as well as inflow from land ecosystems negatively impact	Deforestation, drainage of wetlands but also increased soil sealing and urban environments alter evapotranspiration (ET) and runoff. Frequently, average runoff is increased although impacts on peak flow are more variable (Tanaka et al., 2021; te Wierik et al., 2021; Xu et al., 2022). Feedbacks to precipitation patterns are incompletely understood (Jia et al., 2019). Urban areas with fastest rates of growth tend to be located in regions that are water scarce (McDonald et al., 2011). Dams regulate river flows and result in a re-distribution of water availability and contribute ca. one third (30-40%) of the world's irrigation	Via altering the flow, the drainage of wetlands or deforestation will also affect nutrient transport. Dams (for renewable energy or as freshwater supplies) alter transport of nutrients and particles within catchments and ultimately also flows into marine systems, affecting food-webs, toxic algal blooms and eutrophication (Maavara et al., 2020; Shi & Qin, 2023; X. Wang et al., 2022). Sediments that built up in reservoirs is missing in river deltas, which reduces their capacity to buffer coastal erosion (Maavara et al., 2020; Shi & Qin, 2023; X. Wang et al., 2022). *Well established*	Although the rate of expansion of agricultural land is slowing, increase of land under agricultural use still contributes to supplying food to a growing human population (Mbow et al., 2019). However, expansion of urban land into productive cropland is reducing food production potentials, counter-acting gains achieved through expansion elsewhere even though the total land area is small (d'Amour et al., 2017). Competition for productive land and land used for renewable energy production (e.g. photovoltaics) so far has not yet been identified as interfering with food production but may become an issue in	There is little literature on the impact of land use change on nutritional diversity and quality. Some studies such as Chrisendo et al 2020 (Chrisendo et al., 2020) find indirect positive effects through income generation. *Inconclusive*	Expansion of managed land contributes to feed the increasing human population. But the loss of natural ecosystems can both decrease and increase the distribution of diseases e.g. vector-borne diseases (Perrin et al., 2022; Steiger et al., 2016) and affect respiratory diseases (Ferreira et al., 2022). Expansion of agricultural area or cities can alter bioclimatic conditions (Jia et al., 2019; Perugini et al., 2017), which especially in the tropics can increase heat stress. *Established but incomplete*	Expansion of managed land at cost of natural ecosystems can have negative consequences on mental health e.g. due to less contact with nature and outside activities. In urban environments in particular, has access to green spaces been found to support mental health (Alahuhta et al., 2022; Cirino et al., 2022; Kosanic & Petzold, 2020; Nieuwenhuijsen et al., 2022; Y. A. Wang et al., 2022). Diverse landscapes provide diverse ecosystem services to people, supporting well-being (Kosanic & Petzold, 2020). Likewise, proximity to oceans has also been associated with enhanced mental health (Nash et al.,

	coastal marine habitat (Halpern et al., 2019; Jacob et al., 2020). *Well established*	water (Maavara et al., 2020). *Well established*		future. Agri-voltaic systems have the potential to resolving these potential conflicts (Choi et al., 2021; Kumpanalaisatit et al., 2022). *Well established*			2022). But quantitative evidence on how increasing homogenisation of landscapes or coastal development has affected local populations' mental well-being is scarce (Kosanic & Petzold, 2020; Nash et al., 2022). *Established but incomplete*
Direct exploitation/ utilization	Overexploitation of fishing, hunting, extraction of fruits, seeds, or medicinal species reduces species diversity (Beckmann et al., 2019; Clark et al., 2016; IPBES, 2019; McKuin et al., 2021; Newbold et al., 2015; Seibold et al., 2019; Weigel et al., 2014). Mining reduces local biodiversity both on land and at seas (Miller et al., 2018; Rentier & Cammeraat, 2022; Sonter et al., 2018); increasing demand for renewable energy is increasing mining pressure which requires to develop mining strategies such that transforming the energy sector is done environmentally	Total annual water withdrawal from agriculture, urban areas and industries estimated as < 580 km^3 in 1900 and > 3,900 km^3 in 2016 (Martínez-Valderrama et al 2023). Agriculture is responsible for 70% of ground- or surface-water withdrawals, while area under irrigation increased from <5 Mha pre-industrial to 338 Mha in 2018, depleting river and groundwater (Arneth et al., 2019; Lall et al., 2020; Martínez-Valderrama et al., 2023). Pressure on freshwater supply is now large nearly everywhere, but especially in dryland areas, where 1/3 of the human population	Excessive nutrient runoff from unsustainable land use has contributed to the collapse of coastal marine ecosystems (Altieri et al., 2017). In Europe, N inputs would need to be reduced by 43% on average to meet thresholds for N concentration in runoff to surface water (de Vries et al., 2021). Several million tons of pesticides enter water ways from agriculture each year (Schwarzenbach et al., 2010). Mining is locally an important source of freshwater, coastal and marine water pollution through leaching of sulphate from ores or use of toxic chemicals in	Modern, mostly high to medium-intense agriculture relies to a large extent on fossil fuel-based inputs, with mostly positive (but saturating) effects on yields (Beckmann et al., 2019). Large (increasing) human appropriation of NPP is mostly for food and feed production (Kastner et al., 2022; Krausmann et al., 2013; Mbow et al., 2019). Around one third of the world's marine fish stocks are overexploited and another nearly 60% of stocks are close to reaching that threshold (FAO, 2020). Soil erosion and degradation can reduce yields in the long term (Arneth et al., 2020).	Intensification in agriculture is associated by an increasing homogeneity of crops, which can reduce nutritional diversity (Ickowitz et al., 2019; Khoury et al., 2014). Increasing income often also allows a more balanced, nutritious diet, which affect types of food produced and trade – while also overconsumption and obesity have increased in recent decades (Mbow et al., 2019) Marine and freshwater seafood contributes substantially to nutrition but the realisation of these benefits depends on many factors, such as	Fishing and agriculture have overall positive impacts on human health e.g. through improved nutrition and food security (Kastner et al., 2022; Krausmann et al., 2013; Mbow et al., 2019) although extensive use of agro-chemicals is detrimental to health (de Andrade et al., 2023; Dhuldhaj et al., 2023; Wiedemann & Inauen, 2023). Utilising access to nutritionally valuable food depends also on factors such as education (Althoff et al., 2022; Peeters & Backholer, 2022). *Well established.*	Mining can negatively affect worker's health (anxiety, stress, etc.) (Matamala Pizarro & Aguayo Fuenzalida, 2021). Likewise, prevalence of mental disorders in agricultural producers and fishery workers is observed world-wide (Frumkin & Haines, 2019; Klingelschmidt et al., 2018; Younker & Radunovich, 2022). These studies suggest that mental impacts of resource extraction seem strongest in people directly working in the associated industries. *Established but incomplete*

	sustainably (Pörtner et al., 2021). The variable impacts of changes in armed conflicts on land-use change translate also into variable impacts on biodiversity. *Well established*	live, ca. 40% of irrigation water is used and 90% of the world's water-stressed cropland sub-regions lie (Martínez-Valderrama et al., 2023). The majority of aquifers are depleted unsustainably (Richey et al., 2015). Demand for materials used in construction & industry quadrupled from 1970 to 2010: Ca. 30% of (accessible) renewable freshwater is used by industry, cities and towns (Schwarzenbach et al., 2010). Whether or not per-capita water consumption in cities increases or decreases compared to rural environments depends on multiple socio-economic factors (Bo et al., 2021; Vivek et al., 2021). *Well established*	extraction processes (Gworek et al., 2016; Schwarzenbach et al., 2010). *Well established*	Breeding has improved cereal harvest index (Q. Liu et al., 2022), while land and nitrogen use efficiencies (relates also to material intensity) have improved 1961-2017) (Bai et al., 2021) - although trade-offs exist e.g., between harvest index and nitrogen use. Positive impacts on food production so far are small, but rapid progress in breeding points towards promising outcomes in the near future (Hawkesford & Griffiths, 2019). *Well established.*	handling of the catch, or fish trade vs. local consumption (Blanchard et al., 2017; Temesgen et al., 2019). *Established but incomplete*		
Climate change	Compared to land use change and resource use the impact of climate change currently is comparable small but evident (Arneth et al., 2020; IPBES, 2019).	Climate warming affects catchment water balances by altering precipitation, evapotranspiration, or glacial melt, leading regionally to more or less runoff (Heinke et	Climate change has a limited impact on water quality, although warmer temperatures and/or altered precipitation and evaporation affect biological	Until now, impacts of climate change on food production have been moderate but they exist (Lesk et al., 2016; C. Zhao et al., 2017). Droughts and heatwaves in the	Changes in temperature or precipitation so far have not been shown to conclusively impact nutritional quality (Giulia et al., 2020). By contrast,	Weather extremes such as floods and heatwaves have detrimental health impacts, directly or by enhancing other health-related factors (Arsad et al., 2022;	Increasing temperatures and prolonged droughts, extreme weather events but also permanently altered environments as a consequence of

	In particular weather extremes, which become more frequent and intense with continued climate warming can have large effects on species composition and interaction (Harris et al., 2020; IPCC, 2022; Terry et al., 2022; van Beest et al., 2022). Observed changes in the surface reflectance of large parts of the world's oceans over the past 20 years have been attributed to climate-change induced shifts in phytoplankton (Cael et al., 2023). *Well established*	al., 2019; Zhai et al., 2020). Of concern in this context is that dryland regions, which already experience water shortages, now are expected to get drier overall (Martínez-Valderrama et al., 2023; Yao et al., 2023). In mid-high latitudes lake ice cover is declining, and - globally- evapotranspiration from lakes is increasing, impacting stratification and biological processes (Kraemer et al., 2021; Woolway et al., 2020), Drying trends in lakes have been prevalent worldwide, as a consequence of climate change (increased evaporative demand being higher than input by rainfall and meltwater) direct abstraction of water by humans (Yao et al., 2023). *Well established*	processes and nutrient loads in freshwater systems (Shin et al., 2019). In temperate lakes, warmer temperatures cause overall a decline in dissolved oxygen (Jane et al., 2021). Across nearly 1000 study sites, river water quality has been shown to decline under the impact of heatwaves and droughts, as well as rainstorms and floods (van Vliet et al 2023). Increasing atmospheric CO_2 leads to acidification of ocean waters(Shin et al., 2019), which is detrimental to biodiversity but does not affect humans directly. *Well established.*	period 1964-2007 caused cereal losses in affected countries by ca. 10% (Lesk et al., 2016), but losses up to 30% have also occurred (including in more recent years) (Lesk et al., 2022). Weather extremes will rapidly become an increasing driver of crop losses in many regions, affecting poor regions disproportionally (Dasgupta & Robinson, 2022). Impacts of global yields are variable and buffered to some degree by shifts in growing regions and increasing atmospheric CO_2 (Deryng et al., 2016; Heino et al., 2023; Helman & Bonfil, 2022; Pugh et al., 2016; Schauberger et al., 2017; Toreti et al., 2020). *Well established.*	elevated CO_2 typically reduces protein content and micro-nutrients in many staple crops (Bloom & Plant, 2021; Kumar et al., 2023; Uddling et al., 2018; Ziska, 2022). Dong et al. (Dong et al., 2018) found that elevated CO_2 increased the concentrations of sugars, antioxidant capacity, phenols, flavonoids, ascorbic acid, and calcium in vegetables, while decreasing protein, nitrate, magnesium, iron, and zinc. Elevated CO_2 may also reduce levels of carotenoids (Loladze et al., 2019). *Established but incomplete*	Faurie et al., 2022; Kim et al., 2014). In Europe, the 2003 summer heatwave caused ca, 40000 deaths (Garcia-Herrera et al., 2010), while a heatwave in India with catastrophic crop losses in some regions corresponded with the suicide of >4000 farmers (Zachariah et al., 2023). Based on data from >700 locations in 43 countries, Vicedo-Cabrera et al., identified for 1991-2018 that 37% of warm-season heat-related deaths to be attributable to climate change (Mitchell, 2021; Vicedo-Cabrera et al., 2021). Reduction of cold-related deaths seems to be of minor importance (Q. Zhao et al., 2022). *Well established*	climate change can all lead to different mental health impacts (anxiety, depression, post-traumatic stresses) as well as aggression and violence (Cianconi et al., 2020; Deglon et al., 2023; Palinkas & Wong, 2020; Thoma et al., 2021; To et al., 2021; Vergunst & Berry, 2022). Certain population groups, particularly those most vulnerable to climate change impacts (low and middle-income countries, children) are most susceptible to these effects. However, there is still limited understanding regarding the full range of mental health impacts caused by climate change, and the underlying physiological processes (Cianconi et al., 2020; Cuijpers et al., 2023; Deglon et al., 2023; Palinkas & Wong, 2020). *Established but incomplete*
Invasive alien species	IAS have a notable impact on native species richness and abundance: increasing the risk of native species	IAS can alter water flows in catchments (especially invasive plant species) locally although impacts	There are some IAS that affect water quality locally (IPBES, 2023; Tobin, 2018) but impacts	IAS can affect material and intangible assets to a degree that impacted societies even have to abandon farming or	Some invasive species might provide additional protein sources and therefore enhance nutritional quality (Iyer et al.,	Negative impacts of IAS on health have been found in particular related to allergies or by acting as vectors for	Mental health effects of invasive species arise e.g., through modified ecosystems and biodiversity, and related impacts on

	extinction, affecting the native populations' genetic composition, altering functional diversity and trophic networks, thus also altering ecosystem productivity, nutrient and water cycling (IPBES, 2023; Pysek et al., 2020). 63% of studies found significant differences in plant species, community, or ecosystem characteristics compared to the situation prior to invasion. (Pysek et al., 2020). 85% of reports of IAS impacts on native species document these impacts to be negative (IPBES 2023). Impacts of IAS are particularly strong in island ecosystems *Well established*	globally are small (IPBES et al., 2023). *Established but incomplete*	globally are considered negligible. *Well established.*	fishing (e.g., water hyacinth in Eastern Africa) (Pysek et al., 2020). Other studies have found both positive and negative impacts on people's livelihoods although the negative impacts tend to dominate (Rai & Singh, 2020; Shackleton et al., 2019). *Inconclusive*	2021). But most species are unlikely to serve as a source for additional nutrients for humans (IPBES, 2023). *Inconclusive*	diseases, although injuries and wounds through direct exposure are also possible (IPBES, 2023; Mazza et al., 2014; Pysek et al., 2020; Rai & Singh, 2020). *Well established*.	livelihoods and sense of place (IPBES, 2023). *Established but incomplete*

Pollution	Impacts of anthropogenic chemicals in the environment, but also those of light pollution, are multifaceed and pose a continued threat to biodiversity and ecosystems (Hoelker et al., 2021; IPBES, 2019; Sigmund et al., 2023). More recently, plastic ingestion by animals has been reported for more than 200 freshwater species, ranging from invertebrates to mammals. How the negative effects in species (lethal and sublethal) associated with ingestion reverberate to ecosystems, including the possible interactions with aquatic organisms is still poorly understood. Plastic pollution in freshwater ecosystems may be as detrimental as in the ocean (Azevedo-Santos et al., 2021). *Well established*	Pollution does not affect water quantity directly.	In addition to runoff of chemicals from land use or mining, which are sources of water pollution, other sources exist that detrimentally affect water quality. These include air pollution, oil spills, or industrial and human waste water. Trends in these are globally variable, and reflect presence and absence of e.g., air and water treatment facilities (Fowler et al., 2020; Schwarzenbach et al., 2010). *Well established*	Heavy metal pollution or exposure to ozone reduces crop yields notably (Ashmore et al., 2004; Feng & Kobayashi, 2009; Goyal et al., 2020; Simpson et al., 2014; Tai et al., 2021). Plastic production has grown 20-fold in the past 50 years and reached in 2019 reached 368 million metric tons (Walker & Fequet, 2023) Plastic pollution impacts on fish growth is expected to also affect fisheries and bivalves yields (Allen et al., 2022; Nantege et al., 2023; Vázquez-Rowe et al., 2021); microplastics have also found in freshwater, land biota, soils and air (Allen et al., 2022). Nitrogen inflows to coastal waters and associated eutrophication contributes to marine dead zones with associated negative impacts on fisheries in these regions (Caswell et	Pollution can impact crop or animal protein nutritional quality (Edelstein & Ben-Hur, 2018 e.g., heavy metals or microplastics) although most impacts are likely by the direct toxic effects (direct impacts on health). *Inconclusive*	Acid mine discharge and aerosol pollutants associated with mining have been found to be harmful to humans in many studies (Chen et al., 2022; Jiao et al., 2023; Zhuang et al., 2023). The overuse of chemicals in many sectors of human activity is an increasing risk to human health (Naidu et al., 2021). Exposure to pollutants like airborne particulate matter and ozone has been linked for example to higher mortality rates and increased hospital admissions for respiratory and cardiovascular diseases. Exposure to persistent organic pollutants (POPs) may lead to a range of detrimental health effects, including diabetes, obesity, endocrine disruption, cancer, cardiovascular diseases, reproductive disorders, and other adverse impacts on human well-being (Alharbi et al., 2018). *Well established*	There are few studies that focus on the impact of pollution on mental health. These studies focus mostly on air pollution (Cuijpers et al., 2023; King et al., 2022; Q. S. J. Liu et al., 2021; Ventriglio et al., 2021; Zundel et al., 2022) although other forms of impact such as by noise and artificial lights are also being considered (Cao et al., 2023) There is however still a lack of knowledge about the mental health impacts of other pollutants and about the specific mechanisms leading to mental health impacts as well as the long term impacts on the nervous system (Ventriglio et al., 2021). *Established but incomplete*

				al., 2018; Diaz & Rosenberg, 2008) *Well established*			

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