

Transnational corporations and the challenge of biosphere stewardship

Carl Folke^{1,2,3*}, Henrik Österblom², Jean-Baptiste Jouffray^{2,3}, Eric F. Lambin^{4,5,6}, W. Neil Adger⁷, Marten Scheffer⁸, Beatrice I. Crona^{2,3}, Magnus Nyström², Simon A. Levin⁹, Stephen R. Carpenter¹⁰, John M. Anderies^{1,11}, Stuart Chapin III¹², Anne-Sophie Crépin^{1,2}, Alice Dauriach³, Victor Galaz^{1,2,3}, Line J. Gordon², Nils Kautsky¹³, Brian H. Walker¹⁴, James R. Watson^{3,15}, James Wilen¹⁶ and Aart de Zeeuw¹⁷

Sustainability within planetary boundaries requires concerted action by individuals, governments, civil society and private actors. For the private sector, there is concern that the power exercised by transnational corporations generates, and is even central to, global environmental change. Here, we ask under which conditions transnational corporations could either hinder or promote a global shift towards sustainability. We show that a handful of transnational corporations have become a major force shaping the global intertwined system of people and planet. Transnational corporations in agriculture, forestry, seafood, cement, minerals and fossil energy cause environmental impacts and possess the ability to influence critical functions of the biosphere. We review evidence of current practices and identify six observed features of change towards ‘corporate biosphere stewardship’, with significant potential for upscaling. Actions by transnational corporations, if combined with effective public policies and improved governmental regulations, could substantially accelerate sustainability efforts.

Consolidation among corporations, whereby a small number of companies control a large market share of the overall output or sales for a particular product or product type (that is, oligopoly or, at the extreme, monopoly), is a well-known^{1,2} and predictable^{3,4} feature of economic development⁵. Some 10% of the world's corporations generate 80% of all profits globally⁶. A handful of transnational companies (TNCs) in the information technology sector control 90% or more of the global market share of search engines, operating systems and social media⁷. Three investor firms manage over 90% of all assets under management in passive equity funds⁸, and retailers, which form the interface between consumers and global supply chains, also show high levels of concentration^{9,10}. Such dominance is variously explained by increasing share of returns from growth going to capital rather than labour, the ability of TNCs to navigate regulatory systems opportunistically across multiple jurisdictions, and their capacity to create barriers to entry for smaller firms¹¹.

In fact, the scale at which TNCs operate, and the speed and connectivity they galvanize across the world is unprecedented in history¹². TNCs have become a defining feature of the interconnected planet of people and nature¹³, with humans as a hyper-dominant species in the biosphere affecting global patterns of ecological

change^{14,15}. While concerns have been raised about industry dominance in relation to the environment^{16,17}, others argue that inclusion of corporations in international agreements, like the Aichi Biodiversity Targets, could be beneficial for all¹⁸.

Voluntary TNC sustainability commitments are essential and can translate into improvements¹⁹, but so far, many private-sector supply chain initiatives for sustainability fall short on several fronts^{20–23}. Overall, the past two decades of efforts to leverage supply chain power of major TNCs have failed to meet the expectations for improved sustainability^{24,25}. Conversely, government regulations and international agreements have not been able to meet the growing need to regulate the complex dynamics of an intertwined planet²⁶ with human dominance as a major force shaping it^{27,28}. Understanding and acting upon the new dynamics of the Anthropocene is fundamental for human well-being, and TNCs clearly are part of it.

Here, we focus on the link between dominant TNCs and the biosphere and explore whether such dominance can be acted upon to serve as a leverage towards sustainability. We recognize that small and medium-sized enterprises also play a key role, but many such enterprises are either part of TNCs' global supply chains or serve a domestic market only²⁹. Drawing on empirical observations from

¹Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden. ²Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. ³Global Economic Dynamics and the Biosphere Academy Program, Royal Swedish Academy of Sciences, Stockholm, Sweden. ⁴School of Earth, Energy and Environmental Sciences, Stanford University, Stanford, CA, USA. ⁵Woods Institute for the Environment, Stanford University, Stanford, CA, USA. ⁶Georges Lemaître Earth and Climate Research Centre, Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium.

⁷Geography, College of Life and Environmental Science, University of Exeter, Exeter, UK. ⁸Aquatic Ecology and Water Quality, Department of Environmental Sciences, Wageningen University, Wageningen, Netherlands. ⁹Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ, USA.

¹⁰Center for Limnology, University of Wisconsin-Madison, Madison, WI, USA. ¹¹School of Human Evolution and Social Change, School of Sustainability, Arizona State University, Tempe, AZ, USA. ¹²Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, USA. ¹³Department of Ecology, Environment and Plant Sciences, Stockholm University, Stockholm, Sweden. ¹⁴CSIRO Sustainable Ecosystems, Canberra, Australian Capital Territory, Australia. ¹⁵College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA. ¹⁶Department of Agricultural and Resource Economics, University of California, Davis, Davis, CA, USA. ¹⁷Department of Economics, CentER and TSC, Tilburg University, Tilburg, Netherlands.

*e-mail: carl.folke@beijer.kva.se

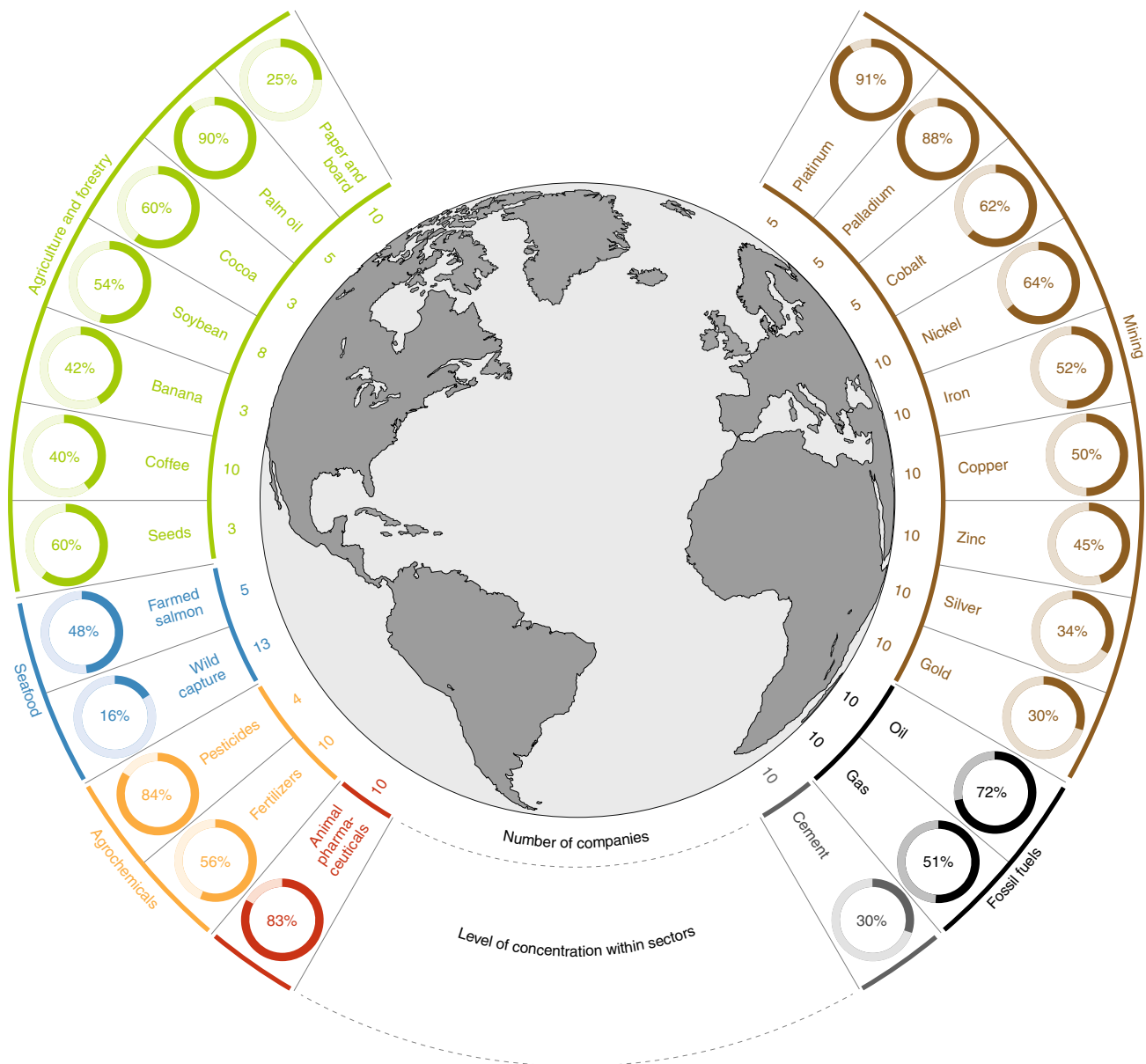


Fig. 1 | The biosphere in the hands of a few. Transnational corporations have become a major force shaping the world's ocean, atmosphere and terrestrial biomes. Based on available data, the figure illustrates estimated levels of concentration for industries shaping the biosphere. Concentration is measured as, for example, proportion of profits or sales, market share, exports, production, trade volumes or access to resource reserves. We use these measures, rather than a consistent economic percentage of sector dominance, to illustrate the disproportionate capacity of TNCs to influence large-scale material flows and processes. The consolidation described here is assumed to be associated with an ability to influence standards, practice and norms in the respective industry in relation to the capacity to shape the biosphere. See Tables 1 and 2 for details on each estimate, source material and a synthesis of industry-related environmental impacts.

diverse sectors, we identify six features at the interface of science–business–society that are stimulating systemic change towards sustainability. Together with effective policies and regulations, these features may provide building blocks for shifting dominance towards biosphere stewardship and a safe operating environmental space for humanity³⁰.

Shaping the biosphere

A handful of TNCs have a major direct or indirect influence on the world's ocean, the global atmosphere and terrestrial biomes, system components that serve critical functions in Earth's dynamics (Fig. 1 and Table 1). TNCs dominate harvesting of the largest and most

valuable fish stocks, including species with important functions in ocean ecosystems³¹. The same is true for the world's forest capacity to regulate Earth's climate³². About 70% of greenhouse gas emissions are attributed to 100 companies, including both TNCs and state-owned monopolies producing coal, oil and gas³³. These companies disproportionately influence climate change and ocean acidification. Sectors that generate contaminated effluents, with impact on ecosystems and biodiversity, show similar dominance (Table 1).

TNCs have also become central in the development of the global food system, a major driver of environmental change, through simplification of landscapes, loss of biodiversity, release of greenhouse gas emissions, and alteration of biogeochemical and freshwater

cycles^{34,35} (Table 1). Following recent mergers and acquisitions, the fertilizers market, the global agrochemical industry and the commercial crop seed market are dominated by ten, four and three TNCs, respectively. The same is true for ten corporations engaged in animal pharmaceuticals (Fig. 1). The observed levels of consolidation in the food system are also striking for individual commodities such as coffee, banana, cocoa, soy, palm oil or farmed salmon (Fig. 1 and Table 2). Mega-merger trends continue to drive consolidation vertically and horizontally within and across sectors, borders, systems and the land–ocean interface^{36,37}, with dominant companies being often interlinked and interdependent.

Clearly, TNCs are central actors in the human-dominated world and possess the ability to influence critical functions of the biosphere. This global keystone actor dimension of TNCs³¹, whether producers, suppliers or financial actors, should be recognized, accounted for and governed in efforts towards sustainability within planetary boundaries^{38,39}.

TNCs and sustainability

Reality presents us with dominance⁴⁰ and the environmental time window for transforming human actions towards sustainability is shrinking²⁸. In this context, could the power of dominant TNCs help leverage large-scale systemic change⁴¹, accelerate positive transformations towards sustainability⁴² and contribute to a safe operating environmental space for humanity³⁰?

In the face of insufficient environmental agreements and regulations, dominance poses a threat to sustainability. For instance, companies able to set barriers to entry in a sector can stifle sustainable practices and technological innovation in general. They can also impose low prices on suppliers, which reduces suppliers' capacity to diversify and can force them into monocultural practices (particularly in the agricultural sector). Finally, TNCs often lobby regulators to weaken environmental and social standards to the benefit of their own businesses^{43–45}.

More generally, there exists scepticism towards businesses as sustainability leaders given two decades of relative ineffectiveness of voluntary corporate social responsibility^{25,46}. Market concentration and corporate power are often regarded as roadblocks to social progress given the business priority of economic profit over non-market values²⁴. Concerns have also been raised about viewing business as the solution to the problems they themselves took part in creating²⁴. Also, emerging TNC sustainability initiatives have been questioned as they do not challenge the underlying imperative of business growth⁴⁷.

On the other hand, should dominant TNCs impose effective sustainability standards throughout their supply chain, this could influence both upstream and downstream market actors, including small and medium enterprises. This was the case when the world's largest retailer committed to certified seafood, which is thought to have catalysed other retailers and triggered a rapid increase in certification⁴⁸. Hence, as dominant actors impose sustainability measures, behavioural changes may propagate throughout global markets. Over the past two decades, 250 to 300 pioneering companies have actively invested for sustainable development, followed by several thousand other companies integrating sustainability considerations in their business⁴⁹.

Reputational risk management represents an important part of corporate strategy, particularly for large household-facing brands that are vulnerable to naming-and-shaming campaigns^{16,50}. Such exposure helped realize the corporate sector soy moratorium, which contributed to reduced deforestation in the Brazilian Amazon⁵¹. The World Wildlife Fund has consequently worked to influence companies with the greatest impacts on commodity demand, with the aim of shifting entire markets towards corporate stewardship of biodiversity, water and climate, and reducing the impact from commodity production on key areas of importance for global conservation⁵².

However, TNC leadership is unlikely to be sufficient unless governments also provide a regulatory context that safeguards non-market ecological and social values. Antitrust law and institutions have a central role to play in regulating dominance and keeping markets competitive, but they are ill suited to address concerns associated with public governance of goals like environmental sustainability or with the political power of large corporations^{53,54}. Importantly, the delineation between public governance and large corporations is increasingly blurred⁵⁵. Private governance is rapidly emerging in a range of biosphere-related sectors^{56,57}, where TNCs play a big role in shaping their own regulatory space⁵⁸ including how sustainability is defined and enacted. Concerns have been raised over such increasing influence, particularly with respect to accountability, fair representation and global equity¹⁶. In this context, major changes in the strategy and practice of TNCs are needed to help shift power away from being exercised to the detriment of sustainable use of the biosphere²⁴.

Towards corporate biosphere stewardship

Are we starting to observe the beginnings of such a shift? Action is urgently needed to stabilize the Earth system within conditions favourable for humanity²⁸ and rising awareness of the dependence of the global economy on the biosphere foundation³⁹ is creating incentives for rapid innovation in business strategy and practice⁶⁰. Although the primary goal of TNCs is not to produce for the common good, different incentives have led some progressive companies to increasingly engage in substantive sustainability efforts^{16,56}.

We call attention to six observed and emerging features of systemic change in the public–private policy interface towards biosphere stewardship. The six features reflect the engagement of large TNCs in major change processes and illustrate how public and private environmental governance regimes could enhance each other since they rarely operate independently²⁰. Examples include TNCs active in biosphere-related sectors (Fig. 1 and Tables 1 and 2) as well as in other sectors from which inspiration could be drawn.

Alignment of vision. Mindsets and values across society are now changing, recognizing that global environmental change concerns the viability of humanity's own future. There is mounting evidence that new norms are emerging among some of the largest brands¹⁶ and corporate initiatives are achieving intensity reductions of greenhouse gas emissions⁵⁶. Fifty-two per cent of a sample of some 450 companies in the food, wood-products and textile sectors that are listed on the 12 largest OECD (Organisation for Economic Co-operation and Development) stock exchanges, use at least one sustainable-sourcing practice⁴⁶. The most progressive CEOs of TNCs often represent role models for entire sectors and play a disproportionately large role in challenging established norms and developing new visions. They also serve to inspire a generation of new sustainability-minded entrepreneurs. In parallel, pressure by non-governmental organizations, consumers and investors lead to more socially and environmentally responsible firms. Broadening the value base from profit only to responsibility, ethics, and creating meaning and purpose is a sign among large TNCs of a potential shift from compliance to conviction with the ambition to become a positive force in sustainability transitions⁶¹. The United Nations (UN) Global Compact (a voluntary initiative of CEO commitments to implement universal sustainability principles and to take steps to support UN goals), and the World Business Council for Sustainable Development, serve as learning arenas for directing business practices towards sustainability and for generating ecologically coherent innovations for biosphere stewardship.

Mainstreaming sustainability. Society needs guiding frameworks to define a problem space, within which innovation can flourish to find sound solutions. Global political agreements like the Sustainable

Table 1 | Global estimates of degree of concentration for industries directly and indirectly impacting the biosphere

Sector	Concentration	Environmental impacts	References
Agrochemicals	Four companies control 84% of the pesticides market and 10 companies account for 56% of the fertilizers market (2014) ^{a,9}	Agrochemicals have been linked to environmental hazards, including global warming, surface and groundwater contamination, marine eutrophication, and stratospheric ozone depletion. Insecticides and fungicides have negative effects on biodiversity and can give rise to pesticide-resistant organisms. Toxic waste is generated during phosphate fertilizer mining and production. Nutrient runoff from agriculture leads to water pollution, algal blooms and biodiversity loss. The increase in reactive nitrogen leads to the production of tropospheric ozone and aerosols, and to the acidification of freshwater. The energy cost of producing and transporting fertilizers is high.	81–86
Animal pharmaceuticals	Ten firms account for 83% of the global market (2014) ⁹	The staggering use of antibiotics in food production in both terrestrial and marine environments is approaching grave limits and antimicrobial resistance is becoming a serious issue in relation to human health. Veterinary medicines can also affect terrestrial and aquatic systems. For instance, carcasses of livestock that were medicated with a non-steroidal anti-inflammatory drug were found to be toxic to raptors.	84,87–89
Commercial seeds	Three companies control 60% of the commercial crop seeds market (2014) ^{a,9}	Patented seeds undermine local practices to select, produce and exchange a variety of locally appropriate seeds. Such standardization of the food supply decreases species diversity at the global level and thus reduces the resilience of the food system.	90–92
Mining	Five companies account for 91%, 88% and 62% of the world's platinum, palladium and cobalt production, respectively. Ten companies produce 64% of nickel, 52% of iron, 50% of copper, 45% of zinc, 34% of silver and 30% of gold global production (2015–2017) ^{93–98}	Effects of the mining industry include habitat destruction, air pollution through the release of unrefined particles when mineral deposits are exposed from the site, loss of biodiversity, soil erosion, land subsidence, formation of sink holes, water and soil contamination caused by leakage of chemicals or trace metals, as well as noise pollution, air blasts and vibration from blasting. The disposal of extensive mine wastes further contributes to air, soil and water contamination with consequences on local communities, livestock and wildlife biodiversity.	99–101
Fossil fuels	Ten companies control 72% and 51% of the world's proved reserves of oil and gas, respectively (2014) ¹⁰²	Fossil fuels are the largest source of anthropogenic emissions of carbon dioxide (CO ₂), heavily contributing to climate change and its consequences on biodiversity. Fossil fuel extraction leads to deforestation, ecosystem destruction and chemical contamination of land and water. Oil spills negatively impact both terrestrial and marine ecosystems. The refining process results in toxic air and water emissions, and hazardous waste. The combustion of fossil fuels also creates air pollution.	103,104
Cement	Ten companies produce over 30% of the world's cement (2017) ¹⁰⁵	With about 8% of global CO ₂ emissions, cement is the second-largest single industrial CO ₂ emitter in the world. Its production requires a great amount of energy (fossil fuels), produces greenhouse gas emissions and releases air pollutants such as mercury, sulfur oxides and nitrogen oxides.	106,107
Forestry	Ten companies account for 25% of the total paper and board production (2015) ^{108,109}	Different forms of forest management have different impacts on climate and biodiversity integrity, two critical features of biosphere stability. Forest management that does not account for changing climate is risking large tracts of forests burning, releasing large amounts of CO ₂ into the atmosphere in pulses and losing large carbon storage capacity for decades to come. Such effects may cause detrimental climate impacts. Plantations can lead to habitat conversion, deforestation, soil erosion, altered water cycles and pollution from agrochemicals. Pulp and paper manufacturing is also one of many industrial sources of emissions of sulfur and nitrogen oxides.	110–113
Seafood	Thirteen companies control 11–16% of the global marine catch and 19–40% of the largest and most valuable stocks (2012) ³¹	Overfishing can provoke the collapse of wild fish stocks and associated marine ecosystems. Fishing causes bycatch and habitat destruction. The reliance of the aquaculture sector on marine ingredients for feeds further increases pressure on wild stocks. The growing use of antimicrobials in aquaculture generates antimicrobial resistance.	31,89,114–116

Sectors exhibit different levels of consolidation, measured as for example, proportion of profits or sales, market share, production, trade volumes or access to resource reserves. Values are based on best available data from the referenced material. ^a2014 figures were used to compute market share but taking into consideration mergers and acquisitions that happened later in 2017.

Development Goals (SDGs) or the Convention on Biological Diversity are examples of normative frameworks that are defined by science but can be magnified by engaging with corporations¹⁸.

In 2017, four in ten of the world's largest companies engaged with the SDGs in their corporate reporting⁶²; in a sample from 2018, more than 70% of some 730 global companies mentioned the SDGs

Table 2 | Global estimates of degree of concentration for various commodities directly and indirectly impacting the biosphere

Commodity	Concentration	Environmental impacts	References
Palm oil	Five companies account for approximately 90% of global palm oil trade (2015) ¹¹⁷	The clearing of land and forest to allow for palm oil production has severe environmental consequences associated with deforestation, habitat degradation and climate change. Monocrop plantations have been mostly created at the expense of biodiversity-rich primary tropical forests. Soil erosion and water pollution from palm oil mill effluent represent further issues.	111,118,119
Cocoa	Three companies control around 60% of the world's cocoa grindings (2013) ¹²⁰	Intensive cocoa plantations negatively impact biodiversity through the conversion of natural forest areas, use of chemicals and forest degradation even in agroforestry systems. The processing of cocoa beans also results in organic waste.	111,121
Soybean	Eight companies control at least 54% of the processing or exports of soybeans (2011/2015/2016) ^{a,90,122,123}	Soybean production is highly dependent on inputs such as fertilizers, pesticides, fuels and land. Forest conversion and the destruction of wild habitats (mostly outside of the United States and Europe) in favour of plantations lead to biodiversity loss.	111,124,125
Salmon	Five companies account for 48% of global farmed Atlantic salmon (<i>Salmo salar</i>) production (2017) ¹²⁶	Environmental impacts of salmon aquaculture include competition and genetic introgression of escaped farmed salmon into wild populations; local and regional pollution from chemical inputs, organic loads and nutrients; sea lice (<i>Lepeophtheirus salmonis</i>) and disease transfer from farmed salmon to wild populations; pressure on wild fisheries for feeds; and antimicrobial resistance.	111,127
Banana	Three companies control 42% of global banana exports (2013) ¹²⁸	Large-scale commercial production of bananas leads to conversion of natural forest areas to plantations, soil erosion, high pesticide use, and pollution of soil and water. Banana production also results in organic and plastic waste. Banana processing (washing and selecting) uses large quantities of water.	111,129
Coffee	Ten companies process almost 40% of all the coffee consumed worldwide (2012–2013) ¹³⁰	Conversion of natural forest areas to full-sun coffee plantations causes biodiversity loss and soil degradation, notably due to the high use of pesticides and herbicides. Coffee processing also has negative impacts on water quality in rivers.	111,121,131,132

Sectors exhibit different levels of consolidation, measured as for example, proportion of profits or sales, market share, exports, production or trade volumes. Values are based on best available data from the referenced material. ^aUnited States data: 2011. Brazil data: 2015. Argentina data: 2016. Country shares data: 2015/2016.

and 27% included them in their business strategy⁶³. The UN 2015 report *Transforming Our World: The 2030 Agenda for Sustainable Development* encourages partnerships between governments, civil society and the private sector to mobilize action and resources for global sustainability⁶⁴. Creating incentives (for example, through regulations and market initiatives) for companies to enable such transformative change represents a promising approach to rapidly scale up sustainability successes^{16,48}. Sustainability is no longer perceived as a choice for progressive companies — it has become institutionalized and increasingly recognized as a necessity.

Licence to operate. Transformative change towards biosphere stewardship can be facilitated by clarifications of a corporate global licence to operate in a democratic, ethical and sustainable manner. Governments increasingly mobilize to regulate TNCs in this direction⁵⁸. For example, the United Kingdom's Modern Slavery Act requires companies to disclose measures adopted to address slavery and human trafficking. The French Corporate Duty of Vigilance Law (adopted in 2017) created a legal requirement for large companies to identify and prevent abuses on human rights and the environment related to their activities and those of their subsidiaries, subcontractors and suppliers applied to entire global supply chains²⁰. This law concerns TNCs with at least 5,000 employees in France or 10,000 employees worldwide. Large TNCs are predominately headquartered in the United States, China, the United Kingdom, Japan, France and Germany. Alignment of direct national transparency regulations from these countries could effectively equate to a 'corporate global licence to operate' and further stimulate TNCs to take on a leadership role before regulations are in place.

Financing transformations. Sustainability concerns are gaining attention from the financial sector⁶⁵. Major pension funds and other institutional investors are starting to redirect capital away from unsustainable practices and towards biosphere stewardship. The UN Global Compact Action Platform for the Ocean aims to develop a business leadership framework to promote the well-being of the world's ocean. This platform supports a wide membership of large TNCs from fisheries, aquafeeds, mining and the finance sectors, including a major Nordic Government pension fund which, for instance, recently divested from companies involved in unsustainable palm oil production. Another example is the Impact Management Project that involves large financial actors to develop and facilitate consensus around shared fundamentals for how impact is measured and managed, to contribute to sustainable development. The Equator Principles, established in 2003, and Principles for Responsible Investment, founded in 2005, provide guidance for responsible investment⁶⁶. Such coalitions, combined with recent high-level statements and strategies from individual major financial actors (for example, banks, insurance providers and pension funds) represent important starting points. Similarly, recent moves in the United Kingdom towards making environment, society and governance considerations mandatory parts of fiduciary duty, represent another indication that change is accelerating⁶⁷. However, many of these efforts are still in their infancy and their impacts on the ground remain unclear. Ultimately, for transformative change to happen, investors and traditional financial services will need to systematically incorporate sustainability criteria into their practices and develop new norms in service of biosphere stewardship⁶⁵.

Radical transparency. Novel technologies are dramatically enhancing transparency within and among TNCs, as well as throughout supply chains that are central to the operation of TNCs⁶⁸. For example, open access database platforms with information on all fishing vessels carrying an Automatic Identification System (AIS), along with smart algorithms to identify vessel behaviour, have radically improved global monitoring of fisheries⁶⁹. Similarly, complex global trade flows are becoming increasingly traceable and transparent thanks to novel technologies (www.trase.earth). The CDP Supply Chain programme, which assesses the climate, water and deforestation impacts of the supply chains of large corporate purchasers, has in 10 years grown to 115 major organizations with over 5,500 top-tier global suppliers engaged. These large public and private sector organizations can lead effective change by using their substantial procurement expenditures as a powerful lever for action towards biosphere stewardship, cascading good practices and commitments further down the supply chain (<https://www.cdp.net/en/research/global-reports/global-supply-chain-report-2019>). By embracing and promoting such transparency, TNCs can minimize risks in their supply chains and contribute to system-wide stewardship norms, while ensuring corporate accountability. If dominant actors engage in radical transparency, they will stimulate other companies to follow their lead. A few very large TNCs have recently adopted B Corps certification and have thereby committed to independent assessments of their social and environmental performance, accountability and transparency (www.bcorporation.net). Such commitment could ensure that the global licence to operate is maintained and would further stimulate enforcement and monitoring of less transparent companies.

Evidence-based knowledge for action. Scientists, as knowledge brokers, increasingly facilitate and monitor transformative change by connecting evidence-based knowledge to action through dialogue and collaboration^{70–72}. The scientific community can independently investigate and define the problems using rigorous methods, while also engaging in co-production of knowledge with TNCs to ensure that co-designed solutions address the problems, operate in line with the SDGs, and make business sense⁷³. Such action arenas represent an increasingly important space for scientists to engage with in order to address global challenges while helping hold corporations accountable and stimulating them to take on a larger responsibility for the planet and develop leadership in sustainability⁷⁴. For instance, the science-based organization Seafood Business for Ocean Stewardship (SeaBOS, www.keystonedialogues.earth) was collaboratively developed by scientists and the largest TNCs in the seafood industry with the ambition to stimulate transformative change towards sustainability and stewardship of the ocean⁷⁵. Such science–business engagement will become increasingly important to ensure that companies' sustainability agendas are framed by science rather than the private sector alone⁷⁵.

Conclusion

Global economic development has generated prosperity but also inequality, at the expense of the environment^{76–78}. Now, within this globalized context, a rising awareness of the finite capacity of the planet creates prospects for change. The global dominance of TNCs is a reality of the Anthropocene, when transformative change is urgently needed. Pioneering companies are learning to persist in their strategies by adapting and innovating in their core businesses, while shaping new strategies and business models that are better fit for the future. Drawing on the six emerging features, and with the intent to help leverage change towards just and sustainable futures, we propose expanding the focus from 'corporate social responsibility' to 'corporate biosphere stewardship'. Stewardship is about caring for, looking after and cultivating a sense of belonging^{79,80}. It incorporates both social and environmental dimensions.

Corporate Biosphere Stewardship involves shifting excessive, wasteful and imbalanced consumption founded on a fossil-fuel-driven economy into a renewable-energy-based economy of low waste and circularity within a broader value foundation beyond profit alone. Furthermore, corporate biosphere stewardship explicitly acknowledges that people, nations and the global economy are intertwined with the biosphere and a global force in shaping its dynamics¹⁵. Corporate biosphere stewardship provides a new business logic with the purpose of shepherding and safeguarding the resilience of the biosphere for human well-being. Combined with effective public policies and improved governmental regulations, this new purpose presents unprecedented opportunities and novel pathways for social innovations towards sustainable futures. The jury is out there, whether or not dominant TNCs will become a major force in driving such systemic transformation.

Received: 24 March 2019; Accepted: 6 August 2019;

Published online: 16 September 2019

References

- Sheth, J. & Sisodia, R. *The Rule of Three: Surviving and Thriving in Competitive Markets* (Simon and Schuster, 2002).
- Jacquet, J., Frank, D. & Schlottmann, C. Asymmetrical contributions to the tragedy of the commons and some implications for conservation. *Sustainability* **5**, 1036–1048 (2013).
- Axtell, R. L. Zipf distribution of US firm sizes. *Science* **293**, 1818–1820 (2001).
- Glattfelder, J. B. & Battiston, S. The architecture of power: patterns of disruption and stability in the global ownership network. SSRN <https://doi.org/10.2139/ssrn.3314648> (2019).
- Gereffi, G. Global value chains in a post-Washington consensus world. *Rev. Int. Polit. Econ.* **21**, 9–37 (2014).
- The rise of the superstars. *The Economist* (15 September 2016).
- Search Engines, Operating Systems and Social Media* (Statcounter GlobalStats, accessed 26 February 2019); <http://gs.statcounter.com/>
- Fichtner, J., Heemskerk, E. M. & Garcia-Bernardo, J. Hidden power of the Big Three? passive index funds, re-concentration of corporate ownership, and new financial risk. *Bus. Polit.* **19**, 298–326 (2017).
- Too Big to Feed: Exploring the Impacts of Mega-mergers, Consolidation, and Concentration of Power in the Agri-food Sector* (International Panel of Experts on Sustainable Food Systems, 2017).
- Global Powers of Retailing* (Deloitte, 2019).
- Stiglitz, J. E. *Globalization and its Discontents* (New York Norton, 2002).
- Vitali, S., Glattfelder, J. B. & Battiston, S. The network of global corporate control. *PLoS ONE* **6**, e25995 (2011).
- Folke, C. et al. Reconnecting to the biosphere. *Ambio* **40**, 719–738 (2011).
- Worm, B. & Paine, R. T. Humans as a hyperkeystone species. *Trends Ecol. Evol.* **21**, 137–93 (2016).
- Williams, M. et al. The Anthropocene biosphere. *Anthr. Rev.* **2**, 196–219 (2015).
- Dauvergne, P. & Lister, J. Big brand sustainability: governance prospects and environmental limits. *Glob. Environ. Change* **22**, 36–45 (2012).
- Clapp, J. Mega-mergers on the menu: corporate concentration and the politics of sustainability in the global food system. *Glob. Environ. Polit.* **18**, 12–33 (2018).
- Barbier, E. B., Burgess, J. C. & Dean, T. J. How to pay for saving biodiversity. *Science* **360**, 486–488 (2018).
- Potoski, M. & Prakash, A. Green clubs and voluntary governance: ISO 14001 and firms' regulatory compliance. *Am. J. Polit. Sci.* **49**, 235–248 (2005).
- Lambin, E. F. & Thorlakson, T. Sustainability standards: interactions between private actors, civil society, and governments. *Annu. Rev. Environ. Resour.* **43**, 369–393 (2018).
- Potoski, M. & Prakash, A. Green clubs: collective action and voluntary environmental programs. *Annu. Rev. Polit. Sci.* **16**, 399–419 (2013).
- Berliner, D. & Prakash, A. "Bluewashing" the firm? voluntary regulations, program design, and member compliance with the United Nations Global Compact. *Policy Stud. J.* **43**, 115–138 (2015).
- Brad, A. et al. *The False Promise of Certification* (Changing Markets Foundation, 2018).
- Dauvergne, P. *Will Big Business Destroy Our Planet* (Polity, 2018).
- Lister, J. The policy role of corporate carbon management: co-regulating ecological effectiveness. *Glob. Policy* **9**, 538–548 (2018).
- Walker, B. et al. Looming global-scale failures and missing institutions. *Science* **325**, 1345–1346 (2009).

27. Vitousek, P. M., Mooney, H. A., Lubchenco, J. & Melillo, J. M. Human domination of Earth's ecosystems. *Science* **277**, 494–499 (1997).
28. Steffen, W. et al. Trajectories of the Earth System in the Anthropocene. *Proc. Natl Acad. Sci. USA* **115**, 8252–8259 (2018).
29. Crona, B. I., Van Holt, T., Petersson, M., Daw, T. M. & Buchary, E. Using social-ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Glob. Environ. Change* **35**, 162–175 (2015).
30. Rockström, J. et al. A safe operating space for humanity. *Nature* **461**, 472–475 (2009).
31. Österblom, H. et al. Transnational corporations as 'keystone actors' in marine ecosystems. *PLoS ONE* **10**, e0127533 (2015).
32. Galaz, V., Crona, B., Dauriach, A., Scholtens, B. & Steffen, W. Finance and the Earth system: exploring the links between financial actors and non-linear changes in the climate system. *Glob. Environ. Change* **53**, 296–302 (2018).
33. Griffin, P. & Heede, C. D. P. R. *The Carbon Majors Database* (CDP, 2017).
34. Clapp, J. & Scrinis, G. Big food, nutritionism, and corporate power. *Globalizations* **14**, 578–595 (2017).
35. Poore, J. & Nemecek, T. Reducing food's environmental impacts through producers and consumers. *Science* **360**, 987–992 (2018).
36. Beladi, H., Chakrabarti, A. & Marjit, S. Cross-border mergers in vertically related industries. *Eur. Econ. Rev.* **59**, 97–108 (2013).
37. Gomes-Casseres, B. What the big mergers of 2017 tell us about 2018. *Harvard Business Review* (28 December 2017).
38. Galaz, V. et al. Global governance dimensions of globally networked risks: the state of the art in social science research. *RHCPP* **8**, 4–27 (2017).
39. Sjöfjell, B. Redefining the corporation for a sustainable new economy. *J. Law Soc.* **45**, 29–45 (2018).
40. Scheffer, M., van Bavel, B., van de Leemput, I. A. & van Nes, E. H. Inequality in nature and society. *Proc. Natl Acad. Sci. USA* **114**, 13154–13157 (2017).
41. Abson, D. J. et al. Leverage points for sustainability transformation. *Ambio* **46**, 30–39 (2017).
42. Westley, F. et al. Tipping toward sustainability: emerging pathways of transformation. *Ambio* **40**, 762–780 (2011).
43. Clapp, J. & Fuchs, D. A. *Corporate Power in Global Agrifood Governance* (MIT Press, 2009).
44. Murphy, S., Burch, D. & Clapp, J. *Cereal Secrets: The World's Largest Grain Traders and Global Agriculture* (Oxfam Research Reports, 2012).
45. Oreskes, N. & Conway, E. M. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Tobacco Smoke to Global Warming* (Bloomsbury, 2011).
46. Thorlakson, T., de Zegher, J. F. & Lambin, E. F. Companies' contribution to sustainability through global supply chains. *Proc. Natl Acad. Sci. USA* **115**, 2072–2077 (2018).
47. Wright, C. & Nyberg, D. *Climate Change, Capitalism, and Corporations* (Cambridge Univ. Press, 2015).
48. Lubchenco, J., Cerny-Chipman, E. B., Reimer, J. N. & Levin, S. A. The right incentives enable ocean sustainability successes and provide hope for the future. *Proc. Natl Acad. Sci. USA* **113**, 14507–14514 (2016).
49. Nelson, J. *Partnerships for Sustainable Development: Collective Action by Business, Governments and Civil Society to Achieve Scale and Transform Markets* (Business and Sustainable Development Commission, Corporate Responsibility Initiative, Harvard Kennedy School, 2017).
50. Jacquet, J. *Is Shame Necessary? New Uses for an Old Tool* (Vintage, 2016).
51. Gibbs, H. K. et al. Brazil's soy moratorium. *Science* **347**, 377–378 (2015).
52. *Market Transformation Initiative Fact Sheet* (WWF, 2015); http://awsassets.panda.org/downloads/how_wwf_market_transformation_works.pdf
53. Shapiro, C. Antitrust in a time of populism. *Int. J. Ind. Organ.* **61**, 714–748 (2018).
54. Scott, I. Antitrust and socially responsible collaboration: a chilling combination. *Am. Bus. Law J.* **53**, 97–144 (2016).
55. Vogel, D. The private regulation of global corporate conduct: achievements and limitations. *Bus. Soc.* **49**, 68–87 (2010).
56. Vandenbergh, M. P. & Gilligan, J. M. *Beyond Politics: The Private Governance Response to Climate Change* (Cambridge Univ. Press, 2017).
57. Auld, G., Renckens, S. & Cashore, B. Transnational private governance between the logics of empowerment and control. *Regul. Gov.* **9**, 108–124 (2015).
58. De Jonge, A. & Tomic, R. *Research Handbook on Transnational Corporations* (Edward Elgar, 2017).
59. Folke, C. et al. Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* **21**, art41 (2016).
60. Geels, F. W., Sovacool, B. K., Schwanen, T. & Sorrell, S. Sociotechnical transitions for deep decarbonisation. *Science* **357**, 1242–1244 (2017).
61. Sukhdev, P. *Corporation 2020: Transforming Business for Tomorrow's World* (Island, 2012).
62. Blasco, J. L. & King, A. *The KPMG Survey of Corporate Responsibility Reporting 2017* (KPMG, 2017).
63. Scott, L. & McGill, A. *From promise to reality: Does business really care about the SDGs?* (PwC, 2018).
64. *Transforming Our World: The 2030 Agenda for Sustainable Development* (United Nations, 2015).
65. Jouffray, J.-B., Crona, B., Wassénus, E., Bebbington, J. & Scholtens, B. Leverage points in the financial sector for seafood sustainability. *Sci. Adv.* (in the press).
66. Scholtens, B. & Dam, L. Banking on the equator: are banks that adopted the equator principles different from non-adopters? *World Dev.* **35**, 1307–1328 (2007).
67. *Fiduciary Duty in the 21st Century: UK Roadmap* (UNPRI, 2016).
68. Gardner, T. A. et al. Transparency and sustainability in global commodity supply chains. *World Dev.* **121**, 163–177 (2019).
69. Dunn, D. C. et al. Empowering high seas governance with satellite vessel tracking data. *Fish. Fish.* **19**, 729–739 (2018).
70. Kristjansson, P. et al. Linking international agricultural research knowledge with action for sustainable development. *Proc. Natl Acad. Sci. USA* **106**, 5047–5052 (2009).
71. Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P. & Spierenburg, M. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio* **43**, 579–591 (2014).
72. Cvitanovic, C., McDonald, J. & Hobday, A. J. From science to action: principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making. *J. Environ. Manage.* **183**, 864–874 (2016).
73. Österblom, H., Jouffray, J.-B., Folke, C. & Rockström, J. Emergence of a global science–business initiative for ocean stewardship. *Proc. Natl Acad. Sci. USA* **114**, 9038–9043 (2017).
74. Lubchenco, J. & Gaines, S. D. A new narrative for the ocean. *Science* **364**, 911 (2019).
75. Dauvergne, P. & Lister, J. *Eco-Business: A Big-Brand Takeover of Sustainability* (MIT Press, 2013).
76. Raudsepp-Hearne, C. et al. Untangling the environmentalist's paradox: why is human well-being increasing as ecosystem services degrade? *Bioscience* **60**, 576–589 (2010).
77. Hamann, M. et al. Inequality and the biosphere. *Annu. Rev. Environ. Resour.* **43**, 61–83 (2018).
78. Kaplinsky, R. *Globalization, Poverty and Inequality* (Polity, 2005).
79. Chapin, F. S. III et al. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends Ecol. Evol.* **25**, 241–249 (2010).
80. Enqvist, J. P. et al. Stewardship as a boundary object for sustainability research: linking care, knowledge and agency. *Landsc. Urban Plan.* **179**, 17–37 (2018).
81. Mateo-Sagasta, J., Zadeh, S. M. & Turral, H. *More People, More Food, Worse Water? A Global Review of Water Pollution from Agriculture* (FAO, 2018).
82. Crews, T. E. & Peoples, M. B. Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. *Agric. Ecosyst. Environ.* **102**, 279–297 (2004).
83. Bünemann, E. K., Schwenke, G. D. & Van Zwieten, L. Impact of agricultural inputs on soil organisms: review. *Soil Res.* **44**, 379–406 (2006).
84. Jørgensen, P. S. et al. Antibiotic and pesticide susceptibility and the Anthropocene operating space. *Nat. Sustain.* **1**, 632–641 (2018).
85. Cordell, D., Turner, A. & Chong, J. The hidden cost of phosphate fertilizers: mapping multi-stakeholder supply chain risks and impacts from mine to fork. *Glob. Change Peace Secur.* **27**, 323–343 (2015).
86. Bennett, E. M., Carpenter, S. R. & Caraco, N. F. Human impact on erodible phosphorus and eutrophication: a global perspective. *Bioscience* **51**, 227–234 (2001).
87. Arnold, K. E., Brown, A. R., Ankley, G. T. & Sumpter, J. P. Medicating the environment: assessing risks of pharmaceuticals to wildlife and ecosystems. *Proc. R. Soc. B* **369**, (2014).
88. Boxall, A. B. A., Kolpin, D. W., Halling-Sørensen, B. & Tolls, J. Are veterinary medicines causing environmental risks? *Environ. Sci. Technol.* **37**, 286A–294A (2003).
89. Henriksson, P. J. G. et al. Unpacking factors influencing antimicrobial use in global aquaculture and their implication for management: a review from a systems perspective. *Sustain. Sci.* **13**, 1105–1120 (2018).
90. Hendrickson, M. K. Resilience in a concentrated and consolidated food system. *J. Environ. Stud. Sci.* **5**, 418–431 (2015).
91. Perry, E. D., Ciliberto, F., Hennessy, D. A. & Moschini, G. Genetically engineered crops and pesticide use in US maize and soybeans. *Sci. Adv.* **2**, e1600850 (2016).
92. *Agriculture at a Crossroads: Synthesis Report* (International Assessment of Agricultural Knowledge, 2009).
93. *Annual Report 2017: Investing in Sustainable Development* (Nornickel, 2017).
94. *Annual Report 2016: Advancing Transformational Change* (Nornickel, 2016).
95. Bell, T. The World's Top 10 Silver Producers. *The Balance* <https://www.thebalance.com/the-10-biggest-silver-producers-2340234> (accessed 26 February 2019).

96. Bell, T. The World's Biggest Zinc Producers. *The Balance* <https://www.thebalance.com/the-10-biggest-zinc-producers-2013-2339743> (accessed 26 February 2019).
97. Els, F. *The world's top 10 largest gold mining companies – 2017*. Mining.com <http://www.mining.com/worlds-top-10-largest-gold-mining-companies-2017/> (accessed 26 February 2019).
98. Top 10 Iron ore producers based on 2015 guidance. Mining Global <https://www.miningglobal.com/mining-sites/top-10-iron-ore-producers-based-2015-guidance> (4 June 2015).
99. Sonter, L. J., Ali, S. H. & Watson, J. E. M. Mining and biodiversity: key issues and research needs in conservation science. *Proc. R. Soc. B* **285**, (2018).
100. Dudka, S. & Adriano, D. C. Environmental impacts of metal ore mining and processing: a review. *J. Environ. Qual.* **26**, 590–602 (1997).
101. Sengupta, M. *Environmental Impacts of Mining Monitoring, Restoration, and Control* (CRC, 1993).
102. *Putting Earnings into Perspective. Facts for Addressing Energy Policy* (American Petroleum Institute, 2016).
103. O'Rourke, D. & Connolly, S. Just oil? The distribution of environmental and social impacts of oil production and consumption. *Annu. Rev. Environ. Resour.* **28**, 587–617 (2003).
104. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **15**, 365–377 (2012).
105. Edwards, P. Global Cement Top 100 Report 2017–2018. *Global Cement Magazine* (4 December 2017).
106. Uwasu, M., Hara, K. & Yabar, H. World cement production and environmental implications. *Environ. Dev.* **10**, 36–47 (2014).
107. Worrell, E., Price, L., Martin, N., Hendriks, C. & Meida, L. O. Carbon dioxide emissions from the global cement industry. *Annu. Rev. Energy Environ.* **26**, 303–329 (2001).
108. Rushton, M. & Rodden, G. *The Pulp and Paper International Top 100 Paper 360* (Pulp and Paper International, 2016).
109. *Facts about Paper 2018* (Verband Deutscher Papierfabriken e.V., 2018).
110. Chaudhary, A., Burivalova, Z., Koh, L. P. & Hellweg, S. Impact of forest management on species richness: global meta-analysis and economic trade-offs. *Sci. Rep.* **6**, 23954 (2016).
111. Clay, J. *World Agriculture and the Environment: a Commodity-by-Commodity Guide to Impacts and Practices* (Island, 2013).
112. Astrup, R., Bernier, P. Y., Genet, H., Lutz, D. A. & Bright, R. M. A sensible climate solution for the boreal forest. *Nat. Clim. Change* **8**, 11–12 (2018).
113. Rogers, B. M., Soja, A. J., Goulden, M. L. & Randerson, J. T. Influence of tree species on continental differences in boreal fires and climate feedbacks. *Nat. Geosci.* **8**, 228–234 (2015).
114. Jackson, J. B. C. et al. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629–637 (2001).
115. Halpern, B. S. et al. A global map of human impact on marine ecosystems. *Science* **319**, 948–952 (2008).
116. Tacon, A. G. J., Hasan, M. R. & Metian, M. *Demand and supply of Feed Ingredients for Farmed Fish and Crustaceans: Trends and Prospects* (FAO, 2011).
117. Kusumaningtyas, R. & van Gelder, J. W. *Towards Responsible and Inclusive Financing of the Palm Oil Sector* (Center for International Forestry Research, 2017).
118. Fitzherbert, E. B. et al. How will oil palm expansion affect biodiversity? *Trends Ecol. Evol.* **23**, 538–545 (2008).
119. Lam, M. K. & Lee, K. T. Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win-win strategies toward better environmental protection. *Biotechnol. Adv.* **29**, 124–141 (2011).
120. *Cocoa Industry: Integrating Small Farmers into the Global Value Chain* (UNCTAD, 2015).
121. De Beenhouwer, M., Aerts, R. & Honnay, O. A global meta-analysis of the biodiversity and ecosystem service benefits of coffee and cacao agroforestry. *Agric. Ecosyst. Environ.* **175**, 1–7 (2013).
122. *Leading soybean producing countries worldwide from 2012/13 to 2017/18 (in million metric tons)* (Statista, US Department of Agriculture, 2018).
123. *Global Canopy* (Trase, Stockholm Environment Institute, 2018).
124. Da Silva, V. P., van der Werf, H. M. G., Spies, A. & Soares, S. R. Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. *J. Environ. Manage.* **91**, 1831–1839 (2010).
125. Fearnside, P. M. Soybean cultivation as a threat to the environment in Brazil. *Environ. Conserv.* **28**, 23–38 (2001).
126. *Salmon Farming Industry Handbook* (Marine Harvest, 2018).
127. Taranger, G. L. et al. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. *ICES J. Mar. Sci.* **72**, 997–1021 (2014).
128. *The Changing Role of Multinational Companies in the Global Banana Trade* (FAO, 2014).
129. De Barros, I., Blazy, J. M., Rodrigues, G. S., Tournebize, R. & Cinna, J. P. Energy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies). *Agric. Ecosyst. Environ.* **129**, 437–449 (2009).
130. *Panhuysen, S. & Pierrot, J. Coffee Barometer 2014* (Hivos, IUCN Nederland, Oxfam Novib, Solidaridad, WWF, 2014).
131. Philpott, S. M. et al. Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conserv. Biol.* **22**, 1093–1105 (2008).
132. Humbert, S., Loerincik, Y., Rossi, V., Margni, M. & Jolliet, O. Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso). *J. Clean. Prod.* **17**, 1351–1358 (2009).

Acknowledgements

We are truly indebted to K. Arrow for deep insights and for inspiring our discussions at the annual Askö meetings in the Stockholm archipelago. Thanks also to K. Nyborg, S. Barrett and P. Ehrlich for valuable comments. Support is gratefully acknowledged from The Beijer Foundation, The Erling-Persson Family Foundation, The Marianne and Marcus Wallenberg Foundation, The Walton Family Foundation, The David and Lucile Packard Foundation, The Gordon and Betty Moore Foundation and Mistra: The Swedish Foundation for Strategic Environmental Research.

Author contributions

C.F., H.Ö. and J.-B.J. designed the research, collected the data and performed the analyses with support from E.F.L., W.N.A., M.S., B.I.C., M.N., S.A.L., S.R.C. and A.D.; C.F., H.Ö. and J.-B.J. led the writing of the paper, with input from E.F.L., W.N.A., M.S., B.I.C., M.N., S.A.L., S.R.C., J.M.A., S.C.III, A.-S.C., A.D., V.G., L.J.G., N.K., B.H.W., J.R.W., J.W. and A.d.Z.

Competing interests

C.F., H.Ö., J.-B.J., B.I.C. and A.D. provide scientific support to companies in the seafood sector through the Seafood Business for Ocean Stewardship (SeaBOS) initiative (<http://keystonedialogues.earth/>). The remaining authors declare no competing interests.

Additional information

Reprints and permissions information is available at www.nature.com/reprints.

Correspondence should be addressed to C.F.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© Springer Nature Limited 2019