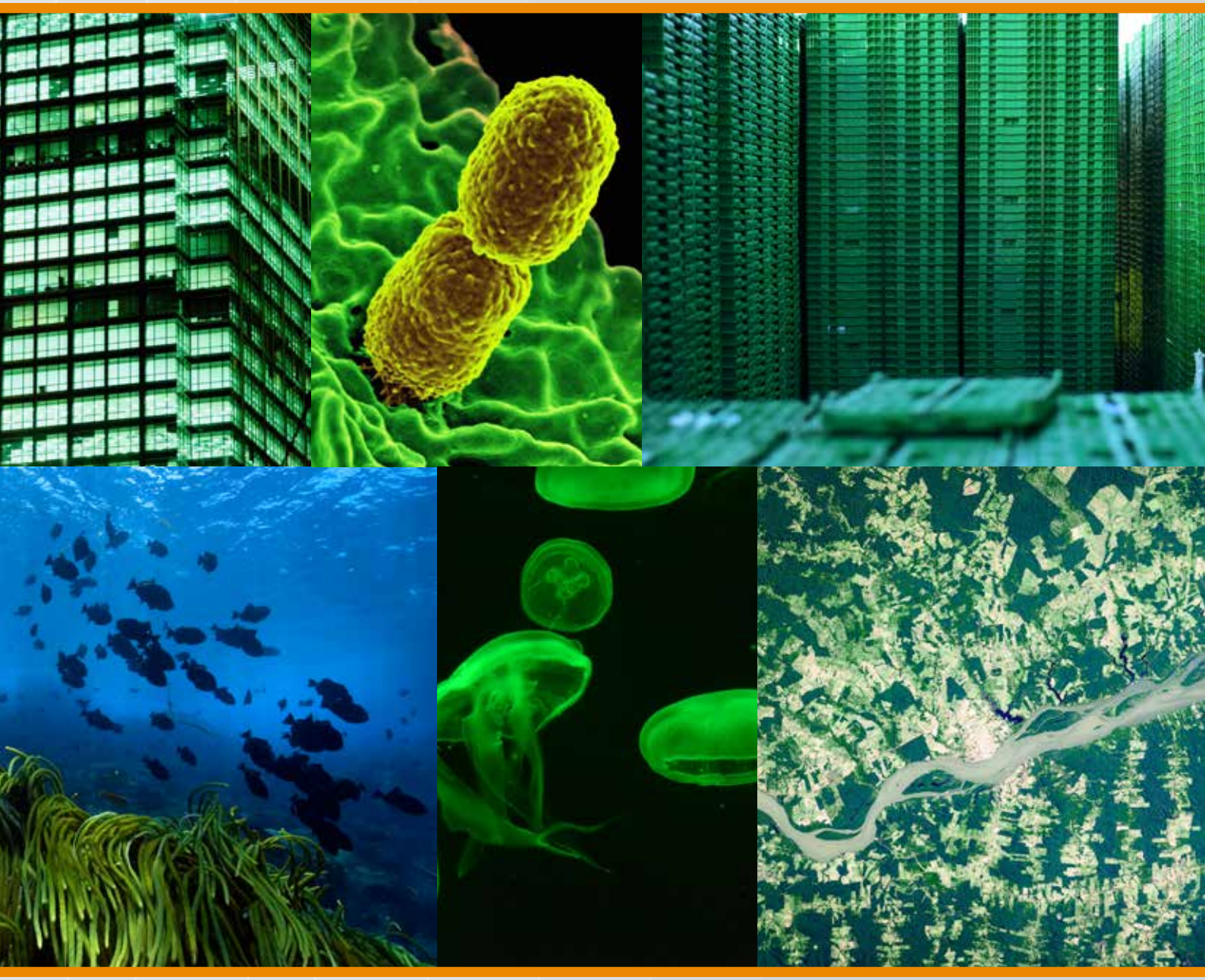
GLOBAL ECONOMIC DYNAMICS AND THE BIOSPHERE

THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Erling-Persson Family Academy Programme

REPORT 2018



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EDITOR: BEATRICE CRONA
PRODUCTION: HANNAH GRIFFITHS-BERGGREN
CONTRIBUTING AUTHORS: BEATRICE CRONA, ALICE DAURIACH, SOFIA KÄLL, CARL FOLKE, JOHAN GARS, PETER SØGAARD JØRGENSEN, EMMY WASSÉNIUS, HANNAH GRIFFITHS-BERGGREN, AMAR CAUSEVIC, ALICE DAURIACH, AMI GOLLAND, JEAN-BAPTISTE JOUFFRAY, MAX TROELL
GRAPHIC DESIGN: ©FRÄULEIN DESIGN
COVER PHOTOS TOP TO BOTTOM, FROM LEFT TO RIGHT: ALAMY STOCK PHOTO / CULTURA RM, CALLISTA IMAGES, ETHAN GRAHAM, ARTESUB, CORINA ADINA PIP, TOMMOT

EXECUTIVE SUMMARY

This is the last annual report of the Global Economic Dynamics and the Biosphere program (GEDB) under the first five-year funding stream, generously provided by the Erling-Persson Family Foundation. The report accounts for 2018 achievements, and summarizes and reflects on the work and activities of GEDB since its inception in May 2013.

The GEDB programme focuses on unexplored interfaces and areas of scientific inquiry with the aim of better understanding global economic dynamics in a biosphere context and to uncover the drivers, mechanisms and effects on social-ecological systems and their resilience at multiple scales.

During its first five years of operation, GEDB has generated over 130 scientific peer-reviewed articles, many published in highly ranked journals. Several of these research findings have also received significant attention among diverse actors in society and business, and in both conventional and social media.

The programme has been flexible in its structure – providing a platform for emergent and innovative scientific inquiry, whilst maintaining strong scientific rigor – essential criteria for ensuring high-impact scientific work of relevance for society. Three thematic areas initially guided the research: (Macro)economy and the biosphere, Marine resource trade and its effects on social-ecological systems, and Interactions between financial markets and the biosphere. New insights have been uncovered under each themes and during the course of the GEBD programme, two additional, cross-cutting themes have emerged: 'Cross-scale dynamics' and 'Systems transformation.'

The impact of the GEDB Academy program ranges from shaping research agendas internationally – creating new research areas and inspiring new curriculum at Universities – to triggering action for sustainability in diverse segments and sectors of society. In particular, new forms of science-practice collaboration have been tested and implemented with the business community. Such transdisciplinary research is rarely supported through normal channels, but urgently needed to understand the new context and find ways to act on it. GEDB has also engaged in fruitful collaboration with change agents at various levels in society, and the research generated has illustrated the benefits of evidence-based science as a foundation for collaboration and action.

Finally, the success of our doctoral and postdoctoral student and young researchers in attracting external funding and publishing in top-tier journals is proof that the program has delivered on its ambition to enhance the capacity of the next generation to conduct cutting-edge transdisciplinary research.

PART 1: **ANNUAL REPORT 2018**

INTRODUCTION

This is the final annual report of the Global Economic Dynamics and the Biosphere program (GEDB) under the first five-year funding stream generously provided by the Erling-Persson Family Foundation. GEDB is a research program of the Royal Swedish Academy of Sciences and focuses on the economic dynamics of global change in a biosphere context, and its implications for a sustainable future.

The program was set up to conduct interdisciplinary research that integrates social, economic and ecological dimensions, perspectives and data to explore scientific frontiers that lie at the nexus between these areas. GEDB performs rigorous high-impact scientific work of relevance for, and in collaboration with, practice, policy, business and society as a whole. The emphasis of the program is on science for change.

The focus and achievements of GEDB so far have been of a highly emergent and innovative nature, combining methods and disciplines across hitherto largely un-explored domains to develop sustainability science. This differs from most other academic efforts in a number of ways. The outcome has been novel and surprising research findings, the emergence of unexplored areas and new fields of research, and informed collaborative platforms engaging central actors in society and business in solving problems and challenges of great relevance for actions towards sustainability.

In this annual report, detailing the achievements of 2018, we also include a short reflection and exposé of our overall scientific achievements, as well as the societal impacts of the program over the course of this first phase.

AIMS AND VISIONS

The broad aim of GEDB is to understand globalisation in a biosphere context, with an explicit emphasis on different economic aspects. The focus is to uncover the drivers and mechanisms behind globalisation that effect the operation of the tightly coupled human-environment system or – in the language of the specialist – of the social-ecological systems at multiple scales. Specifically, we strive:

- To create a platform for interdisciplinary collaboration on the challenges of global change and sustainability, with specific focus on how local-to-global, cross-scale interactions affect human wellbeing and the sustainable use of natural resources and ecosystems.
- To facilitate and promote collaboration between early career economists and scientists with other backgrounds, focusing on sustainability science.
- To combine diverse knowledge systems and experiences, and conduct research for a broader understanding of the preconditions and opportunities for sustainable societal development in the new global context of the Anthropocene.

Our vision is to conduct research that integrates social, economic and ecological dimensions, perspectives and data to explore scientific frontiers that lie at the nexus between these academic disciplines. Below, we report on the achievements of GEDB in 2018 in this context.

Photo Credit: Alamy

RESEARCH ACHIEVEMENTS AND ACTIVITIES IN 2018

Heavy commuter traffic on the pedestrian walkway of the Long Bien cantilever bridge, Hanoi, Vietnam. GEBD researchers have contributed to publications to better knowledge of commuting behaviour.

(Macro)economy and the biosphere

During 2018, the work under this theme has been conducted along several tracks. The first concerns international trade and agricultural production. A paper studying the role of international trade as a mechanism for coping with variability of agricultural production has been completed and accepted for publication (Ferguson and Gars 2018). The paper uses a combination of theoretical modeling and econometric analysis to determine the extent to which trade flows respond to agricultural production shocks. The main finding is that trade flows react relatively little to variability in production and highlights the need to better understand what role trade could (or should) play, as a coping mechanism in a world of increasingly variable food production.

A second track investigates the role of fossil fuel in the global macroeconomy, both for patterns of growth, and for patterns of international business cycles. Concerning growth, one paper titled *Fuel for economic growth* led by GEDB researcher Johan Gars, uses a multi-country growth model (and historical data) to show that access to efficient energy (historically fossil fuel) is important for growth. It also shows that more advanced countries can drive up international fossil-fuel prices and thereby hinder growth in less advanced countries (i.e., contributing to "the great divergence"). A second paper on the *International business cycles: quantifying the effects of a world market for oil*, finds that considering the role of oil actually helps explain well-documented, but previously difficult to explain, patterns in the international business cycle.

Spatial aspects of the valuation of pollutants and ecosystem services is a third area where GEDB authors (specifically Gustav Engström) have contributed through a publication which develops novel methodology for how new data sources can contribute to better knowledge of commuting behavior. The hope is that this can help improve future studies trying to assess the economic impact of ecosystem services and/or pollutants. Within this track, topics such as urban green spaces and the risk of nuclear disaster have also been studied.

Co-funded by Ragnar Söderberg Foundation, another study examines economic linkages between the planetary boundaries. It does so by mapping out the most important drivers behind the pressures on the boundaries and the economic activities underlying them. It shows that agricultural and energy production

is jointly responsible for a large portion of all pressures. This mapping has formed the basis of a model that incorporates these (and other) activities, and which allows for analysis of how efforts to reduce some pressure (e.g., carbon-dioxide emissions from fossil-fuel use) can be expected to change other activities and their pressure on the planetary boundaries. This work was presented at a thematic session at the World Congress of Environmental Economics, chaired by Gustav Engström.

'Boundaries and Goals'

Throughout 2017–2018, GEDB researcher Peter Søgaard Jørgensen developed a collaboration with the Programme for Industrial Ecology at the Norwegian University of Science and Technology (NTNU). This has led to the first assessment of the trajectories of national economies toward staying within the nine planetary boundaries. The first paper from this collaboration, submitted in 2018, shows that advanced economies have surpassed per-capita shares of the planetary boundaries but are slowly starting a trajectory back towards staying within these boundaries. Emerging economies, on the other hand, have just recently started to transgress their boundaries and are on a trajectory to greatly increase their exceedance in the future. 2018 also saw the advancement of work to reframe the SDGs into an agenda to Achieve Sustainable Development in the Anthropocene (Jørgensen 2017, Lim et al. 2018).

A tool for collaboration

Finally, work has been ongoing to develop a new tool for economic analysis, called "Walras". The aim is to significantly simplify analysis of economic systems and their response to various events (e.g., introduction of taxes or changed supply conditions for goods). Walras will provide an easy-to-use graphical interface where models are set up by introducing economic agents or sectors and specifying the relationships between them by drawing arrows. For economists, this tool will significantly decrease the required work and for non-economists, it will lower the bar engaging with economic analysis. The tool will greatly facilitate the involvement of non-macro economist in modeling exercises and thus promises to greatly enhance the collaborative capacity between macroeconomics and other disciplines.

Activities

* A thematic session was held in August at World Congress of Environmental and Resource Economists in Gothenburg, Sweden, to discuss *perspectives on policies for the Anthropocene* and to present the papers *Policies for planetary boundaries and International business cycles: quantifying the effects of a world market for oil*.
* A seminar was organized by GEDB at SLU on *International business cycles: quantifying the effects of a world market for oil*.

Marine resource trade and its effects on social-ecological systems

This research theme examines how existing and emergent markets affect the functioning of marine social-ecological systems at different scales. It looks at the economic, social and environmental components of fisheries and aquaculture production systems. Transitioning to sustainable fisheries and seafood production will involve changes in how seafood is produced, but equally important are the types and volumes of species demanded by markets, and how these market choices can help support more sustainable seafood production and consumption. Understanding how such a transformation can be achieved requires a focus on the production of seafood and the market system, and on the supply chains connecting production and consumption. Below are some examples of research that uncovers important aspects for sustainable production, marketing and consumption, in a world of changing climate and increasingly globalized trade.

Seafood trade and sustainable supply chains

The long-term collaboration and dialogue fostered between GEDB researchers and fisheries industry actors (such as the Sustainable Fisheries Partnership) through the GEDB programme is now paying off. In 2018, GEDB have established and developed collaboration with several actors to examine processes of change in global seafood value chains and studies of traceability schemes for sustainability in small-scale fisheries. The latter project is also in collaboration with and University Diponegoro, Indonesia and NFI Crab Council, one of the most important players in US crab industry. Another study recently initiated, will examine how specific supply chain incentives influence fishers. For example, researchers will be studying how the introduction of credit cards improves the savings and household economy of small-scale fishers, as part of an economic incentive and traceability initiative by seafood processing company Blue Star Food. This work is being done in collaboration with the University of Visayas, in the Philippines.

Photo: Max Troell.

Ocean fish farming.

Sustainable Seafood – the role of aquaculture

Food production is the single largest source of environmental degradation and impact on the Earth system. The role that seafood can play for enabling humanity to stay within planetary boundaries is still unknown, but research indicates a potential for seafood to contribute positively to a transformation towards environmental sustainability and improved human health. The environmental footprint from seafood production is often (but not always) smaller compared to many land-based animal production systems. As capture fisheries are almost fully exploited and unlikely to provide an increased production, the world is increasingly looking to aquaculture to provide the necessary increase in aquatic animal protein. However, seafood is a very diverse food group and different products (species) will have very different environmental, social and human health impacts. Work recently initiated within this research theme has looked closer at the future role of aquaculture and how the diversity of species and systems relates to global sustainability. Below we show a few examples.

Is off-shore aquaculture a potential game-changer?

During 2018, GEDB researchers were also involved in a global estimate of areas suitable for mariculture (Oyinlola et al. 2018). While there are plenty of suitable sea space for farming and the promise of a "quick fix" to the global food challenge by aquaculture, there are other limitations, such as sustainable feed ingredients, that need to be considered (Troell et al. 2017). Related research has involved a deeper look into Integrated Multi-Trophic Aquaculture (IMTA) techniques in offshore environments and asking the question, what role these techniques could play for improving sustainability of large-scale expansion of marine food production (Buck et al 2018)? This work shows how IMTA holds scope for multi-use of offshore areas (i.e. integrated with energy systems) and how it can bring environmental benefits from making use of waste products and transforming these into valuable co-products. The overall sustainability will, however, depend on main species that will be targeted.

Feeds and the rising challenge of antimicrobial resistance

Increased use of antibiotics for animal husbandry purposes has raised global concerns regarding the accelerating effects it has on the development of antimicrobial resistance (AMR). Aquaculture is no exception, and as shown by GEDB work, several antibiotic compounds are used globally for aquaculture production and some of these are listed as critically important to human (Henriksson et al. 2018). As a result of the above outlined studies, work under this theme has included the development of a framework for identifying mechanisms that trigger antibiotic use, with the aim of supporting and enabling retargeted mitigation efforts.

Photo Credit: Max Troell

Fish pond farm of tilapia in Timor Leste.

How sustainable is it? LCA as a tool for assessing environmental impacts

The diversity within the aquaculture sector means there are varying environmental impacts depending on species produced and the mode of production. Life-cycle analysis (LCA) is one of the primary forms of analysis used to assess environmental impact of the production of all forms of commodities. During the past year, GEDB has contributed to the application of such analysis in the seafood sector. This has been done for an improved understanding of how different species and systems relate to multiple sustainability domains (Henriksson et al 2018a; Henriksson et al 2018b), as well as critically examining how LCA should be performed to become a useful sustainability tool. The outcomes of this research highlight the difficulties of comparing LCA results and therefore the remaining challenges for assessing sustainability of food production in general, and seafood in particular.

Marine genetic resources – a new (research) frontier

Trade in marine resources is increasingly extending to novel forms of commodities that are not generally included in analysis of the ocean domain. In 2018, GEDB researcher Jouffray was involved in research designed to examine patterns of corporate on global governance of marine genetic resources (Blasiak et al. 2018), as part of a *Science Advances* special issue dedicated to the science of the High Seas. This issue was subsequently distributed to all participants at the UN negotiations for a new treaty for the high seas, in New York, early September 2018, to inform their discussions.

Activities

* GEDB co-convened an international workshop on the future seafood ("Doubling aquaculture by 2050"), 13–15 February 2018, Worldfish, Penang, Indonesia. Outputs include an academic paper and were also used as an entry point for a panel discussion held at World Aquaculture Symposium in Montpelier, Autumn 2018 (chaired by Max Troell).

* GEDB researchers co-convened one "Disruptive Dialogue – The Big Catch: Collaborative Ocean Action Towards Food Security", at the 2018 annual EAT Forum.

* The EAT Lancet report on how food systems can stay within planetary boundaries and improve human health was released in January 2019. During Dec 2018, Crona and Troell led short scientific scoping report to examine the EAT-Lancet commission report through a blue lens

* GEDB convened a two-day, in-depth discussion among leading scientists and expert practitioners to develop an evidence-based framework for what a comprehensive Ocean Stewardship should comprise. Hosted at the Royal Swedish Academy of Science in Stockholm in June, it was provided an opportunity to contribute to ongoing efforts towards advancing corporate transparency in the seafood sector. Multiple academic outputs have been developed from this workshop during the year and will be reported on in 2019.

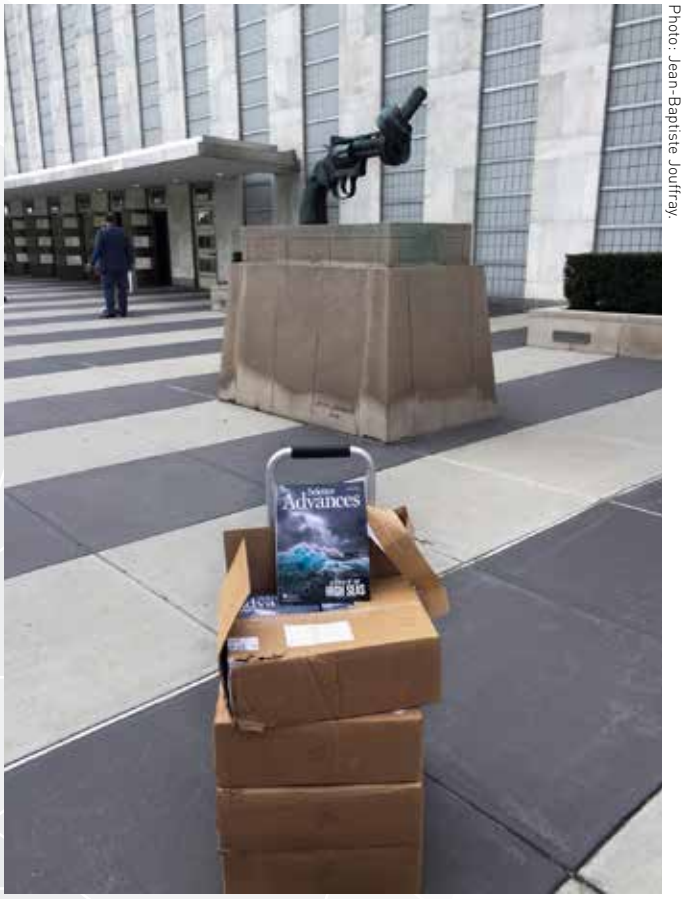


Photo: Jean-Baptiste Jouffray.

Marine genetic resources research outside of the UN, New York.

Links between biosphere dynamics and the financial system

Earth system finance

Much of the work carried out under this theme over the last two years has come to fruition in 2018. This includes two major research undertakings, the first of which explored and mapped the links between investors and key stabilizing elements of the Earth climate system (such as the Amazon and Boreal forests). This work was published as an academic article in Global Environmental Change. A report based on the research was also launched in New York in September (during the UN Global Assembly), at a seminar hosted by the Sustainable Development Solutions Networks (SDSN) and discussed by a panel consisting of GEDB Executive Director Crona, Jeffrey Sachs (founder of SDSN), Victor Galaz and Naoko Ishii (CEO and Chairperson of the Global Environment Facility, and former Deputy Vice Minister of Finance in Japan). This report has proven to be a valuable resource for discussion with various actors in the financial sector. The report can be downloaded at: https://sleepinggiants.earth/backgroundreport/

Tax havens and global sustainability

The work to trace links between capital routed via tax havens and linking this to global environmental commons also proceeded and was published in Nature Ecology and Evolution in August. The study explores how offshore jurisdictions subsidise environmental degradation and reduce transparency at a scale that has implications for the resilience of the Earth system. The impact of this work has been widespread with extensive media engagement with international media channels around the world such as Le Monde, The Guardian, El Pais, DN, Mongabay, BBC, SVT, Reuters, The Times and The Independent amongst others (see Section X:X for more on Societal Impact). Our work for this article also attracted publicity in Sweden around the problem of academic freedom and the threat of legal risk when studying corporate practices. As a result, Beatrice Crona was invited to give a talk at a symposium on "The shrinking academic freedom in Europe", arranged by the Swedish Young Academy and UNESCO, at the Government Offices in November, and multiple media outlets ran stories on the case in the autumn. For one example, see: https://universitetslararen.se/2018/12/20/sjalvcensur-ett-hot-mot-akademisk-frihet/.

The environmental impact of financial crises

Under the broader theme of linking the biosphere to finance, GEDB researchers have also worked to synthesize the evidence for environmental impact of financial crises, and to be able to predict this for the future. This work, led by Peter Jørgensen and carried out in collaboration with Ami Golland (GEDB) and Asgeir Torfason (University of Iceland, School of Business), is now nearing its conclusion. It will contribute to the emerging field of sustainable finance by integrating models of macro-level financial dynamics with classical models of social-ecological dynamics to provide a framework for predicting the environmental impact of various types of financial crashes and crises in relation to four general types of policy responses.

The past year has also seen some explorative work to map investor ownership in the fertilizer and mining sector. We see this as potentially important as GEDB, in its next phase, will aim to expand the Earth System Finance stream and more explicitly examine global economic patterns with bearing on human health and food production.

Activities

* Gave a talk at a symposium on "The shrinking academic freedom in Europe", arranged by the Swedish Young Academy and UNESCO, at the Government Offices in

Photo: Marie Sparréus, Azote.

Tax haven team. From left, Alice Duriach (GEBD), Henrik Österblom (SRC), Jean-Baptiste Jouffray (GEDB), Viktor Galaz (GEDB) and Beatrice Crona (GEDB).

November (based on our experiences with the work of tax havens and global environmental commons)

* Launch of the report from the Earth System Finance project, targeted at investors: Sleeping Financial Giants. Opportunities in financial leadership for climate stability (at seminar hosted by the Sustainable Development Solutions Networks (SDSN) during the UN Global Assembly; Sept 24, 2018).

* Co-organizers (with Principles for Responsible Investment) of a dialogue with PRI signatories in London 23 March 2018 where we presented our research and discussed plausible strategies and actions by the finance industry to address the issues raised.

Cross-cutting theme: Systems transformation

The Systems transformation theme has developed through the recurring focus of several research efforts on factors that bolster or impede transformative change in a system, and the role of governance in microbial drug use in food production for halting antimicrobial resistance.

Antibiotic resistance and the Anthropocene operating space

The previous two annual reports have featured our work to develop a global indicator framework for AMR, analysing policy

frames, and assessing opportunities for actively combating AMR through approaches which promote organisms that can help control resistant ones (see also Living with Resistance project 2018). The recent year has drawn on these achievements and developed work that highlights practical pathways and areas of intervention for alternatives to continuing chemical escalation (Living with Resistance project *in revision*). A paper introducing the Anthropocene operating space of biocide susceptibility (antibiotics and pesticides) was published in Nature Sustainability, and another article in the Lancet Planetary Health conducted a sustainability assessment of antibiotic use in livestock production.

Additional work in this theme includes quantitative analysis of the diminishing ecosystem services of susceptible organisms due to increasing pesticide and antibiotic use; a quantitative assessment of whether current government actions are enough to de-escalate impacts of antibiotic resistance; and finally a definition of a new type of governance to sustainably navigate intertwined human-biosphere dynamics such as those of antibiotic and pesticide use.

During 2018, Peter Jørgensen also attracted significant funding (ca. 10 m SEK) for the AMResilience consortium (https://amresilience.wordpress.com/), to investigate resilience and transformations in One Health systems in the context of antibiotic resistance. Besides GEDB, the consortium involves partners from Canada (University of Waterloo) and Switzerland (University of Geneva) and aligns well with the next research phase of GEDB focusing on global health and biosphere stewardship as a grand challenge. As a result of this additional funding, the GEDB team will grow with at least one post-doc during 2019.

Trajectories of the Earth System

A significant contribution in 2018 is the work on trajectories of the Earth System (Steffen et al. 2018), which gathered a group of leading scholars including Carl Folke, to explore the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold. If crossed, this could prevent stabilization of the climate at intermediate temperature increase and cause continued warming on a "Hothouse Earth" pathway, even if human emissions are reduced. The article pleaded for active stewardship of our own future in concert with the biosphere as a means to stabilize the planet in conditions hospitable for human civilizations.

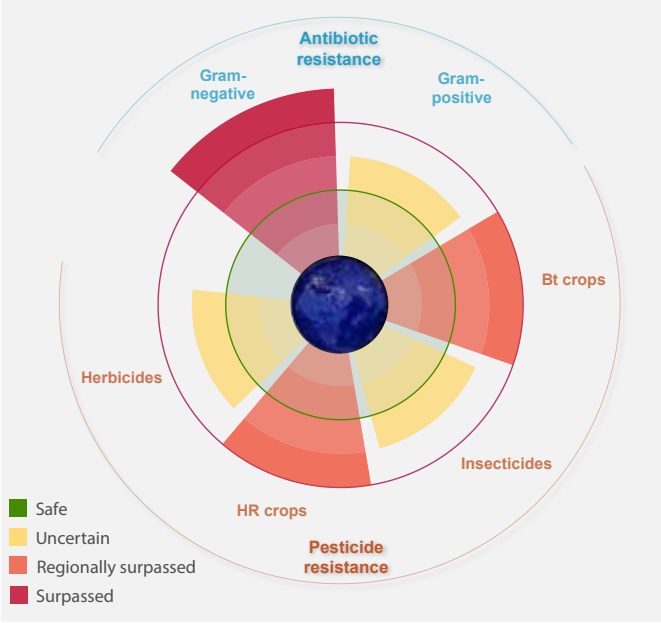


Illustration: Living with Resistance Project.

The Anthropocene operating space of biocide resistance is an assessment of the risk posed by resistance to some of the major types of antibiotic and pesticides and can be used as an indicator of need for global or regional system transformation. Resistant Gram-negative bacteria are in the zone of highest risk follow by two groups of transgenic crops.

Activities

* The AMResilience inception meeting took place at the Kungliga Vetenskapsakademien between the 16–18 May. The purpose was to launch the AMResilience project that aims to provide a framework and document what resilient one-health systems to the challenge of antibiotic resistance look like through the lens of interventions. The project spans partners at the University of Waterloo, Canadian Public Health Agency, University of Geneva and the University of Geneva Hospitals.

COMMUNICATION AND IMPACT IN 2018

Photo: Radhika Gupta, SRC.

Company CEOs and representatives and researchers who participated in the third SeaBOS Keystone Dialogue in Amersfoort, the Netherlands, May 2018.

In the limelight

2018 became a year of exceptional media attention for work developed by GEDB. In fact, 46% of GEDB's scientific publications from 2018 are among the top 5% in the Altmetric database, scoring 23 or above. Altmetric is a tool used to assess impact across a diverse array of scientific and public media outlets. In general, according to Altmetric, if an article scores 23 or more, it is doing "far better than most of its contemporaries", by being among the top 5% of articles read. Below we highlight some of the media coverage relating to four research outputs, from the various themes under the program.

Tax havens and global environmental degradation

The work on offshore jurisdictions and environmental degradation attracted significant media attention. The work was featured in the Guardian (UK), BBC News and The New York times and another 40 international news venues. In Sweden, it was covered by DN, SvD, SVT and Studio Ett (SR) among others. Since the initial wave of attention, the work has also been covered in other journalistic venues such as MongaBay, The Japan Times, La Vanguardia and France 24.

Antibiotic and pesticide susceptibility and the Anthropocene operating space

This Nature Sustainability paper was featured in Swedish media and radio, including TT and Svenska Dagbladet amongst other 40 Swedish newspapers. The paper also received interest from leading research communities in both sustainability science, health and agriculture and was reported by the AAAS sponsored Science and Development news site, SciDev and the Spanish newspaper, El Pais.

Corporate control and global governance of marine genetic resources

The publication of this paper also saw significant attention, including with The New York Times, The Scientist, The Independent, The Financial Times, La Vanguardia, BBC, France Inter, Vetenskapradion, Radio Canada International, Reporterre, and Quartz.

Trajectories of the Earth System

This article was published in August 2018 and received over 470 media reports within 24 hours of release and within a month the article had been downloaded more than 260 000 times. The article was listed as number 4 among the Top 100 research papers in terms of media impact in 2018 according to Altmetric, which tracked about 10 million research outputs in 2018.

Societal Impact of GEDB research

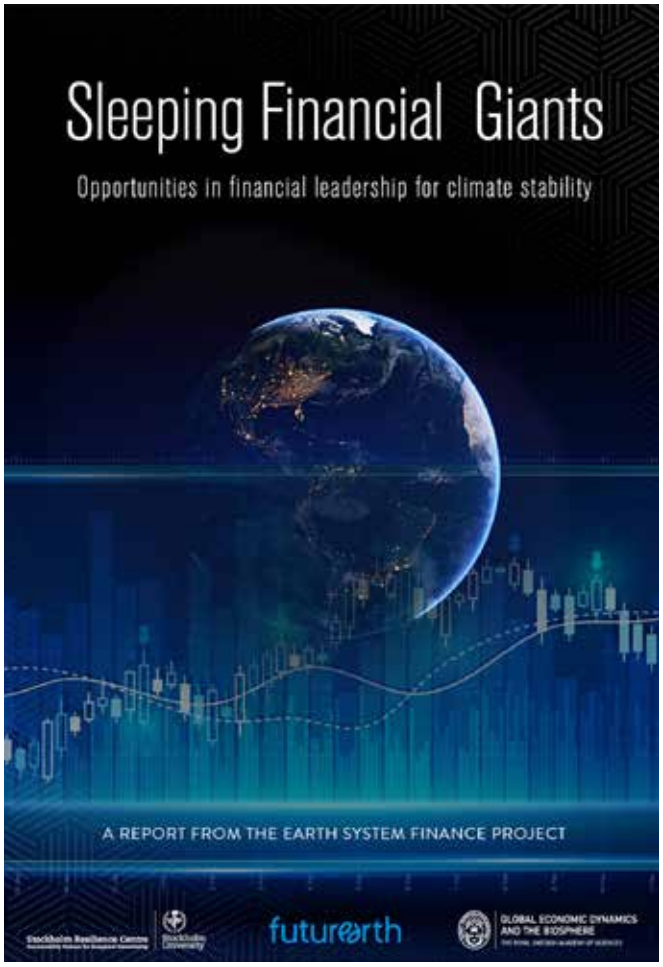
Shifting the focus of sustainable finance

This theme has gone from an idea and action plan for cross-pollination between fields of research, to the emergence of an entirely new academic field and ways of conceptualizing and empirically investigating links between the financial sector and the biosphere.

As part of our impact strategy the GEDB Earth System Finance (ESF) team has conducted two high-level dialogues with key representatives from the financial sector. The first was in Stockholm in June 2017, where many key Swedish actors were involved, including large pension funds and ethical investors, but also international banks and credit rating agencies. The second dialogue was co-organized with the Principles for Responsible Investment (PRI), at their City of London office, and around the table were ten of PRIs signatories. The key message of the GEDB research is that the financial sector cannot singlehandedly focus on green-house gas emissions reductions, but must also consider planetary regions of extreme importance for global climate stability, and reorient allocation of capital to enhance the resilience of these so called 'Tipping Points'.

The research, and dialogue with key actors in the financial sector, jointly led GEDB to produce a report targeted at the financial (and corporate) sector. The report has two aims. First, to introduce to the financial sector the notion of tipping elements in the Earth system, and to provide a short, state-of-the-art review of the scientific knowledge surrounding this rapidly evolving field of enquiry. Second, it makes explicit the links between the investment sector and such tipping elements, and outlines a preliminary approach for how to examine such links using two cases: The Amazon rainforest and the boreal forests of Russia and Canada.

The report (and key messages) has received an overwhelmingly positive response, as reflected in some of the feedback below



The Sleeping Financial Giants report launched in September 2018.

from financial actors participating in dialogues or interacting with the report. Along with news media coverage of the related research article, the report has led to invitations to present the work at multiple national and international venues. Notably, invitations to present at Credit Suisse annual Insurance-Linked Securities conference, an address at the UN Environment Finance Initiative's biennial Global Roundtable on sustainable finance in Paris, presentations at Handelsbanken, SEB, AMF Pensioner, and Svensk Försäkring. Lead scientists Crona and Galaz have also been invited as experts providing input to the Technical Expert Group on Sustainable Finance and the development of an EU taxonomy (as part of the EU Directive on Sustainable Finance).

According to *Figshare*, the sleeping financial giants report has 253 individual views and 504 downloads to date.

SeaBOS

2018 has seen significant progress within the keystone actors' dialogues. This ranges from action within member companies to improve transparency and traceability, to the establishment of a formal organization entitled "Seafood Business for Ocean Stewardship (SeaBOS)" with strong commitments by the involved Transnational Corporations and an organizational structure in place. In other words, the initiative has become formalized, with the role of science clearly articulated as playing a key role in ensuring that evidence-based science guides the activities and actions of SeaBOS.

Other signs of impact

GEDB researcher Gustav Engström (along with Beijer colleague Anne-Sophie Crépin) contributed to a government report entitled, *Möjligheter och begränsningar med samhällsekonomiska analyser* (*Opportunities and limitations of cost-benefit analyses*). This report discusses the use of economic analysis as a basis for decision making, and argues that analyses used for decisions support at the societal level need to incorporate consideration of nonlinearities, thresholds and uncertainties in the climate system and ecosystems, and the implications for sustainability. The report was delivered to The Swedish Scientific Council for Sustainable Development (Vetenskapliga Rådet för Hållbar Utveckling).

GEBR related work to integrate spatial data in maps of human and natural drivers of Hawaiian coral reefs (Wedding et al. 2018, Donovan et al. 2018, Jouffray et al. in review) was referred to by the governor of Hawaii, David Ige, as the *"first-ever comprehensive map documenting the impact of human activities and natural events on reef recovery"* and was described as a useful tool to help practitioners effectively anticipate, avoid and respond to coral reef change.

Photo: Jean-Baptiste Jouffray.

Quote from governor of Hawaii, David Ige.

PART 2: REFLECTIONS ON A RESEARCH ADVENTURE, GEDB 2013–2018

The GEDB program has focused on finding and connecting areas at the frontier of scientific inquiry. It has allowed for an unusual degree of scientific experimentation. The motivation has been to gain scientific insight and act on it, in relation to environmental change and sustainability in the new global context of the Anthropocene – the age where mankind has emerged as a global force on planet Earth.

The program has gathered early career researchers and created a space for them to bloom and develop, in a research environment exposed to internationally leading scholars and research groups. Over the five years, GEDB research has managed to strike a balance between novelty and scientific rigor. The team has worked hard to create spaces that allow us to seize opportunities and benefit from sparks of innovation, while simultaneously maintaining coherence. New insights have emerged, insights advancing the frontier of sustainability science, and even forming the frontier. This is unique in that it has created the freedom to try novel ideas and approaches – to do high-risk high-reward scientific research. The funding from the Erling-Person Family Foundation has been instrumental in achieving this.

The impact of the GEDB Academy program ranges from shaping research agendas internationally, creating new research areas and inspiring new curriculum at Universities, to triggering action for sustainability in diverse segments and sectors of society. In particular, new forms of science-practice collaboration have been tested and implemented with the business community. Such transdisciplinary research is rarely supported through normal channels, but urgently needed to understand the new context and find ways to act on it. GEDB has successfully pioneered transdisciplinary science by conducting research for a broader understanding of the preconditions and opportunities for sustainable societal development in the new global context of the Anthropocene. It has engaged in fruitful collaboration with change agents, from more local stewards to transnational corporations. The science for change generated through GEDB has illustrated the benefits of evidence-based science as a foundation for collaboration and action.

Academic impact

To exemplify, our findings have clearly shown the significance of the biosphere and the Earth System for human wellbeing, prosperity and development. In particular, the work on Planetary Boundaries and trajectories of the Earth system in the Anthropocene have received major recognition in science and in policy. Also, the work has clarified the intertwined web of interactions of people and the environment, from local levels to the planetary scale. Humans and nature are coevolving in new ways, witnessed in the work of the program from antibiotic resistance to transnational corporations and financial actors shaping the biosphere and climate dynamics at regional and global levels. GEDB research has clarified the connectivity between the local and the global, for example, in work on small scale fisheries and the different pathways that they are part of in relation to international markets. It has also challenged the old way of approaching macro-economic models and climate change, by taking real world dynamics and biophysical realities into account.

Completely new academic areas have also been created, like the Earth System Finance theme, or work on the keystone actors and biosphere dynamics. Here, new approaches and methods that did not exist before have been developed, both in terms of data gathering and analyses, but perhaps most significantly in combining evidence-based science with skills, competencies, and strategies of the business community. Two noteworthy outcomes are the Keystone Dialogues with the largest seafood businesses, including the development of the SeaBOS organisation for ocean stewardship, as well as the rapidly increasing interest among financial actors in our work to shift the focus of sustainable finance away from simply greenhouse gas emissions reduction. It is very rewarding to observe the rings on the water that these efforts have spurred.

Scientific publications

Grouping the *Web of Science Journal Citation Report* subject areas together into categories, 31 of the journals are listed

Figure A:

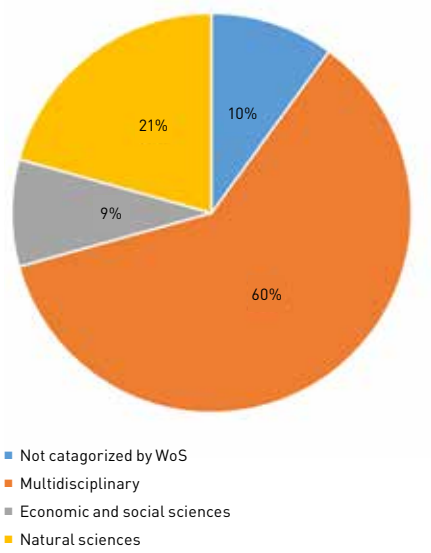


Figure B:

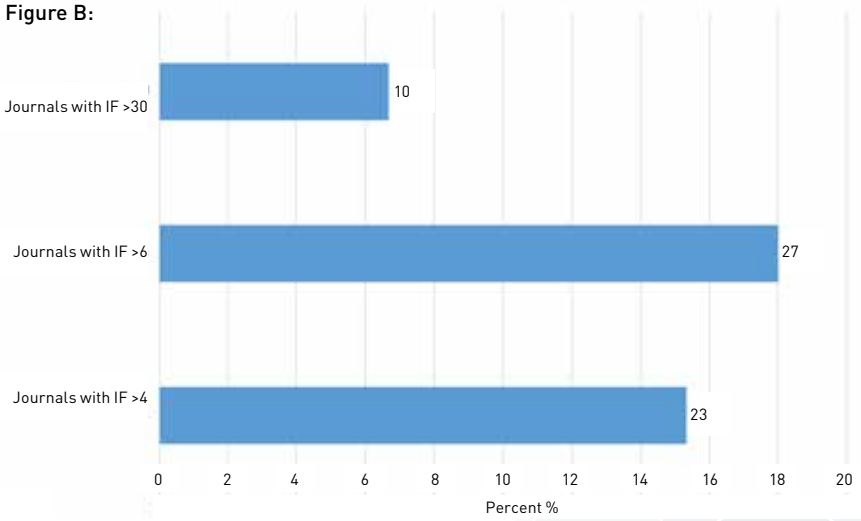


Figure C:

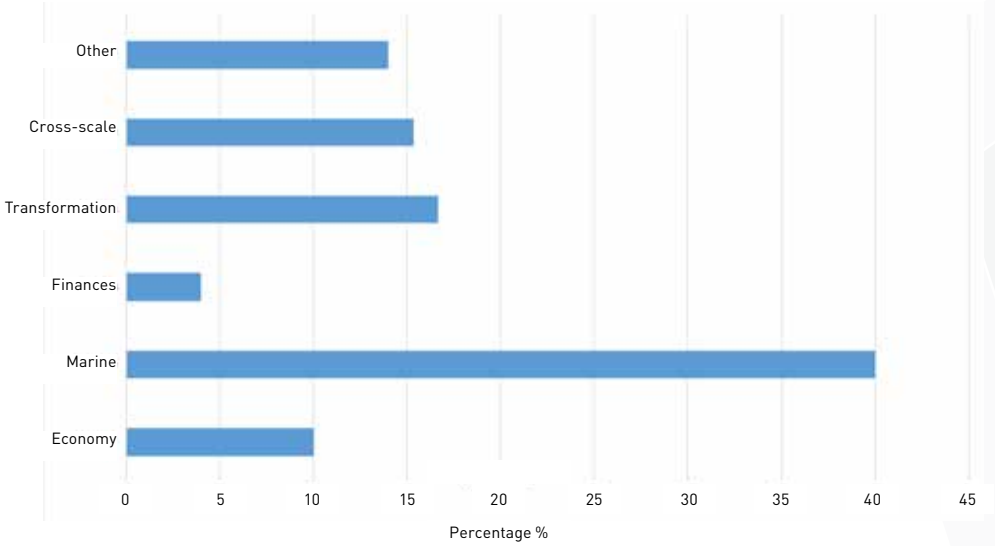


Figure A: Percentage of articles by subject areas, as grouped by the Web of Science Journal Citation Report (2013–2018).

Figure B: Percentage and count of articles published in journals with Impact Factor (IF) higher than 4, 6 and 30 respectively between the years 2013–2018.

Figure C: Percentage of journal articles (published) per research theme (incl. crosscutting themes) between 2013–2018.

as natural science, 13 as economic & social sciences, 91 of the journals are multidisciplinary and 15 are uncategorised (see figure A). Of the scientific articles, 60% (N=90) have been published in journals with an impact factors lower than 4, 15% (N=23) have been published in journals with an impact factor higher than 4, 18% (N=27) articles in journals with an impact higher than 6 and 7% (N=10) articles in journals with an impact factor higher than 30 (see figure B). A full list of publications is provided in Appendix B.

Of the published articles, 40% (N=60) relate to the 'Marine trade' theme, 10% (N=15) deal with issues that fall under the '(Macro)economy and the biosphere' theme, and 4% (N=6) fall under the 'Financial markets' theme (see figure C). Moreover, 17% (N=25) of the articles relate to the cross-cutting theme 'Systems transformation' and 15% (N=23) relate to the crosscutting theme 'Cross-scale dynamics' (see figure C).

Since the inception of GEDB, its members have published a total of 150 peer-reviewed scientific articles in academic journals. A further seven scientific articles are in press, and 8 scientific articles are in preparation (and near submission). A total of 15 books and book chapters and over 25 working papers have been produced (see appendix B).

The remit of GEDB is to be a platform for interdisciplinary scientific collaboration and most GEDB publications are the result of multi-disciplinary collaborations, with authors from

Figure D:

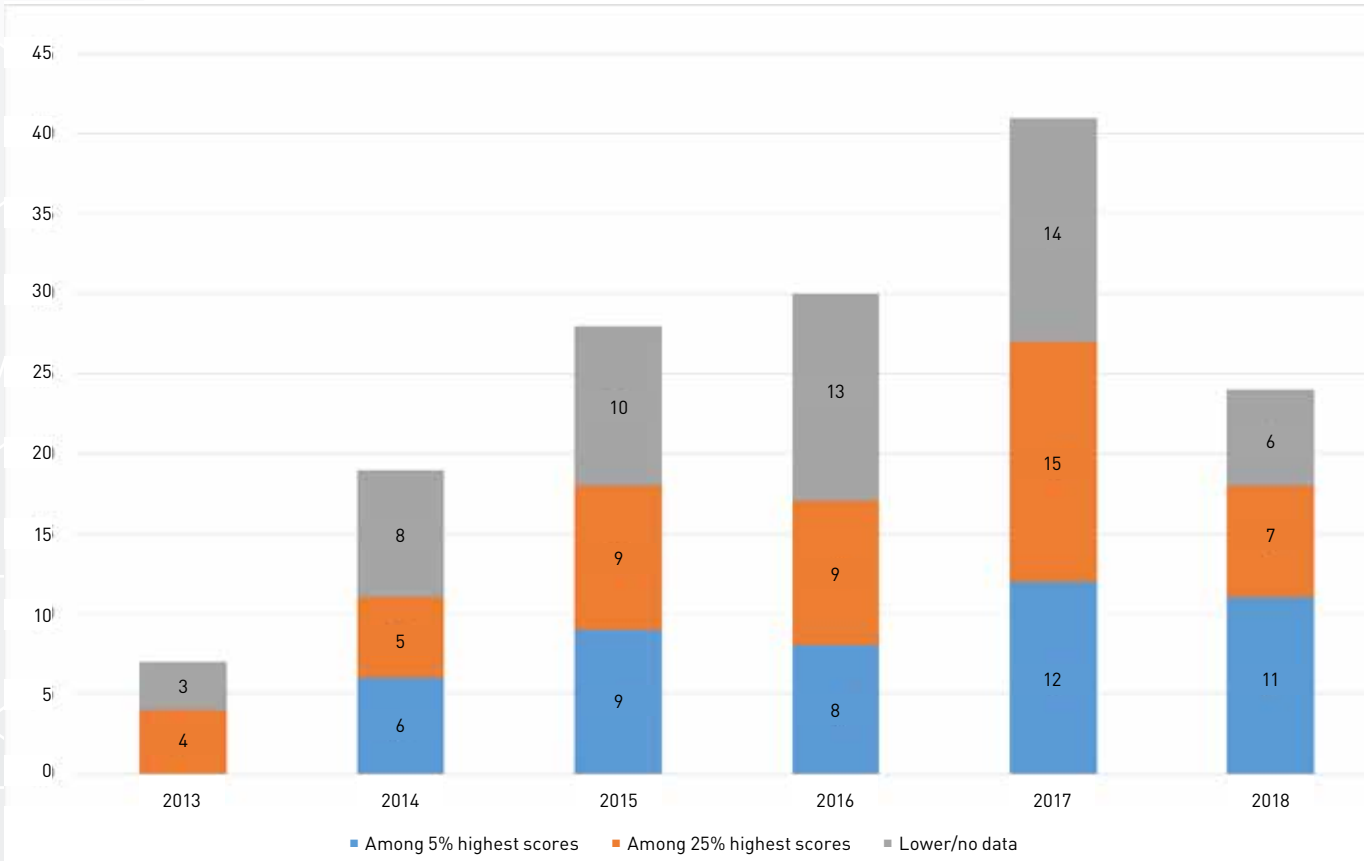


Figure D: Altmetric performance of GEDB scientific journal publications: Bars show the count of articles scoring in the top 5% and 25% respectively. The Altmetric score is a quantitative measure of the media and policy attention that academic articles can receive. The higher the score, the more attention is received.

diverse fields ranging from fisheries science to macroeconomics, modelling, sociology, industrial economics and finance. Published articles have appeared in 75 different journals (a full list of all journals is available in appendix B), spanning, 32 different subject areas (as categorized by *Web of Science Journal Citation Reports*)

Altmetric is a tool used to assess impact across a diverse array of scientific and public media outlets. It uses data such as citations in public policy documents, mainstream media coverage, mentions on social media and discussions on research blogs to track research publications. Data is gathered from 11,5 million research publications. Although it cannot reveal the quality of the research, it demonstrates aspects of uptake and reach outside academia. In general, according to Altmetric, if an article scores 23 or more it is doing "far better than most of its contemporaries", by being among the top 5% of articles read. Many GEDB papers score extremely high. In fact, 31% of GEDB's academic papers to date score among the top 5% in the Altmetric. Five GEDB articles from scored above 500 in Altmetric, which places them between place 29 to 7,620 out of all 11,5 million research outputs (see figure D).

Bridging science, policy and practice

While the core remit of GEDB is to conduct first-rate scientific research, a specific aim of the programme is to combine diverse knowledge systems and experiences to produce research that provides an understanding of the preconditions

Figure E:

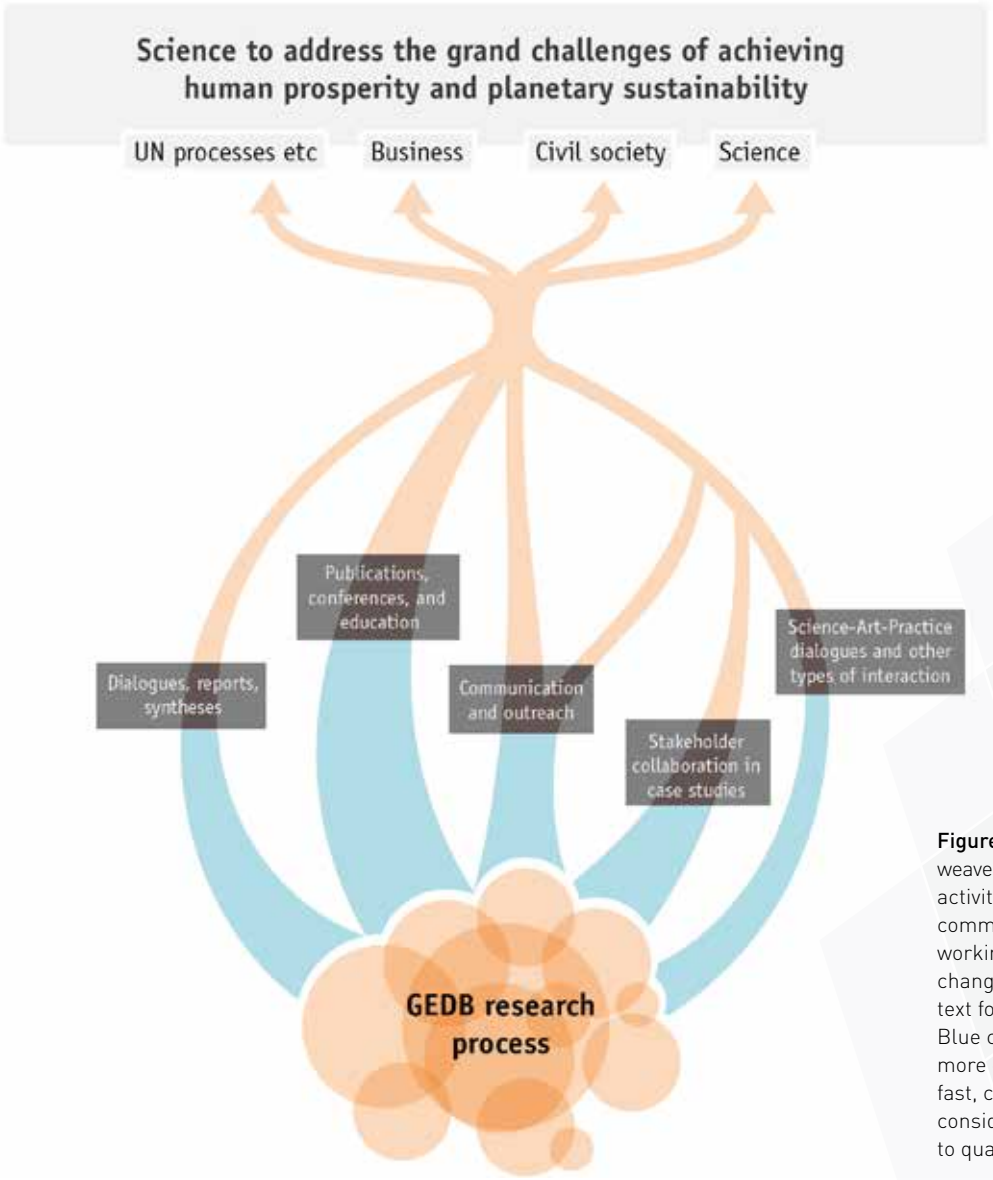


Figure E: An illustration of how GEDB weaves together all parts of the programme's activities (in science, education, dialogue, communication, administration and working environment) to affect societal change towards sustainability. See main text for explanation of the five pathways. Blue colour refers to pathways that are more direct, measureable and relatively fast, compared to the orange which are considered to be slower and more difficult to quantify.

and opportunities for sustainable societal development in the new global context. Ultimately, we have strived to generate knowledge that can contribute to a move towards positive change for biosphere stewardship and sustainability. In this regard, engagement with non-academic actors has been critical to accurately understand key systems features and assessing barriers to, or levers for, change; but also to provide a platform for dialogue where scientific findings can be discussed and translated into practice.

Over the five years, GEDB has developed a model relying on five distinct, but often overlapping, pathways of knowledge generation and dissemination to contribute to change (see figure E); (1) direct diffusion of scientific insights through scientific publication, conferences, education and training; (2) research methods that also engage stakeholders in knowledge generation; (3) interplay with policy processes or business development (e.g. UN bodies, financial institutions or international corporations) through dialogues, syntheses and reports; (4) conventional science communication/outreach and diffusion of knowledge and understanding; (5) slow diffusion of insights contributing to shifting values, through various forms of science-art-music concepts that enhance connectivity and understanding between science and practice.

As highlighted in previous reports, several of the events funded by the programme have a strong element of participation by external (non-academic) partners or contributors. Examples include, the Stockholm Summit on Natural Capital, where a shared action plan was agreed to scale up efforts and pave the way for an array of global initiatives now underway, such as Future Earth, the Natural Capital Coalition and the World

Business Council for Sustainable Development's (WBCSD) Natural Infrastructure Group. Another example is the collaboration with fishing industries under the umbrella of SeaBOS and also our work on Fisheries Improvement Projects worldwide. Finally, our multiple formal and informal dialogues with the financial industry to promote a deeper understanding of factors affecting climate stability and biosphere health, are all good examples of how GEDB has deployed a multifaceted approach to conducting high quality science that can generate change at multiple levels in society.

This desire has evolved into an ongoing process of reflection on knowledge generation, how it may contribute to change, and how this change is likely to happen. This process, sometimes referred to as a 'theory of change' (c.f. James 2011), has guided the broad strategic approach of GEDB knowledge generation and dissemination. The degree to which it has been successful is always difficult to assess, but below are some quotes from financial actors with whom we have engage, reflecting their view and impact of our work.

Reflections on the Sleeping Financial Giants report and the work within Earth System Finance

"My main take-away was that as investors we should not only be concerned about global GHG emission reductions and using our shareholder influence to trigger corporate action on that, but also about the specific ecosystems / landscapes that are prone to tipping points. We need to think of creating impact through effective landscape-based coalitions of investors, businesses, government and civil society."

Lucian Peppelenbos,
SENIOR RESPONSIBLE INVESTMENT & GOVERNANCE SPECIALIST AT APG ASSET MANAGEMENT

"As a global insurer, we feel the consequences of the world approaching tipping points. Whether it is in the increase in severity and frequency of severe weather events, wildfires or sea level rises. This report points out how ignored they have been in the past and what can be done to reverse this trend."

Linda Freiner,
GROUP HEAD OF SUSTAINABILITY AT ZURICH INSURANCE GROUP

"Robeco is a global asset manager with 171 billion EUR assets under management with a strong focus on sustainability investing. The report Sleeping Financial Giants provides us with additional insights on the relationship between global multi-national companies, their impact on deforestation through their business operations and the ultimate impact this has on climate change. The tipping point of the Amazon biome and many other global ecosystems described in the report are deeply concerning and a reason to conduct further analysis on climate change scenario's and how these would affect our investment portfolios in the long term."

Peter van der Werf,
SENIOR ENGAGEMENT SPECIALIST & ACTIVE OWNERSHIP AT ROBECO

Photo: Sofia Käll

GEBD PhD Sofia Käll (second from right) with Helen Ågren (second from left), Sweden's Ambassador for the Ocean at the Ministry for Foreign Affairs.

Enhancing the capacity of the next generation

GEDB has continuously budgeted for different forms of collaborative efforts, such as workshops, working groups, seminar series and other networking activities. Such activities are critical in providing opportunities for our Early Career Academy Researchers to: develop and expand their academic networks, have a chance to take on more leadership roles (e.g. through workshops and working groups) and show their capacity at attracting funding. We focus on training our doctoral and post-doctoral students to conduct cutting edge research published in top tier journals. This has led to work that has contributed to ground breaking initiatives such as, SeaBOS. All while being supported by senior expertise in their field.

The programme also employs research assistants to assist programme researchers with various research tasks, ranging from data collection, analysis and modelling to assisting in the running of workshops. Most of the research assistants contribute to tasks throughout the research process, including writing, and many therefore also become members of the authoring team of scientific publications. Through this set-up, a system has been developed that provides a good opportunity for young scholars (primarily Master's level students) to get early hands-on experience of academic research and exposure to a wide network of contacts, as well as authorship of scientific publications. This has led to several of them becoming PhD students at GEDB or elsewhere. Below are examples of some of the personal achievements and commissions of our young scholars in recent years:

Presentation and communication skills. Sofia Käll was selected as participant of the "Our Ocean Youth Leadership Summit" 28 –30 October 2018 in Bali, Indonesia, and met with Sweden's Ambassador for the Ocean Helen Ågren. Even our assistants get invited to lecture at other universities. Alice Dauriach gave a 2-hour lecture at CEMUS course "The Global Economy", Uppsala University. Topic: Sun, sea and tax avoidance: Corporations and Finance. http://www.web.cemus.se/gec/

Transdisciplinary in practice by working with other academic disciplines and also with societal actors. Exemplified through Jean Baptiste Jouffray's work with large transnational

corporations in the seafood industry within the SeaBOS project. Skills in interdisciplinary research implementation and the benefits of being immersed within a multidisciplinary group has helped students and assistants to develop thinking about sustainability issues from a global perspective.

Developing research proposals and attracting funding and scientific attention. Peter Søgaard Jørgensen, through the AMResilience Project (https://amresilience.wordpress.com/), has been exceptionally successful. He was also recently invited to write an Annual Review on Ecology, Evolution and Systematics on The Five major ways evolutionary biology informs policy.

Qualitative and quantitative methodological skills. GEDB research assistants cite developing these skills as particularly useful for applying mixed-methods approaches, the ability to navigate complex databases and to construct sound scientific methodology.

Looking ahead

While the research portfolio and outputs of GEDB over the years has been wide-spanning, a few key elements have emerged as a red thread throughout our work, and these are what we build our research strategies on as we enter the next phase of GEDB scientific exploration. The red-thread elements relate to how we study and convey complexity in societal and economic processes with fundamental bearing on human organization, and how we use these insights to both study and inform transformative processes towards sustainability.

The work by GEDB on global value chains and their intersection with the financial industry, the rising use and threat of biocides, and our work on food production and its human and biosphere health implications, have all placed us at an advantageous position for embarking on the two themes that will be at the core of the next phase of GEDB: *Biosphere Finance and Global Health and Biosphere Stewardship*.

Once again, we extend an enormous thank you to the Erling-Person Family Foundation and look forward to the next five years of exciting and innovative research!

APPENDIX A:
STAFF 2013–2018

Director
Carl Folke

Executive Director
Beatrice Crona

Senior Academy Researcher
Victor Galaz
Thomas Hahn
Max Troell
Tracy Van Holt

Early Career Academy Researcher
Johan Gars
Peter Søgaard Jørgensen
Eny Buchary
Gustav Engström
Mark Sanctuary

PhD candidates
Jean-Baptiste Jouffray
Sofia Käll
Ami Golland

Visiting Professors
Gretchen Daily
James Wilen

Science Impact Advisor
Cecilia Repinski

Research Assistants
Amar Causevic
Alice Dauriach
Grazzia Maria Matamoros
Matilda Petersson
Mauricio Portilla Ospina
Johan Rostedt
Evelyn Strombom

Finance and HR administration
Sofia-Kristin Kokinelis

Communications Officer
Agneta Sundin
Hannah Griffiths-Berggren (standing in October 2018–May 2019)

ADVISORY BOARD

GEDB has an advisory board comprising a list of prominent academics. The role of the advisory board is to advise on strategically important research directions and decisions, and to provide guidance, suggestions, contacts and networks for collaboration. From time to time, members of the advisory board are also invited to participate in specific research endeavours in the form of working groups/ workshops designed with a specific thematic focus.

Neil Adger, *University of Exeter*
Scott Barrett, Columbia University
Steve Carpenter, *University of Wisconsin*
Jane Lubchenko, *Oregon State University*
Bonnie McCay, *Rutgers University*
Stephen Polasky, *University of Minnesota*
Marten Scheffer, *Wageningen University*

APPENDIX B:
GEDB PUBLICATIONS

2018

Aston, E.A., G.J. Williams, J.A. Green, A.J. Davies, L.M. Wedding, J.M. Gove, J.-B. Jouffray, T. T. Jones and J. Clark. 2018. Scale-dependent spatial patterns in benthic communities around a tropical island seascape. Ecography 42: 1–13.

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Overview of journals that have published GEDB articles. Journal title, number of publications in journal, and journal Impact Factor (as stated by Web of Science) given.

JOURNAL TITLE	NUMBER OF PUBLICATIONS	JOURNAL IMPACT FACTOR
Nature	4	41.577
Science	6	41.058
Nature Climate Change	1	19.181
Trends in Ecology & Evolution	2	15.938
Nature Communications	1	12.353
Science Advances	3	11.51
PNAS – Proceedings of the national academy of sciences of the United States of America	5	9.504
Global Change Biology	1	8.997
Frontiers in Ecology and the Environment	5	8.302
Fish and Fisheries	1	6.99
Global Environmental Change – Human and Policy Dimensions	7	6.371
Annual review of Envrionment and Resources	1	6.025
Conservation Biology	2	5.89

Journal of Applied Ecology	1	5.742
Philosophical Transactions of the Royal Society B– Biological Sciences	4	5.666
Functional Ecology	1	5.491
Landscape and Urban Planning	1	4.994
Proceedings of the Royal Society – Biological Sciences	1	4.847
Reviews in Fisheries Science & Aquaculture	1	4.75
Ecology	1	4.617
Science of the Total Environment	2	4.61
Environmental Research Letters	1	4.601
Ecological applications	1	4.393
Annals of the New York Academy of Sciences	1	4.277
Ecography – A Journal of Space and Time in Ecology	1	4.25
Current opinion in Environmental sustainability	3	4.186
Scientific Reports	1	4.122
Ecosystems	1	4.03
PLoS Computational Biology	1	3.955
Journal of the association of envrionment and resource economists	1	3.862
Sustainablility Science	1	3.855
Landscape Ecology	1	3.833
AMBIO – A journal of the Human Envrionment	6	3.616
Advances in Water Resources	1	3.512
Ecology & Society	16	3.256
Land Use Policy	2	3.194
World Development	2	3.166
ICES Journal of Marine Science	3	2.906
Policy Studies Journal	1	2.83
PLOS ONE	6	2.766
Aquaculture	1	2.71
Ecosphere	1	2.671
Royal Society Open Science	2	2.504
American Journal of Agricultural Economics	1	2.457
Ocean and Coastal Management	1	2.276
Marine Policy	6	2.109
Sustainability	2	2.075
Annual Review of Resource Economics	1	2.022
Environmental & Resource Economics	3	1.961
Marine Resource Economics	3	1.851

International Environmental Agreements – Politics Law and Economics	1	1.844
Society & Natural Resources	1	1.823
Structural Change and Economic Dynamics	1	1.542
Land Economics	1	1.5
Aquaculture Research	1	1.475
Sage Journals	1	1.471
Theoretical ecology	1	1.453
International Journal of the Commons	1	1.447
Human Dimensions of Wildlife	1	1.317
Environmental Policy and Governance	1	1.268
Agroecology and sustainable food systems	1	1.14
Coastal Management	1	0.973
CESIFO Economic Studies	1	0.831
Pacific Science	1	0.822
Risk, Hazards and Crisis in Public Policy	1	0.75
BMJ Global Health Journal	1	NA
Complexity, Governance & Networks	1	NA
Frontier in Marine Science	2	NA
International Review of Environmental and Resource Economics	2	NA
Journal of Environmental Investing	1	NA
Journal of Sustainable Finance and Investment	1	NA
Nature Sustainability	1	NA
Solutions	1	NA
Western Indian Journal of Marine Science	1	NA
Nature Ecology & Evolution	2	NA

GLOBAL ECONOMIC DYNAMICS AND THE BIOSPHERE
THE ROYAL SWEDISH ACADEMY OF SCIENCES
BOX 50005 SE-104 05 STOCKHOLM, SWEDEN
VISITING ADDRESS LILLA FRESCATIVÄGEN 4A STOCKHOLM, SWEDEN
WEBSITE www.gedb.se